MODIFICATION AND EVALUATION OF AUTOMATED DRIP IRRIGATION SYSTEM

By

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Modification and evaluation of automated drip irrigation system"** is a bonafide record of research done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Arjun Prakash, K. V

Dedicated to

My profession

and family

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SYMBOLS AND ABBREVIATIONS

GSM - Global System for Mobile communications

UN - United Nations

TDR - Time Domain Reflectometry

ADC - Analog to Digital converter

EC - Electrical Conductivity

mm - Millimetres

ml - Millilitre

kPa - Kilo Pascal

kg/ha - Kilogram per hectare

cm - Centimetres

min - Minute

WCR - Water Content Reflectometer

^{0}C - Degree Celsius

SIS - Scientific Irrigation Scheduling

WSN - Wireless Sensor Network

GPRS - General Packet Radio Service

m - Meters

LCD - Liquid Crystal Display

RAM - Random Access Memory

ARM - Advanced RISC Machine

RTC - Real Time Clock

Fig - Figure

dS/m	-	Decisiemens per Meter
F	-	Farad
µm	-	Micrometre
C.D	-	Coefficient of Deviation
DAP	-	Day After Planting
Kg	-	Kilogram
V	-	Volt
MCU	-	Micro Controller Unit
CMOS	-	Complementary Metal Oxide Semiconductor
USB	-	Universal Serial Bus
AC	-	Alternating current
DC	-	Direct current
IDE	-	Integrated Development Environment
i.e.	-	That is
ppm	-	Parts per Million
PVC	-	Poly Vinyl Chloride
LDPE	-	Low density polyethylene
lph	-	Litre Per Hour
SDK	-	Software Development Kit
TTL	-	Transistor –Transistor Logic
TIA	-	Telecommunications Industry Association
EIA	-	Electronic Industries Alliance
pH	-	Potential of Hydrogen

Introduction

CHAPTER 1

INTRODUCTION

Water is the most valuable resource in the world and it is essential for all the forms of lives on the earth. Human beings need around 120 litres of water for their daily activities. Water usage without proper planning, depletes the water level in dams, reservoirs and other water sources. During 21st century water has become the scarcest commodity in the world due to the ever increasing demand and over exploitation. According to UN, more than 200 crore people are troubled because of water shortage. All over the world, during next two decades, usage of water will increase by 25 per cent, resulting in doubling the scarcity. In India per capita water availability was around 6042 cubic meters at the time of independence from 1000 bore holes and this availability got reduced in an alarming rate year by year. In 2016, per capita availability is about 1500 cubic meters and if this situation continues, it may further reduce to 1,300 cubic meters by 2025. State of Kerala though receives an average annual rainfall of 3000 mm and 44 rivers flowing across the land, due to the uneven and unplanned use of water, people are face water scarcity during summer season.

As water scarcity problems increase, the long term predictions on global climate also changes. From the economical point of view agriculture consumes fresh water to the tune of 60-70 per cent of the total resources, 20 per cent is consumed by industrial application and remaining 10 percent is used for domestic purposes (Anon., 2009). Reduction of the available water resources during the 21st century caused increase in temperature and decrease in annual precipitation (Turral *et al.*, 2011). In India, only 40 per cent of the gross cropped area is under irrigation and the use of conventional methods of irrigation, with higher amount of water results a low water use efficiency of 35 to 40 per cent.

The surface irrigation techniques cause seepage losses, erosion, waterlogging problems, deep percolation, salinization and runoff. For getting satisfactory growth, right quantity of water at right time and at right place is very important and this can be accomplished only through micro irrigation techniques. The drip or trickle systems work with low pressure and it apply water more precisely to the plants. Micro irrigation systems are widely used for high value horticultural and nursery crops and this technique contributed more accuracy in water application to agricultural and horticultural crops. Water loss in irrigated agriculture occurs through percolation and evaporation and in the case of micro irrigation water loss due to percolation and evaporation is very less, hence the water use efficiency of the crop becomes increased.

In India, where 60-70 per cent economy depends on agriculture, there is a great need to modernize the conventional agricultural practices for the better productivity. Due to over exploitation of water the ground water level is depleting day by day. According to the observation of central ground water board, around 50 per cent of the wells showed decline of ground water level in 2013 as compared to the water level in last 10 years. From the analysis of ground water depletion level, during 2016, 1371 wells out of 14974 wells are showing 2 m reduction, 4958 wells are showing 2 to 5 m whereas remaining wells are showing a decline of more than 10 m. In Kerala, average ground water level depletion was estimated as 1 m in 2016. Lack of rains and scarcity of water results reduction of available water on the earth. In automated drip irrigation system, water is provided to root zone of plants drop by drop which results in saving of large quantity of water, increasing crop yield, conserving energy and reducing labour cost. Automated drip irrigation has number of advantages like greater precision, efficiency and reduction of human errors. A site-specific wireless sensor-based irrigation control system is a potential solution to optimize yields and maximize water use efficiency for fields with variation in water availability due to different soil characteristics or crop water requirement. Presently the systems available are costly and are not affordable to most of the marginal farmers.

On account of increased population, India has to conserve water, increase land use and preserve other vital natural resources to meet the ever increasing demands. But Indian agriculture faces more challenges for the production of safe and quality food. Sometimes it can cause de-merits like wilting of plants by the over application of water and lead to pollution of the environment by fertilizer application at dozes higher than recommended. Hence new innovations are developed in such a way that it should be both ecofriendly and accepted by marginal farmers. Certain strategies are to be undertaken for the protection of natural resources and the environment in the food security race. Through irrigation and fertigation, we can easily attain the agriculture intensification.

During past two decades, many experiments have been conducted at various levels for the design as well evaluation of automated drip irrigation system. In India the concept of water management by automated irrigation is relatively newer which is getting stabilized slowly. Automated drip irrigation management refers to those innovations which fully or partially replace manual incorporation in watering operations. Automated drip irrigation includes automation at farm level or regional level coding with the soil type and characteristics. The modified high capacity low cost microprocessors and the impressive growth of computer performances were used to develop the automated drip irrigation systems restrained the power of computerized controllers to enhance water use efficiency in the last two decades. The addition of sophisticated equipment in to the automation system minimizes the utilization of inputs, increased production, reduced losses and man power and finally increases farmer's net income.

Now-a-days, sensor which works based on soil moisture, temperature, humidity and light intensity are coupled with the automation of drip irrigation systems to ensure efficient application of water to the plants. The soil moisture sensor works to ensure exact quantity of water application automatically according to the requirement of crop. Automated irrigation based on soil water sensor, seeks to control optimal growth of plant by maintaining a desired soil water range in its root zone. These types of system adapt the quantity of water applied according to the soil conditions and plant needs throughout the season.

The strategies are altered, depending on the feedback from sensors when the irrigation decisions are made and necessary action is carried out. These types of sensors contain two electrodes inserted into the soil and it work on the conductive property of moisture for measuring the resistance, conductivity and capacitance between these electrodes. The conductivity and resistance property of soils changes with its chemical composition and soil properties such as salinity and acidity greatly affect resistive and conductive properties. Capacitances are controlled by the ionic content in the soil.

The present study aims to modify the existing automated drip irrigation system developed by Sharma and Hakkim, 2014 based on moisture content. In order to get popularity and wider adoption of automated drip irrigation system, it is essential to bring out a cost effective system for automated drip irrigation technique. The components of the system may change according to the study.

Hence the present work is proposed for modification and evaluation of automated drip irrigation system with the following objectives.

1. To calibrate the soil moisture sensors in different soils.
2. To modify the automated drip irrigation system with solenoid valves to perform the different irrigation levels into different segments and GSM modem technique for controlling system operation.
3. To evaluate the performance of modified automated drip system under sensor based irrigation scheduling for salad cucumber grown inside polyhouse.

Review of literature

CHAPTER 2

REVIEW OF LITERATURE

This chapter outlines brief reviews on moisture measurement, particle size analysis, drip irrigation, automatic drip irrigation, TDR based automation, automation based on soil moisture sensor, wireless automation etc.

2.1 MEASUREMENT OF SOIL MOISTURE

Soil moisture content is an important parameter for relating the plant growth and soil condition. Irrigation controlling and estimation of crop water requirements are regulated using moisture content in the soil. Evapotranspiration also gives a measure corresponds to the depletion of moisture from the soil. Soil moisture is expressed by the amount of water carried by given amount of soil and water held in the soil under stress or tension principles. Generally soil moisture content was determined using gravimetric method. The soil moisture is expressed in dry weight (Michael, 1978; 2008)

Charlesworth (2005) reported that for making decisions on irrigation management, soil moisture act as a fundamental measurable parameter and the soil moisture at different soil depths can be computed by various measuring methods in relation with rooting depth of plants. These methods are classified as direct and indirect methods. Gravimetric method is a direct method and now a day's technology like sensors has been used for indirect measurement.

2.1.1 Direct method (Gravimetric method)

In this method soil moisture in the field can be measured in volume or weight basis. Samples collected from each plot were put in to air tight containers to avoid moisture loss. Augers are used for the sample collection in which 15 cm depth samples were collected. Then samples were weighed and placed in an oven at a temperature 105^{0}C for 24 hours. Then samples were taken out and weighed again for measurement of moisture content (Michael, 1978; 2008)

Stafford (1988) stated that moisture content in the soil can be expressed in terms of centimeters of water per meter depth of soil or water percent by volume. This method was more accurate, easy and less expensive. But in the case of rocky soils the method usually needs more human power and it is time consuming. Moreover it was difficult and destructive to do.

2.1.2 Indirect methods

Sophisticated equipment's and soil moisture sensors were used for the indirect determination of moisture content. These methods can be broadly classified based on two principles, dielectric properties and electrical conductivity. The earlier stage tensiometer reads the soil tension or metric potential corresponding to the moisture level in the soil. It has merits like easiness of handling, less expensive and less time consuming. This device was used widely by farmers because of these merits in the time of measurement (Campbell and Mulla, 1990).

2.1.2.1 Capacitance

The electrical capacitance of a capacitor that measures the soil properties corresponds to the soil moisture content. Electrical circuit of capacitor was formed by the coupling of an oscillator and a change in the frequency of the circuit detects the variation in moisture content of soil. From the resonance frequency determined by the restriction of oscillator frequency within a specific range, capacitance probes determine the water content of the soil (Carpena *et al*., 2004).

Capacitance technique gives precise results but requires specific calibration of soil. The uncertainty in measurements via capacitance instruments are, sphere of influence restriction, automatic instrument timing, air gap problem, soil salinity, temperature, bulk density and clay content (Erlingsson *et al*.,2009).

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Terzic *et al.* (2012) defines that capacitance is the measure of quantity of charges stored in the capacitor. It is generally expressed in Coulomb/volt and measures in terms of Farad. Configuration connection of two or more capacitors gives parallel or series circuits and hence the capacitance varies. Capacitors are made by filling a non-conducting material such as glass, wood or rubber etc. in the space between two electrodes. So it measures the permittivity related to the material. The non-conducting material has some dielectric constant, so capacitance will vary according to the material fed in between the electrodes.

Wang (2014) reported that the capacitive sensor technology is used in the field of gesture proximity detection, material analysis and sensing of liquid level. Main merits of this type of sensors are, small size sensors can sense large areas, basically cost effective and less power consumption. Topology of capacitive sensor depends on the dielectric constant, sensitivity and sensor to target space. Parallel plate, human recognition sensor and parallel fingers are the main topologies. In the capacitive sensor, charges from electrode of the sensor are transferred to ADC via switched capacitor circuit.

2.1.2.2 Electrical conductivity

Determination of relationship between volumetric water content and electrical conductivity of the soil was used for the mapping of field capacity over a field. In addition, they derive the relationship between Electrical conductivity (EC), pH and other soil test parameters (Morgan *et al*., 1998).

Kuligud *et al.* (1999) stated that soil salinity was determined using the proper development and calibration of EM-38 equations. It is a quick detection tool but EM-38 is not used widely in India because of the high expense of the device and its limited application in mapping of saline lands.

Hartstock *et al.* (2000) studied the nature and cause of soil conductivity variability using a Veris 3100 soil electrical conductivity sensor. Soil fertility (pH, P, K, Ca, Mg and organic carban), 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 of clay and 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 increased in the soil, the soil solution becomes a better conductor of electricity and EC increases.

Ristolainen *et al*. (2005) measured soil electrical conductivity (EC) and permittivity dependent on soil water from four fields with different soils. 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 holing 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.

2.2 PARTICLE SIZE ANALYSIS

There are generally two methods adopted for the particle size analysis of soil samples, namely sieve analysis and sedimentation analysis. Sieve analysis is usually dry method of coarse or fine particle detection whereas sedimentation analysis is a wet mechanical method for fine grade particles.

2.2.1 Sieve analysis

Method describes the particle size determination using sieving. In this method samples collected from different locations are oven dried. In fine analysis sample kept in sieves size of 2mm placed above 1mm, 600,425, 300, 212, 150, 75 microns and a retainer arrangement. The sieves are shaked using mechanical shakers at least 10 min according to the type and texture of the soil. Weigh the sample retained in each sieve. In the case of coarse analysis, analysis was carried out in 100 mm, 63 mm, 20 mm, 10 mm, 4.75 mm sieves and a retainer (Punmia *et al.*, 1994; 2005).

2.2.2 Sedimentation analysis

Method used to found out the distribution size of particles of sample contains organic matter less than 5%. Test needs 2-2.5 hour time for each sample, so several hydrometers are used for testing more samples at a time. The procedure includes separation of coarse particles greater than 2mm by sieving and weighs the remaining fine textured particles. Make sample solution by adding 250 ml of distilled water into 50g sample taken in a 500 ml beaker. 50 ml calgon dispersion agent and soil solution are taken in the dispersion cup and mix the solution thoroughly for 15 min. Transfer the solution in to a cylinder and add water up to 1 litre for dilution. Mix the solution using plunger and take the reading using hydrometer at 40 sec and after 2 hours. (SFU soil science, 2012)

2.3 DRIP IRRIGATION

Drip or trickle irrigation method was used in the areas with less availability of water and poor quality water. In drip irrigation, water was applied on the root zone of crop frequently with less pressure. This irrigation method was suited for undulating terrains, crops in orchards, in rows and plantation crops. The method saves large amount of water in cultivation and it provides several advantages like avoiding pest and diseases, prevention of salt accumulation in the root zone of plants, reduce labor cost and fertilizer application, improves the produce quality and increase the crop yield (Michael, 2008).

Kanislaw and Dysko (2008) conducted a study for the comparison of drip irrigation by surface and subsurface method on the quality and yield of roots of parsley grown on flat ground and on ridges. Water application to the plants through center line of two rows by subsurface irrigation at a depth of 50 mm below the surface of the ridges via drip line and drip lines are placed on the ridge surface between two rows of plant in the case of surface irrigation method. Irrigation carried out when soil water potential was between -30 and -40 kPa and Nitrogen fertilizers (100 kg/ha) were applied in two doses. Two doses were applied in different manner, like first before planting and next through fertigation after planting. In addition second dose of nitrogen was applied by broadcasting in control treatment without irrigation. The experiment shows that both surface and subsurface irrigation used in the cultivation on ridges and on flat ground had a notable effect on the marketable yield of parsley roots. But yield from flat cultivation was twice as high as that in ridge cultivation in the case of non-marketable parsley roots.

Another study to investigate the effects of drip irrigation methods in solar green house and different irrigation levels on quality, yield, and water use characteristics of lettuce, the result showed that the largest production was derived from treatment by 100 percent of Class A pan evaporation rate and subsurface drip irrigation at 10 cm drip line depth. The irrigation use efficiency and water use efficiency increased as the less irrigation application and decreased with high water application (Bozkurt *et al*., 2009).

Vijayakumar *et al.* (2010) conducted field experiment in brinjal crop at agricultural research station, Bhavanisagar to increase the water and fertilizer use efficiency. The study laid with nine treatments includes three fertigation levels, 75, 100 and 125 percent by the use of recommended quantity of K and N through drip irrigation and three irrigation levels 75, 100 and 125 per cent. It is found that 75 percent drip irrigation followed by 75 percent fertigation shows maximum water use efficiency 111.5 kg/ha and the recommended application of N and K through 75 percent fertigation gives increased shoot length and more number of branches on the plant.

2.3.1 Automatic drip irrigation

The quality and productivity of Nagpur mandarin was tested using drip irrigation by two different ways, automatic scheduling of daily irrigation and time scheduling on alternate days. Four treatments were carried out as three times automatic application of water daily in 60 min, two times automatic irrigation daily in 90 min, three times automatic irrigation 120 min in alternative days and two times automatic irrigation 180 min alternative days. Soil depth was set at 41cm and it has clay loam texture. Yield of the Nagpur mandarin was influenced significantly by the different scheduling of irrigation. Highest yield was recorded from the irrigation in 120min (around 30.9 tonnes/ha) and lowest yield was from the 60 min irrigation (about 24.5 tonnes/ha). But in the case of fruit growth, it was higher in 180 min alternate day irrigation. So the automated drip irrigation shows better crop production and quality compared with manual irrigation (Shirgure and Srivastava, 2014).

2.3.1.1 Volumetric method of irrigation

Zella *et al.* (2006) designed a micro irrigation system based on volume control method. The method consists of delimiting an elementary volume of the lateral, equipped with an emitter. Microcomputer program was used to speed up calculation and convergence. In this study, the sum of average emitter discharge was chosen as the total average flow rate of the network according to the average water requirement of plants and complex networks are designed using thousands of emitters and by uniformity of water distribution. In addition to this three other programs that measure velocity, pressure at both laterals and submain pipes were created and resulted that, it covers area of 12.5 ha with 5000 emitters efficiently and economically.

Casadesus *et al.* (2012) depicts an algorithm for automated scheduling of drip irrigation in tree crops to support a low price-low labour management for irrigation. The system coordinates seven automatable task estimation of irrigation needs, adaptation to a particular irrigation setup, execution of schedule, soil or plant monitoring, interpretation of sensor data, reaction to occasional events and tuning the model of irrigation needs. The experiment was carried out in peach orchard and observations are recorded. A typical water balance based on reference evapotranspiration (ETo) and a variation based on the measurement of solar radiation intercepted by canopy are the alternative methods used to determine the crop water needs by moisture probes and dendrometers supplied to regulated deficit irrigation. The observations shows that resultant algorithm provide a common frame work that could be used under different irrigation levels to support autonomous control through the season. The system which combines a feed forward estimation of irrigation needs with water balance method by means of a turning mechanism in bases of feedback from soil plant sensor is an advanced and useful tool, by its property of self-adjusting algorithm, fast response to changes in factors like weather condition etc.

2.3.1.2 Time domain reflectometry (TDR) based automation

Study was conducted for the measurement of relative permittivity using capacitance theta probe and TDR probes in sandy soil. The findings are tested against multiple linear regression results and noted that capacitance probe measures apparent permittivity relatively to the inter electrode conductivity and it is done in small extent by TDR probes but not by theta probes. The theta probe estimates the apparent permittivity of soil around 1.5 times compared to the results by TDR. The inclusion of inter conductivity improve the result by regression analysis and neglected the effect of bulk soil electrical conductivity in sandy soil when value less than 0.05 S m^{-1}. So water content is estimated by relating square root of the soil apparent permittivity and E_r (Robinson *et al.*, 1999).

The study was conducted using time domain reflectometry for the measurement of electrical conductivity and water content. For this study he used different samples like bulk soil or electrolyte solution and soil then pour water and checked with two-wire type and three-wire type probes. Impedance of the probes is widely affected by the wire spacing and diameter of the rods. Study not fully investigated the effects on waveforms developed by water, solute or solvent particles (Noborio, 2001).

Stangl *et al.* (2009) tested TDR based probes in a landslide soil with high clay content in Austria. They used CS615 water content reflectometer for checking the water dynamics in the creeping flow and calibration was done with intractable soil material according to inverse regression method and compared the linear and multiple regression models and polynomial relations, in this multiple regression models shows best result. The porosity and temperature variables get related to sensor position in the field and sensor responses are influenced by difference in slopes and coefficient of field observation.

Arsoy (2014) calibrated the moisture probes based on permittivity by considering natural variations of dry density by pre-positioning. The probes are inserted in soil by using guides and pre-drilling in order to reduce the tertiary variables. The calibration approaches are evaluated using time domain reflectometry probes and two relatively affordable soil probes with different operating principles. Three probes shows accuracy level of 0.016, 0.015 and 0.012 for wet season, are taprobe and TDR probe respectively. According to this study, for the selection of particular probes quantitative comparison are done, like time efficiency, cost, ease of use etc. and TDR probes shows more accuracy and it can be used for large scale application, more economically.

2.3.1.3 Automation based on soil moisture sensor

Abraham *et al.* (2000) reported that 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. The automated systems based on soil resistance was found to be working efficiently without frequent supervision and maintained the pre-set moisture content in the root zone. So it liberalizes the work of farmers and increases the plant growth.

Seyfried and Murdock (2001) checked the soil water sensors using variable soil, temperature and water content. In this study they selected WCR method for calibration. Under controlled laboratory condition sensors are more precise and significant sensor differences are noted while variability of sensor found out in air and ethanol media. Calibration of sensor was done at 40^0C temperature under varying water content and four types of soils like sheep creek, summit, foothill and sand. The results are fair in the case of sand, but shown more errors in other soils.

The amount of irrigation and the time interval are the two main areas for the efficient control of water applications in the farm. Precise calculation of quantity of water irrigated is done through technologies of soil moisture sensors as well as transpiration and crop evaporation data in the scientific irrigation scheduling (SIS). Timely and efficient water management is scheduled by the incorporation of this technology to commercial farm practices (Leib *et al.*, 2002). Available soil moisture, air or soil temperature, weather and plant developmental stages are the factors for making decisions on seasonal irrigation to both high tunnel grown crops and field crops. Irrigation management decisions require a regular monitoring of soil moisture at varying soil depth to complement a farmer's subsequent water application to the field incorporation with time.

For reducing the production cost of vegetables and making the industry sustainable, an automated irrigation based on soil moisture is introduced. It has been noted that once this system is installed and verified, only weekly observation is required. Techniques used for the estimation of soil moisture are volumetric and tensiometric. The system includes an advanced soil water sensor which is completely automated. Soil water limit is set, which is optimal for plant growth. Thus the tensiometers and granular matrix sensor (GMS) sense the soil water level and provide proper irrigation. It is easy to determine the soil water content by measuring the soil bulk permittivity by means of dielectric sensors ie, for a composite material like soil bulk permittivity is mainly governed by liquid water content. In dielectric method empirical relation between volumetric water content and the sensor signal content is used. Continuous reading through automation, instantaneous measurements and no need of maintenance makes the system popular (Carpena and Dukes, 2005).

Brevik *et al.* (2004) reported that upper 10 cm of the soil temperature will fluctuate considerably during day by day and this soil temperature influence EC reading. In this study everyday 8 A.M. to 8 P.M electrical conductivity (EC) reading was taken in the horizontal and vertical dipole orientations. Soil temperature readings were also taken for four depths at the same time periods. EM-38 reading remains steady in the 3 days and all the four sites. Plot of upper 10 cm soil temperature verses EC yielded low slopes and values shows no relation between EC values and soil temperature in the upper 10 cm.

Nemali and Iersel (2006) designed an automated system for controlling drought stress and irrigation in potted plants. The system supplies required amount of water for normal plant growth at the root zone of the plants when the water level is below the previously set limit. The system can subsequently reduce leaching and run off and wastage of water due to excess application. This system is developed with a dielectric moisture sensor with an interfaced data logger and solenoid valves, which provide proper irrigation. It is noted that the system is capable of maintaining four distinct level of water content for a period of 40 days in bedding plants, with respect to the changes in plant and environmental conditions. The controllers have vast application in stress physiology as it is efficient to control the rate of drought stress.

Merlin *et al.* (2006) conducted experiment for the calibration of Stevens hydroprobe soil dielectric sensor in heterogeneous terrain, using national airborne field experiment data. They measured the soil moisture, salinity, conductivity and dielectric constants for this experiment. The temperature effects are evaluated using sandy and clay soil with different moisture conditions. In clay, temperature effect is high and its moisture changes up to 4 percent and for sand it is negligible and moisture changes around 1 percent.

Nemali *et al.* (2007) calibrated and evaluated the performance of moisture sensors in soilless media. They used two sensors, theta probes and ECH$_2$O for computing water content and effect of substrate temperature and increasing EC on the voltage output of probes were analyzed using calibration equation. This study shows that for accurate water content measurement theta probes are used. But it has no effect of increasing substrate temperature. For less precise work of irrigation ECH$_2$O-10 probes can be used.

Thompson *et al.* (2007) conducted a study for the determination of lower limit of irrigation using water content sensors by the assessment of crop water uptake. Green house vegetables are irrigated using drip system and well-watered control treatments are applied on each crop in one or two dry cycle. The lower limits of soil water content evaluated by two approaches, breaking point and use of indices. The calculation of indices are carried out in daily daylight conditions and two different soil depths 0-20 and 20-40 cm. the work suggested that system can be used reasonably to control the water usage in to the crop suffer due to water stress.

Lailhacar and Dukes (2010) introduced an advanced model of soil moisture sensor system for irrigation control under field condition. The main objectives of the experiment were to determine a relation between volumetric soil water content and the soil water sensed by four commercially available sensors, qualify the proportion of scheduled irrigation cycle. Acclima, Rain bird, Irrometer and water watcher sensors are fixed at the root zone at a depth of 7 to 10cm for monitoring the Q continuously, a calibrated ECH_2O probe was installed in every plot. Significant relationships were found by Acclima when the ECH_2O reading where compared with Q sensed by SMSs. The SMSs based irrigation treatment bypasses the majority of the SICs during rainy season and allows proper irrigation during summer. An average of above 71 percent of SICs has been bypassed by the system.

Varble and Chavez (2011) calibrated and evaluated the performance of soil water content sensors and soil potential sensor in Colorado. Three type of soil water content sensors such as CS616/625, digital TDT and 5TE and soil potential sensor, watermark 200SS are tested in both fields and lab using three field soils, furrow irrigated corn field, commercially operated alfalfa field and research field operated by CSU between July to October. The values Q_v +. $0.02m^3\ m^{-3}$ MBE and less than $0.035m^3\ m^{-3}$ for RMSE set as the acceptable error range of sensor. Analysis shows that the diurnal variation in the soil temperature influences the reading of CS616, 5TE and watermark sensor, but not in TDT sensor reading.

Miller *et al.* (2014) conducted a study on field evaluation and performance of capacitance probes for automated drip irrigation in water melons. The aim of study was to determine utility of multi sensor capacitance probes for automating high frequency drip irrigation. Irrigation process was tested in sandy coastal plains with 15 percent available water depletion, 50 percent available water application and without water application. Soil water status determined at top 50 cm soil profile and provides automation in irrigation when an average 0-30 cm soil water content reaches the irrigation set point. Irrigation scheduling capability of the multisensory capacitance is highly advantageous, by the proof of short and frequent irrigation at root zone, 15 AWD irrigation gives better yield. MCP software was able to measure real time volumetric moisture content. The system is applicable in southern sandy soil which has low water holding capacity.

Sharma *et al.* (2015) developed an automated drip irrigation system and evaluated the performance of soil moisture sensors by using the relationship between moisture content and electrical conductivity. They used 3 conductive type soil moisture sensors and 1 capacitor type soil moisture sensor in the field for a season under the crop amaranths and it was observed that it is working properly and the motor gets switched ON or OFF automatically with respect to the pre-set value of moisture content.

2.3.1.4 Wireless automation

The advanced sensor network, wireless sensors are promising an in-situ measurement technology useful for monitoring soil water content in large areas with high spatial and temporal resolution. The system maintained with a low cost soil water content sensor. The experiment carried out in fields reveal a comparison of water content of a forest soil at 5cm depth using TDR and EC-5 sensors. Laboratory experiments deals with dielectric permittivity and featured that the EC-5 sensor gives good output voltage sensitivity for permittivity below 40 and less sensitive when permittivity increases. EC-5 measurements explain to a large degree with correction function derived from laboratory when tested. The study suggest that by compensating sensor reading using appropriate correction functions, the EC-5 sensor act as most useful and suitable wireless sensor (Bogena *et al.*, 2007).

Xiang (2010) designed a fuzzy drip irrigation control system based on zigbee wireless sensor network for sensing soil moisture, temperature, light intensity information and sending instructions for proper management of drip irrigation. The wireless network CC2430 node design is used for this study. Fuzzy controller monitors the factors effecting soil moisture, temperature, light intensity and creates a fuzzy control rule base. This low cost, low power, wireless technology has a high precision value. The system implements control over soil moisture by introducing water use rules and mathematical models which are difficult to establish in normal systems. Interesting part of the system is that, it completely avoids the inconvenience of wiring and improves flexibility of water saving controller. The system plays an eminent role in water saving, optimal scheduling and improving efficiency of the crop with more scientific approach which have a great value in applications.

Dursun and Ozden (2011) designed wireless soil moisture sensor network for automatic irrigation scheduling of 1000 dwarf cherry tree. Two solar powered pumps are used for irrigation. First pump used for convey water from lake to water tank and next for getting required pressure in orchard irrigation. The wireless system contains sensors, valves and base station. Application of overall system gives merits like reduced water usage, prevention of moisture stress and avoids salinity.

Gutierrez *et al.* (2013) proposed a system for automated irrigation based on GPRS modules and wireless sensor. They measure the soil moisture and temperature and transfer it in to WSN using zigbee technic. The GPRS module also combined with this network for the transmission of data to the web server. This system used for variety of crops and it needs less maintenance. In addition to this the module configuration adjusted for automated irrigation in large scale up to the big green house.

Majone (2013) developed a wireless sensor network consist of 27 temperature sensors and 135 soil moisture sensors, for an area of 5000 m^2 in an apple orchard located in the municipality of Cles. Different irrigation scheduling is applied to the orchard where it divided into three parts. The objectives of this study was to monitor the soil moisture dynamics in the top soil and space and time details used to analyze the relation between plant physiology and soil moisture dynamics. The multi hop WSN connected to vertically align 27 locations and 5 soil moisture sensors are equipped with each of network and arranged at the depths of 10, 20, 30, 50 and 80 cm, and a temperature sensor at the depth of 20 cm. The developed evaluation system was connected to the interface by wireless platform for the measurement of real time and historic data management, but the working of the system was independent of sensor nodes. Weather station monitors the meteorological data, where it is located at a distance of approximately 100 m from the experimental field. Calibration of the capacitance sensors were executed in both laboratory and on farm in order to reduce the noise caused by small oscillations in the input voltage. The experiment shows that WSN greatly facilitates the collection of soil moisture accurately and gives useful information for controlling hydrological processes.

According to Giri and Wavhal (2013) the automated intelligent wireless drip irrigation system using linear programming provides to be a real time feedback control system which monitors and controls all the activities of drip irrigation system efficiently as well as it helps us for to do the efficient water management in order to get more profit with less cost.

Study was conducted for the development of automated irrigation system and examined soil by wireless. They used several sensors like moisture sensor, humidity sensor, pressure regulating sensor, digital camera etc. and checked the water content, salinity, chemical constituents and fertilizer requirement of plants and it was stored in data logger for planning irrigation. Digital to analog and analog to digital converters were used to change the phase of output data from the field. This method of irrigation ensures limited use of inorganic fertilizers and water sources (Hade and Sengupta, 2014).

Nikolidakis *et al.* (2015) proposed a wireless network irrigation system with sensor for efficient utilization of water for cultivation of crop automatically. The values collected by sensor changes according to climatic condition. When collected value is above the threshold, more data are collected and minimize the quantity of water. In other case, if the value is below threshold, data collection interval increased to save sensor energy. So it improves the lifetime up to 1825 min and it provides around 110 sec efficient operation of small water quantities.

Power management, low cost, less human interventions and advanced technology makes the automated drip irrigation system popular in market. This study gives a detailed description on various automated irrigation system. An automated drip irrigation system based on WSN and GSM-Zigbee for remote monitoring and Zigbee and GSM in industrial field is used for making a low cost irrigation system which is automated. It checks and controls the condition of soil with low energy consumption. Physical parameters of soil such as humidity, light intensity, air temperature and soil moisture are monitored and controlled by this system. GSM system informs the farmer to take action remotely when some abnormal conditions occure. The issues like over power consumption in irrigation system can be compensated by wireless sensor network and Zigbee technology. An effective way to rehabilitate the situation with apt solution is by adopting a WSN which consist of small, lightweight and wireless sensor network with sensor nodes being the key component of wireless sensor network. A wireless sensor node essentially encompasses a transistor, sensors, memory and power source which can sense the data, process it and communicate it for further correspondence. Thus sensor node has an inevitable part in the modern phase of agriculture (Shikha and vibha, 2016).

2.3.1.5 Automated system based on microcontroller

Bhosale and Dixit (2012) developed a system for automatic irrigation and water saving. In their experiment they checked the different parameters like atmospheric temperature, humidity, wind direction etc. and working of a system containing PIC16F877A microcontroller in addition with RTC, driver circuit relay and LCD monitor. The results are recorded in the microcontroller every day at 8.30 am with central server using GSM modem. The system used to set up and maintain optimum soil moisture saturation, minimize plant wilting and more over control of nutrient level.

Prathyusha and Chaitanya (2012) designed a microcontroller based drip irrigation mechanism which gives very effective feedback control system for monitoring and controlling all activities of drip irrigation. They used an advanced microcontroller LM3S5T36 which is 32-bit ARM Cortex™-M3 with features of 32kb single flash memory, 12kb RAM and three 32bit timers and two 10 bit analog to digital converter. The flow of water in the field is automated by the use of timers and sensors. The microcontroller based drip irrigation system helps the farmers to modernise agriculture industry at large scale with least expenditure.

Gunturi (2013) proposed an automatic system for plant irrigation based on 8051 microcontroller. In addition to that humidity sensor, temperature sensor, solenoid valve etc. were used for the development. According to change in temperature and humidity, sensors sense and transfer to the microcontroller, thus it activates the sprinkler unit by signals. Main merits of this system are discourages weeds, controls fungal attack, improve growth, save water and time.

Mahendra and Bharathy (2013) introduced a microcontroller based automated drip irrigation system, which is an essential part of greenhouse based modern agricultural industry. The system precisely monitors and controls humidity and temperature. This system uses valves to turn ON and OFF the irrigation. The valves are controlled by solenoids and controllers. Automated system is capable of applying proper irrigation to plants by reducing runoff from over watering in saturated soils. The system ensures adequate water and nutrient supply when needed and enhance crop performance. This system is simple and precise, which is an appropriate tool for accurate soil moisture sensing in green house vegetable production. The microcontroller based embedded system is capable of maintaining uniformity in different physical parameters.

The objective of automatic irrigation system is to provide water to the farms according to their moisture and soil types. This study deals with the design of microcontroller based automatic irrigation. System consists of wireless sensor network for sensing and controlling an irrigation system. Increase in water level at root zone causes diseases to plants and may die out. The system is capable of providing required water for plain as well as slope areas. Software used in this system is useful for sensing and controlling an irrigation system. The system which consists of updated solenoid valves programmed according to the set point of temperature, humidity and moisture content. A controller senses the water level and irrigates when water level become too low. The study shows that combination of hardware and software provides an automated irrigation system for implementing a low cost user friendly technique with the use of zigbee networks (Thakeur et al., 2013).

Abdurrahman *et al.* (2015) developed an irrigation management system based on simple and low cost sensor network. Hardware of the system contains PIC16F887 microcontroller unit for the operation of water pump and solar battery and 16x4 LCD also connected for display. Different sensors are used to check the solar intensity as well as moisture level and water supplied according to its requirement. Water tank works automatically and gets filled when it became empty.

Chaware *et al.* (2015) developed an automated irrigation system based on sensor for orange orchard. ARM controller was used for the input collection and transfer incorporate with GSM module. Water supplied at the time when evapotranspiration will be least and RTC was used to monitor the sensed value after every 5 hours. For ensuring high yield with less use of water, they adjusted the system in such a way that it stops when the plant has got adequate amount of water.

Kansara *et al.* (2015) presented a sensor based automated irrigation system with IOT. They used rain gun as a media for the automation system. The system provides irrigation only when an intense use of water is required. A software stack called Android is developed. Android supports operating system, middle ware and key applications. APIs is used to begin developing applications on android pattern using java programming language and the tools are provided by android DSK. The GPRS system of mobile is also used for microcontroller based irrigation. GSM (RS-232) module monitors the system and supports water management in crops. It continuously senses the water level in the tank and provides sufficient amount of water required for plant or tree. The system also monitors the humidity and temperature and maintains the nutrient level for optimum plant growth.

Nagarajapandian *et al*. (2015) had done a study by sensing moisture content in the soil for irrigation automation. They used an Arduine board AT mega328 microcontroller for the collection and storage of dampness content of the earth detected by sensor unit and turns the pump ON or OFF according to the dampness content. The sensor contains two probes, which measures resistance while current passes through it. The sensor is made with nickel and coated with gold, thus it protects the nickel part from oxidation. A main advantage of the system is that it reduces the human interference as well as easy and accurate irrigation.

The study aimed at the development of an automatic irrigation system based on RF module. Irrigation on the paddy field was done automatically using messages from the RF module to ARM-LPC2148 controller. Apart from this, the system has two sensor unit, soil moisture and temperature sensor having wireless connection for getting sensed readings (Rane *et al*., 2015).

Materials and methods

CHAPTER 3

MATERIALS AND METHODS

This study was mainly focused to develop an automated drip irrigation system with moisture sensors, GSM modem and solenoid valves and to evaluate the performance of the different types of soil moisture sensors, viz. capacitor type and conductive type carried out using the relationship between electrical conductivity and soil moisture content.

3.1 STUDY AREA

The experiment was conducted in the polyhouse located in the instructional farm of KCAET Tavanur, Malappuram district located at 10° 51'5" North Latitude and 75° 59'14" East Longitudes. Climate of the study area is humid tropical with an average annual rainfall of 3000 mm, mainly from South-West and North-East monsoon.

3.2 DRIP AUTOMATION SYSTEM

The system is developed using electronic equipment so that it regulates the flow of water through the laterals and provide adequate quantity of water to each plant on time. The system connected to the drip lateral has less weight, portable and is water resistant. All measurements can be done rapidly because the calibration of system is dependent upon response time and soil types.

3.2.1 Components of automation system

Soil moisture is measured in terms of electrical conductivity. The probes are designed in such a way that it gives optimal value of EC from the representative samples and the automation system is designed as light weight, simple in operation and easy to handle. The sensors are calibrated and tested to use as automated irrigation system. Fig. 1 shows the block diagram of the system.

The automation system consists of

1. Conductive type soil moisture sensors
2. Capacitor type soil moisture sensors
3. Electronic control board (microcontroller unit)
4. Interfacing circuits
5. Control keys
6. LCD display
7. Serial interface
8. Water flow sensor
9. Relay interface
10. Electrical relay
11. GSM modem
12. Solenoid valve
13. PC

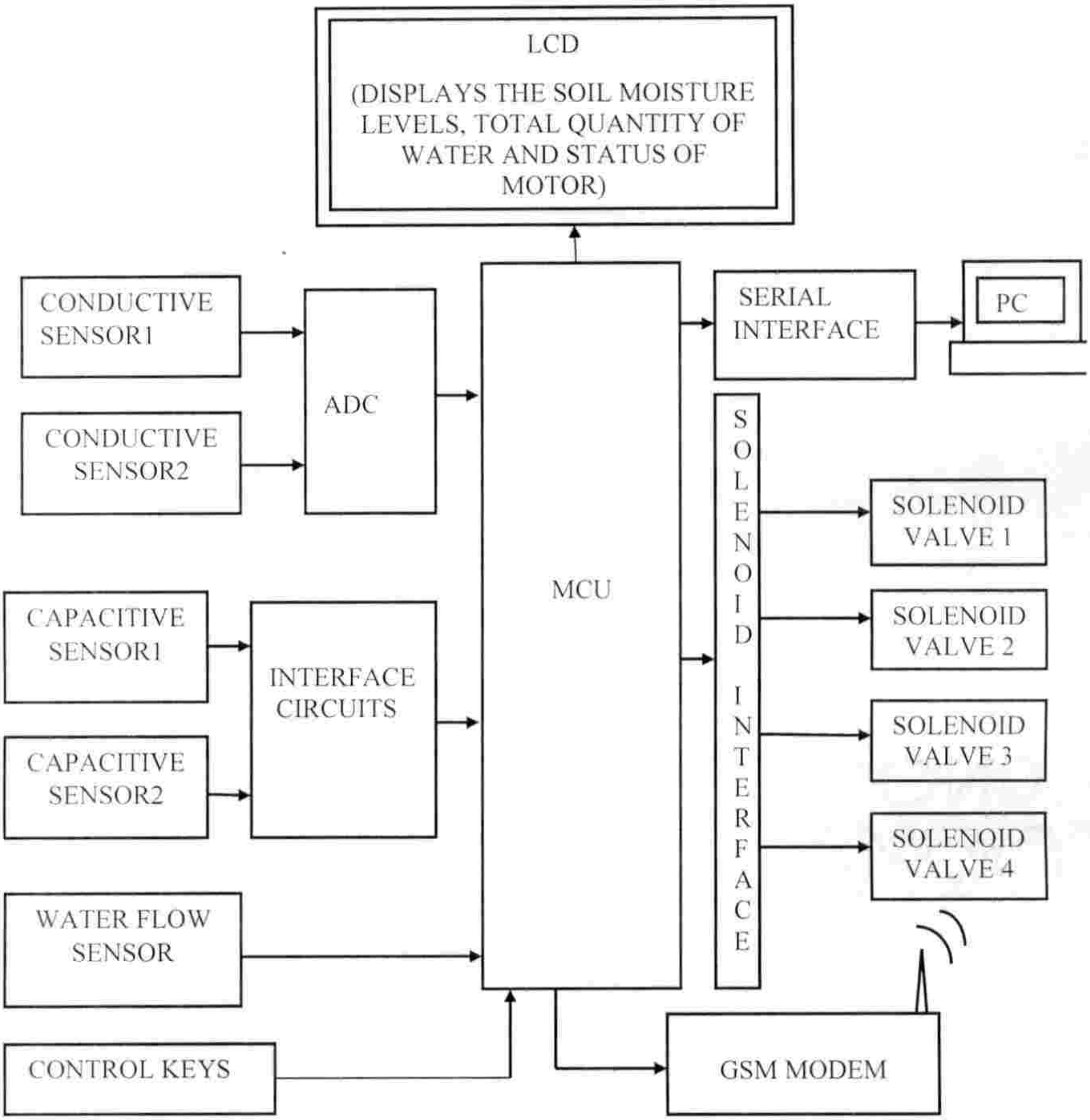

Fig.1. Block diagram of irrigation control system

4

3.2.1.1 Conductive type soil moisture sensor

The term moisture content is used in a wide range of practical and scientific areas and is expressed as a ratio. The water contained by the soil is named as soil moisture content and it can be identified by using metallic probes. Generally the probes measure the soil conductivity and it compare with the soil moisture content. Two conductive type sensors are attached with the system, which count the moisture content of the soil by means of deflection in conductance.

These sensors are placed in the field, which can determine the quantity of soil moisture content with the help of probes arranged as voltage divider with a pull up resistor. Electrical conductivity between the probes would fluctuate directly to the soil moisture content. Signals, received from the voltage divider arrangement of probes are amplified and then transferred to the electronic control board. Plate 1 shows the conductive type sensor arrangement.

Plate 1. Conductive type soil moisture sensor

High quality stainless steel is used for the fabrication of probes for better durability and detection of electrical conductivity. The conductive type soil moisture sensor contains two electrodes, viz. positive and negative terminals divided by a nylon circular plate acting as nonconductor medium. The shape of each electrode is cylindrical with 4 mm diameter, 100 mm length and spaced 55 mm apart. Each sensor weighs around 100 grams and stainless steel is used to avoid the oxidation with the soil. One probe is connected to Vcc through a 1.0 M ohm resistor, which acts as a voltage divider and the other one is grounded in the soil. Since conductivity value of the sensor increases with moisture content in the field, voltage divider output also increases and is transferred to a CA3140 operational amplifier based voltage follower. The output of the sensor is given to MCU via voltage follower made by the CA3140. The sensor outputs are interfaced to MCU through RA0 and RA1 shown in Fig. 2.

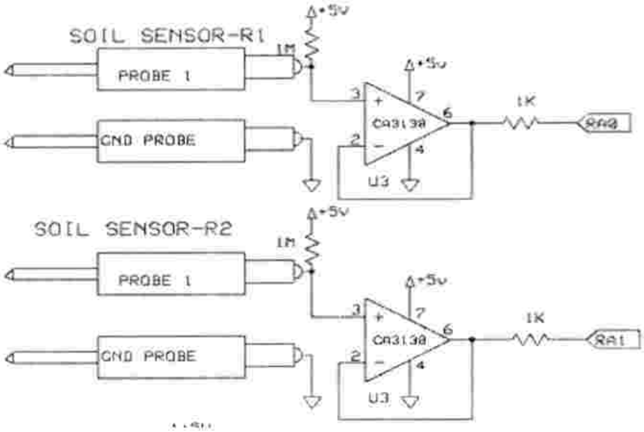

Fig. 2. Circuit of conductive type soil moisture sensors

3.2.1.2 Capacitor type soil moisture sensor

A capacitor is a device, which comprises an insulator that separates two electrodes. Capacitors are generally composed of a non-conducting substance that divides the two conducting plates which is called dielectric material. The dielectric sensors use the dielectric constant of a surrounding medium for determining the capacitance. Two capacitor type soil moisture sensors are also attached with the system having two legs, fixed in to the soil which measure soil moisture content in terms of variation in the ironic content of the soil medium. The measured values are transferred to the microcontroller, which stores it. Plate 2 shows the capacitor type sensor arrangement.

Plate 2. Capacitor type soil moisture sensor

The capacitor type sensor has very high resolution and consumes less power. The probe of this sensor is made up of Teflon material which is connected to a circuit board. The sensor has a total length of 200 mm and a thickness of 3 mm. The single soil moisture sensor weighs approximately 10 grams and it can perform a number of measurements over a long period of time with less power consumption. In addition, the sensor measures soil moisture content accurately in any type of soil with the integration of a high frequency oscillation. The sensor output is connected to the microcontroller via interface circuit as shown in Fig. 3.

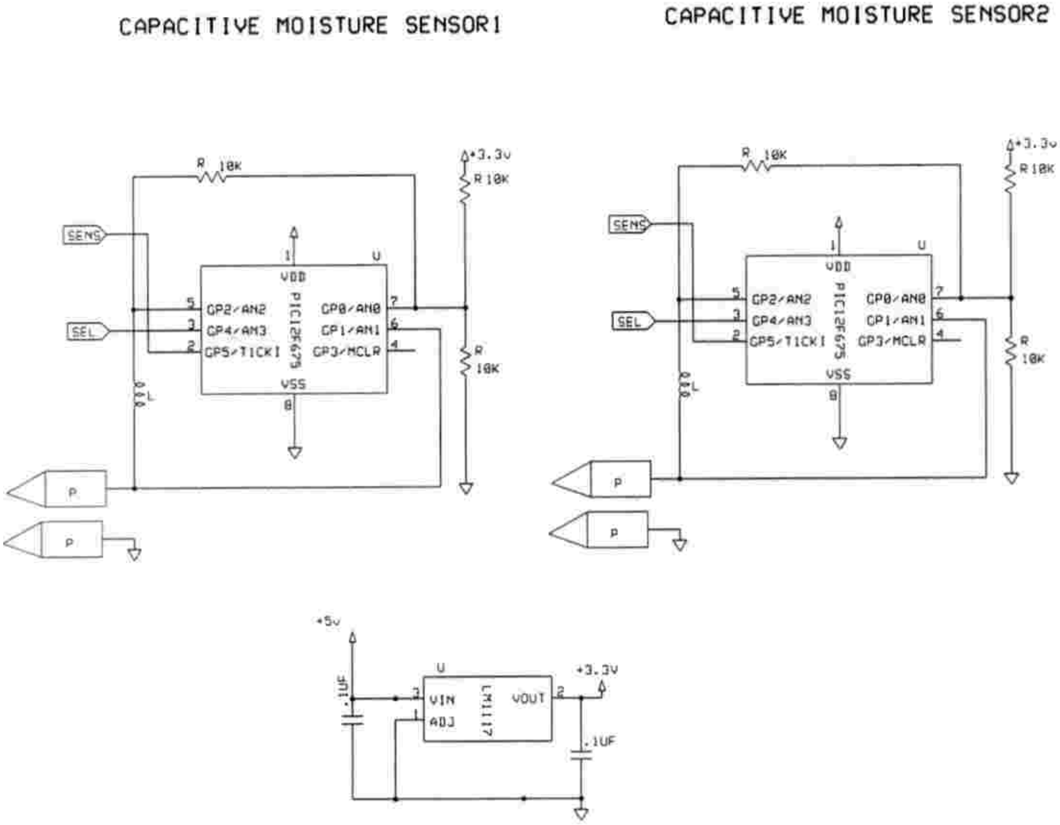

Fig. 3. Circuit of capacitor type soil moisture sensors

3.2.1.3 Electronic control board (microcontroller unit)

Microcontroller unit receives data from soil moisture sensors and these data are transferred to LCD for data display. MCU can read data from soil moisture sensor and control keys. If the measured parameters differ from the pre-set levels, the microcontroller unit will send SMS through GSM modem.

MCU controls certain devices to retain the greenhouse parameters to the required conditions when it receives instruction from the user. These devices are controlled by the MCU through relay and interfacing circuits. In this study motor and four solenoid valves were connected with the relay circuit. Whenever moisture level reaches above or below the limit, then MCU will send SMS to the pre stored mobile number (user). If MCU receives ON/OFF messages from the user, it automatically turns ON/OFF the motor. Otherwise the MCU receives messages to operate solenoid valves. The MCU operates particular valves as per the message received. The microcontroller stores data according to the recorded interval in the system ranged up to 255 and the data can be transferred to the computer via upload key. The microcontroller arrangement is shown in Plate 3.

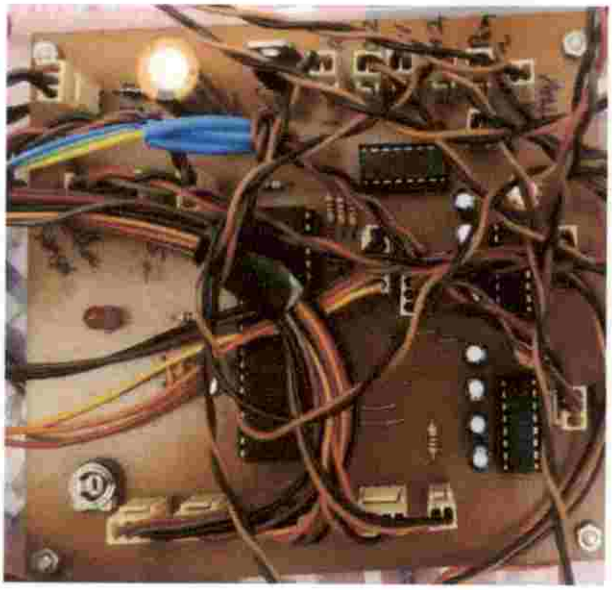

Plate 3. Board with microcontroller

In this study, the PIC 16F877 type microcontroller is used for the system. Most popular PIC microcontrollers are 8 bit type, which are available in different range of memory capacity, pin outs, and several integrated area like, SERIAL modules, EEPROM and ADC. The PIC 16F877 consist of 40 pin DIP package, which has 8 Kb program memory capacities of, 368 bytes RAM and EEPROM of 256 bytes. It works in the range of 0 Hz to 20 MHz of clock speed and fully static in operation. It contains 5 I/O ports such as PORT A, PORT B, PORT C, PORT D and PORT E, in which PORT A has 6 bit space, PORT E has 3 bit space and all the other have 8 bit space. PORT C pins have multiplexed functions for most of the peripherals, whereas the ADC input are available in PORT A and PORT E. Fig. 4 shows the microcontroller unit circuit.

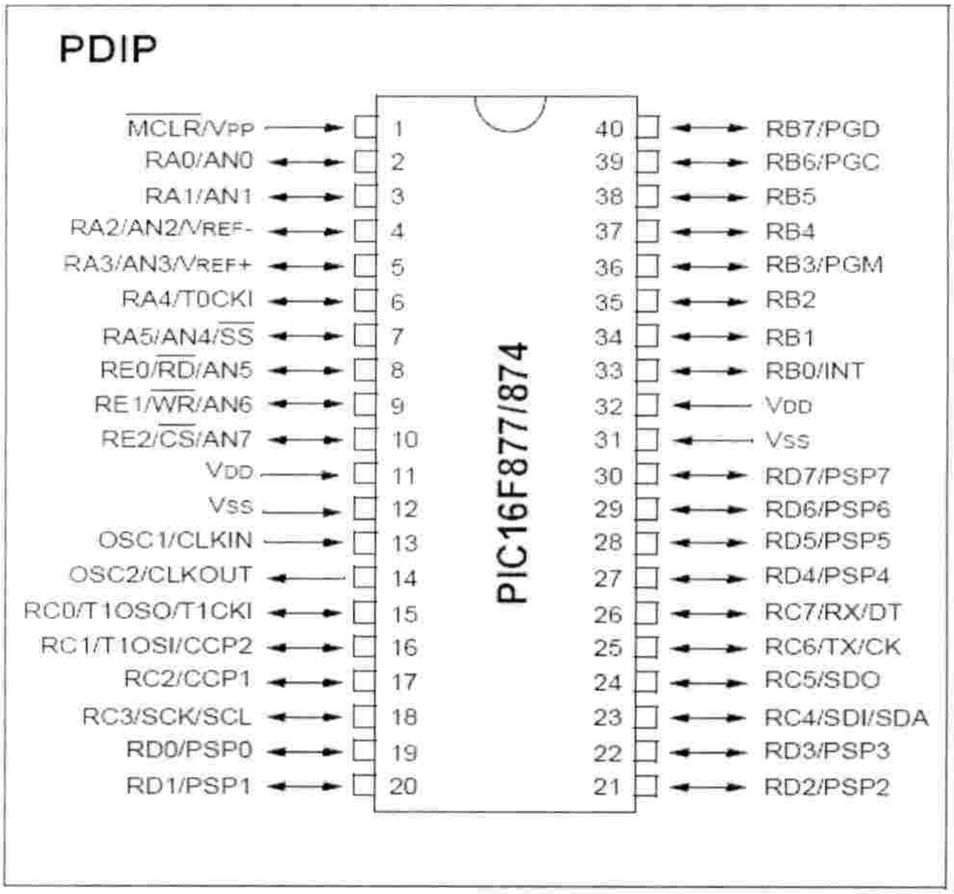

Fig. 4. Pin diagram microcontroller unit

3.2.1.4 Interfacing circuits

These circuits are used to connect soil moisture sensors to microcontroller unit. The microcontroller receives the signals from the soil moisture sensors regarding the conductivity and capacitance corresponding to the soil moisture level. The data are stored in MCU and give commands for the operation of other systems.

3.2.1.5 Control keys

Control keys consist of four micro switches attached to the display unit and microcontroller. The two manual switches are used for setting the upper and lower limits of the sensors. The 'up key' is used for incrementing limit and 'down key' is used for decrementing limits. The first key is used for changing the display, whereas the last key is used for uploading sensed data to computer. The control key arrangements are shown in Plate 4.

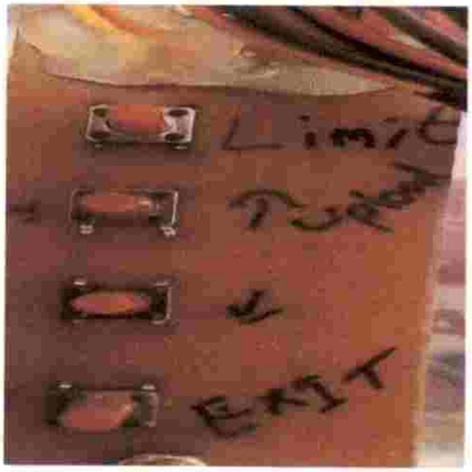

Plate 4. Control keys

The system has SET UP, INC, DEC and EXIT keys and these keys which are connected to RB1, RB2, RB3 and RB4 of the MCU respectively. Miniature type of micro switches is momentarily operated and to which voltage divider network is connected. 100 K resistor array is used to interface the switches with the MCU. The logic state transition from high to low is detected from the MCU by the action of each switch. If the keys are open, specified pins of the MCU will be in logic high. When they are pressed, the respective pin of the MCU will be grounded through it and hence that pin reaches to logic zero. Circuit connections of control switches are shown in Fig. 5.

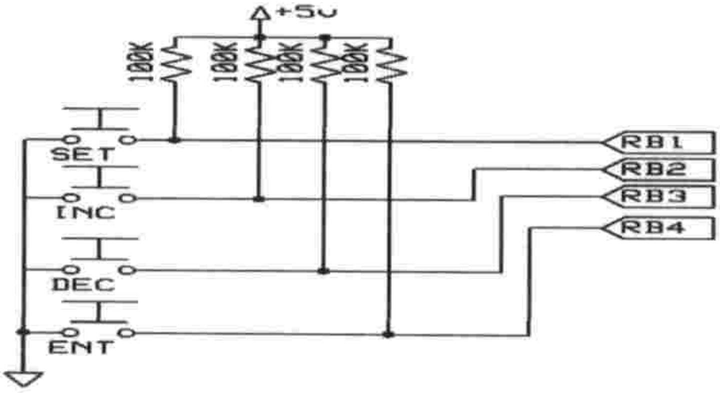

Fig. 5. Circuit of control keys

3.2.1.6 LCD display

The display section is used for showing the reading of four sensors, its average, status of motor and the reading of water flow sensor. Generally it displays the characters like alphanumeric, symbols and kana. It is a dot matrix liquid crystal type display which is connected to the 4 or 8 bit microcontroller unit via LSI driver and controller built. The device works by CMOS technology, which makes it light weight, portable and consumes less power and also act as an ideal part of the system shown in Plate 5.

Plate 5. LCD display

The HD 44780 type display unit is capable of showing 16 characters in 2 lines consisting of liquid crystal dot matrix display module, which contains LCD control driver, LCD panel and driver. It requires a controller, a character generator ROM and a data RAM for providing display. Data interface is 8-bit parallel or 4-bit parallel microprocessor used to write or read data. It consists of 16 pins in which 1st, 2nd, 3rd and 5th pins are used for power supply. 4th pin is to register for selection of data display of low or high valve. 5th pin is R/W if it is low it performs write operation. 6th pin is acting as 'enable pin' and remaining pins are in data lines. The circuit diagram of LCD is shown in Fig. 6.

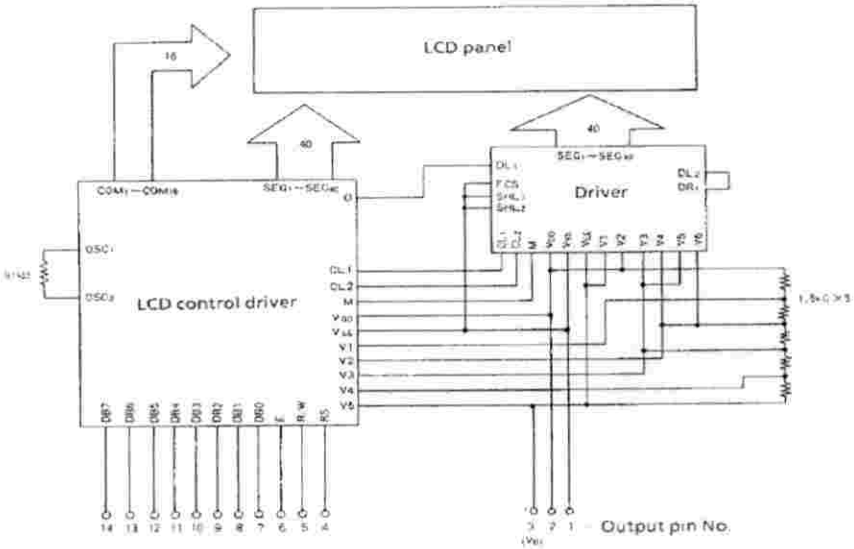

Fig. 6. LCD screen circuit diagram

3.2.1.7 Serial interface

The communication between MCU unit and GSM modem is done through the serial interface unit. In case of serial interface the information in form of bits are transmitted one after another. The MCU and the GSM modem are connected by RS232 and serial interface is used to convert RS232 to TTL compactable. MAX 232 IC can be used as serial interface.

Capacitive voltage generator is connected with the MAX232, which is a dual driver/receiver for providing TIA/EIA-232-F voltage levels from a single 5V supply. The driver converts TTL/CMOS input levels into TIA/EIA-232-F levels, whereas each receiver has a typical hysteresis of 0.5 V, threshold value of 1.3 V and ±30-V inputs that converts TIA/EIA-232-F inputs to 5V TTL/CMOS levels. Fig. 7 shows the circuit connection of serial interface.

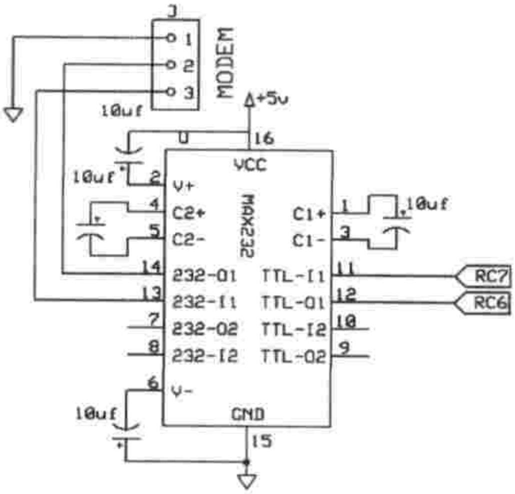

Fig. 7. Circuit diagram of serial interface

3.2.1.8 Water flow sensor

The sensor consists of a drum placed inside a plastic casing. It calculates the amount of water supplied for plants in litres by counting the rotation of drum. Plate 6 shows the arrangement of water flow sensor.

Plate 6. Water flow sensor

3.2.1.9 Relay interface

Interfacing is required for connecting a relay with any microcontroller. This is because relays are used according to voltage requirements other than logic supply voltage and also consumes a considerable amount of current when operating. Relays have inductive loads and operated in range of 12 V which should not be connected directly to the microcontroller ports due to the back emf problem. So a driver circuit is fixed between relays and processor pins. The output of the microcontroller is fed to the relay driver for current boosting. The output of this magnetizes the relay. Darlington pair array IC ULN2003 is used for interfacing and it is interfaced to microcontroller via RB5, RB6 & RB7. The circuit of relay interface is shown in Fig. 8.

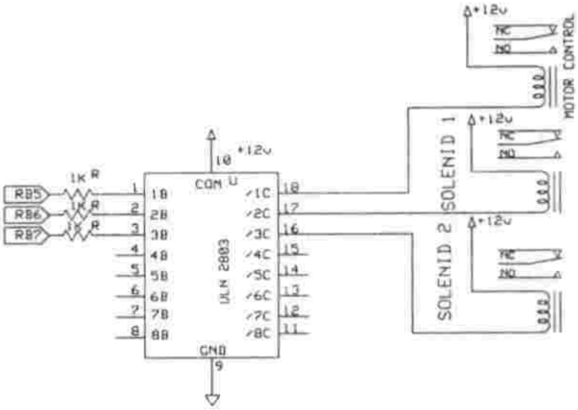

Fig. 8. Relay interface

3.2.1.10 Electrical relay

This block is used to control the action of water pump. The relays are magnetized by the current from the relay interfacing circuit, which is further controlled by the microcontroller. A relay is an electrical switch, which opens and closes under the control of another electrical_circuit. In the original form, the switch was operated by an electromagnet to open or close one or many sets of contacts. A relay is able to control an output circuit of higher power than the input circuit, so it can be considered as an electrical amplifier in the broad sense. Plate 7 shows the electrical relay of the motor.

Plate 7. Electrical relay

3.2.1.11 GSM modem

The modem is used to send and receive messages through the SIM inserted into it. GSM (Global System for Mobile communications) is an open, digital cellular technology used for transmitting mobile voice and data services. A GSM modem is a wireless modem that works with a GSM wireless network. A wireless modem behaves like a dial-up modem and wireless modem sends and receives data through radio waves. An external GSM modem is connected to a computer through a serial cable or a USB cable. Like a GSM mobile phone, a GSM modem requires a SIM card from a wireless carrier in order to operate. The number of messages that can be processed by a GSM modem per minute is very low, ie only about six to ten SMS messages per minute. Sim900 GSM/GPRS modem is used for the operation and is shown in Plate 8.

Plate 8. GSM modem connection

3.2.1.12 Solenoid valve

A solenoid valve is an electromechanical device used for controlling liquid or gas flow. The solenoid valve is controlled by electrical current, which is run through a coil. When the coil is energized, a magnetic field is created, causing a plunger inside the coil to move. Depending up on the design of the valve, the plunger can either open or close the valve. When electrical current is removed from the coil, the valve will return to its initial state. Four valves are placed for irrigation of four beds, which will work in accordance with the message received from the operator. Plate 9 shows the solenoid valves installed in the field.

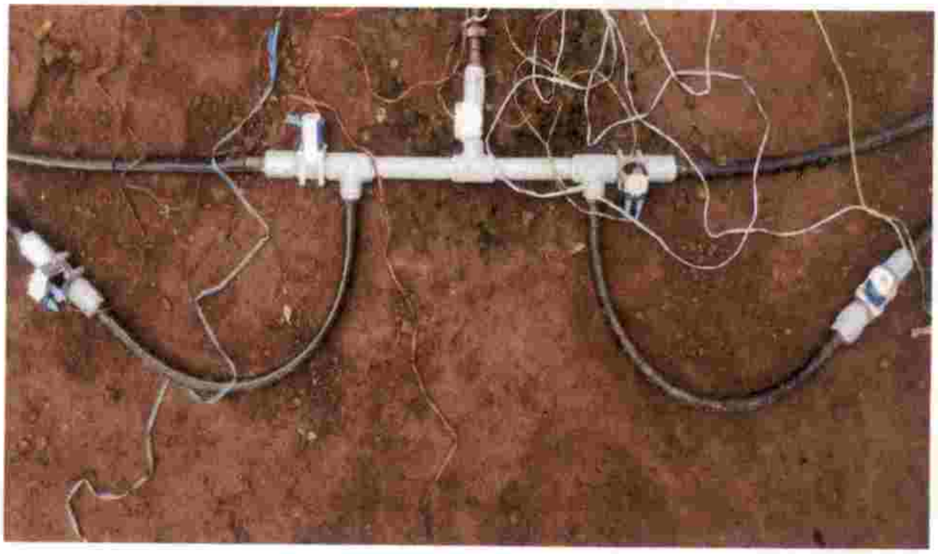

Plate 9. Arrangement of solenoid valves in lateral pipe

3.2.1.13 PC communication

The PC is used for downloading data from the system via microcontroller interface. Real term software is used for the collection and storing data in correct order at every interval. The circuit of the system is shown Fig. 9.

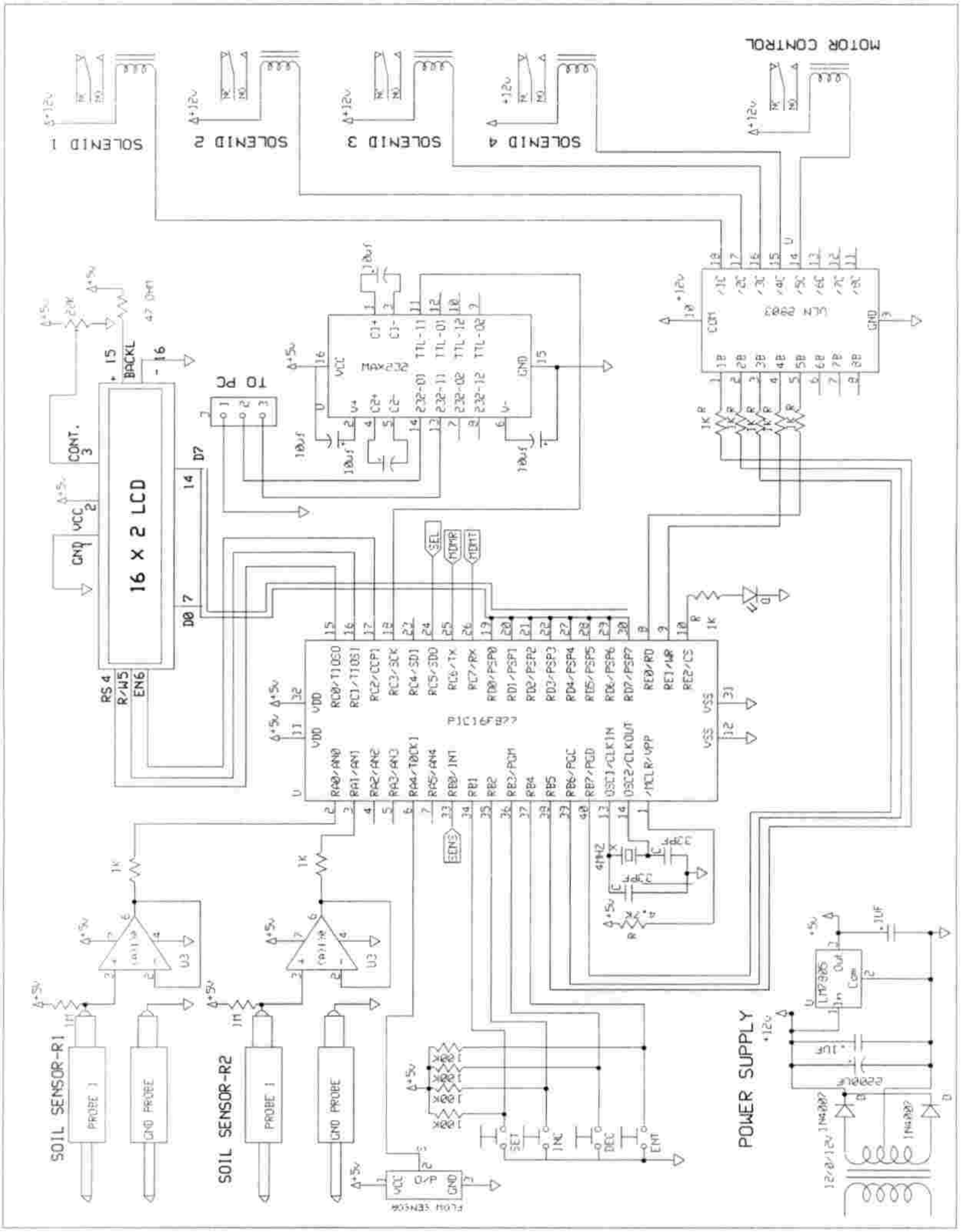

Fig. 9. Circuit diagram of irrigation control system

3.2.2 Power supply

The transformer steps down the AC voltage to desirable DC voltage, when 220V AC voltage is supplied. The diode rectifier connected with transformer gives a fully rectified voltage and it is initially filtered by a simple capacitor filter to produce a DC voltage. The ripples are controlled and cleared by regulator circuit and it maintains the same DC value even if the input DC voltage changes or the load linked to the output DC voltage differ. This voltage regulation is usually obtained with voltage regulator IC units. Power supply arrangement is shown in Fig. 10.

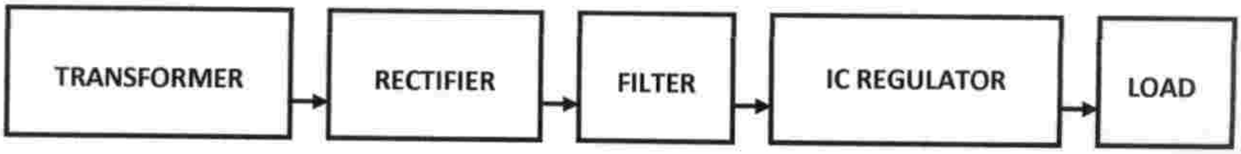

Fig. 10. Block diagram (Power supply)

3.2.2.1 Transformer

The center tap 230V /12-0-12 transformer is used in this system, which is made with inductor or half way point connected to a winding of a transformer or a potentiometer or along the element of a resistor. For the pairing of signals sometimes taps are used on inductors and may not necessarily be at the half-way point, but sometimes closer to first end. Plate 10 shows the transformer.

Plate 10. Transformer

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3.2.2.2 Rectifier

An electrical rectifier is a device that converts alternating current (AC), to direct current (DC), using rectification process. Bridge rectifiers are connected to the system, which produces a higher output voltage than the conventional full-wave rectifier circuit. Fig. 11 shows the rectifier circuit.

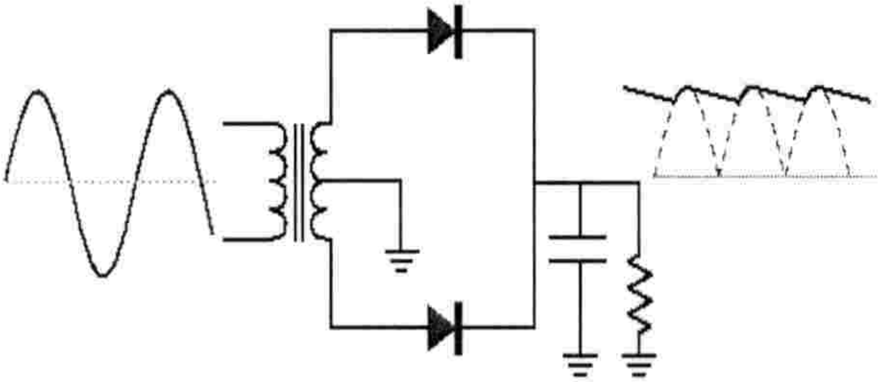


Fig. 11. Rectifier circuit

3.2.2.3 Filter

The capacitor type filters are fitted with the system for filtering the rectified signals from the rectifier and is regulated by means of LM7805 type regulator. Inductive effect due to long distribution loads can be eliminated by the connection of C2 capacitor to the input of the regulator and the transient response can be improved by output of C6 capacitor.

3.2.2.4 IC voltage regulators

Power supply is the most essential part of any circuit, which is regulated here using versatile and relatively inexpensive IC regulators. The integrated regulator circuit, also called the three terminal regulators consists of control device for reference source error amplitude and single IC chip for overload protection. They are connected in between input of the load and output of the filter and the regulated circuit is used to maintain constant output level.

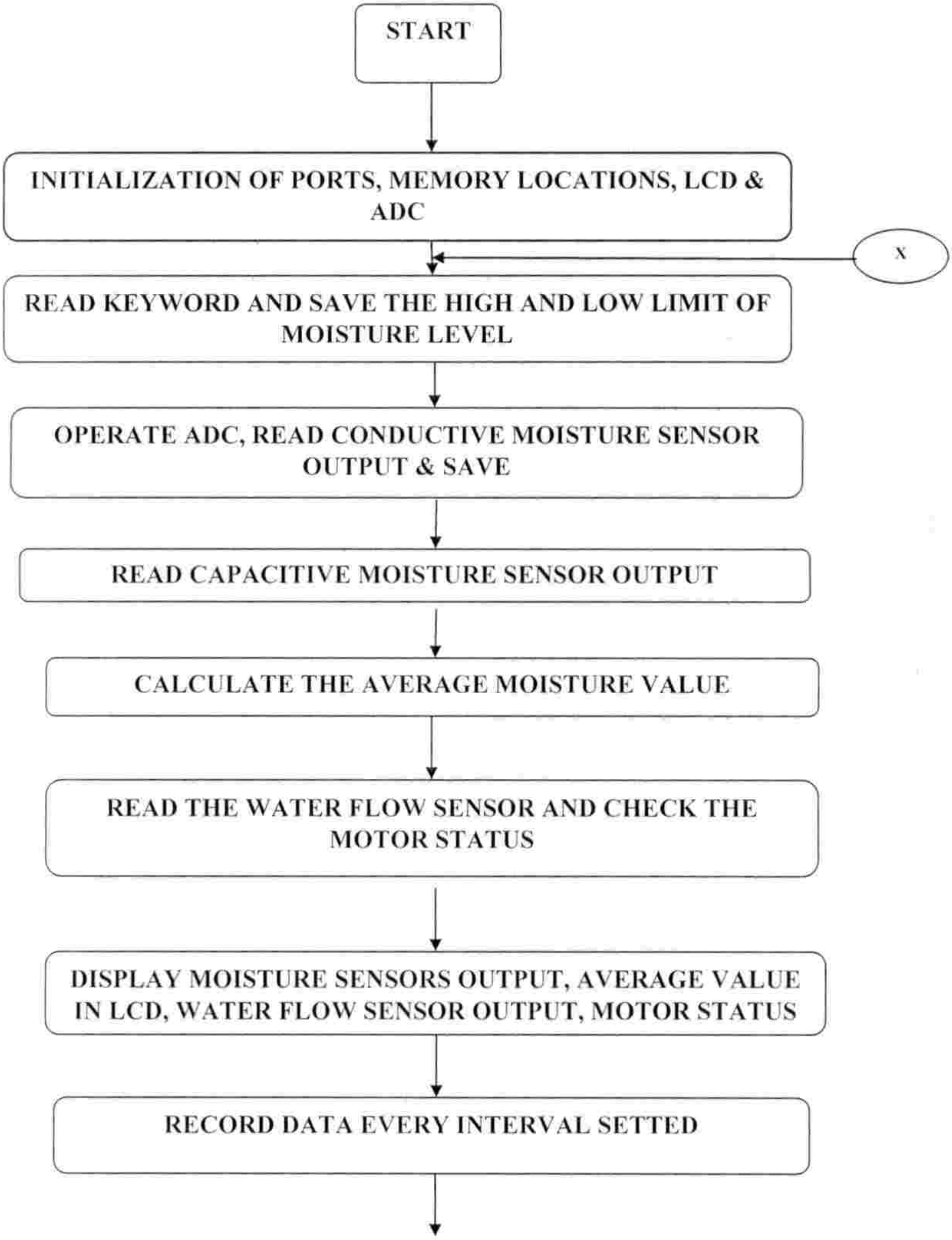
3.2.3 Simulation software

MPLAB software is used for the simulation automation circuit. The software is generally easier for developing and writing the programs and includes a host software component for debugging and built up applications. It could be best 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.

3.2.3.1 Functions of MPLAB

- The project files of different projects based on places and methods are grouped using the software.
- The programs are generated according to the requirement.
- Simulation program functions on the microcontroller is done using written program simulator of the software
- The simulated programs are checked using different commands

Program flow chart is shown in Fig. 12.


START
INITIALIZATION OF PORTS, MEMORY LOCATIONS, LCD & ADC
X
READ KEYWORD AND SAVE THE HIGH AND LOW LIMIT OF MOISTURE LEVEL
OPERATE ADC, READ CONDUCTIVE MOISTURE SENSOR OUTPUT & SAVE
READ CAPACITIVE MOISTURE SENSOR OUTPUT
CALCULATE THE AVERAGE MOISTURE VALUE
READ THE WATER FLOW SENSOR AND CHECK THE MOTOR STATUS
DISPLAY MOISTURE SENSORS OUTPUT, AVERAGE VALUE IN LCD, WATER FLOW SENSOR OUTPUT, MOTOR STATUS
RECORD DATA EVERY INTERVAL SETTED

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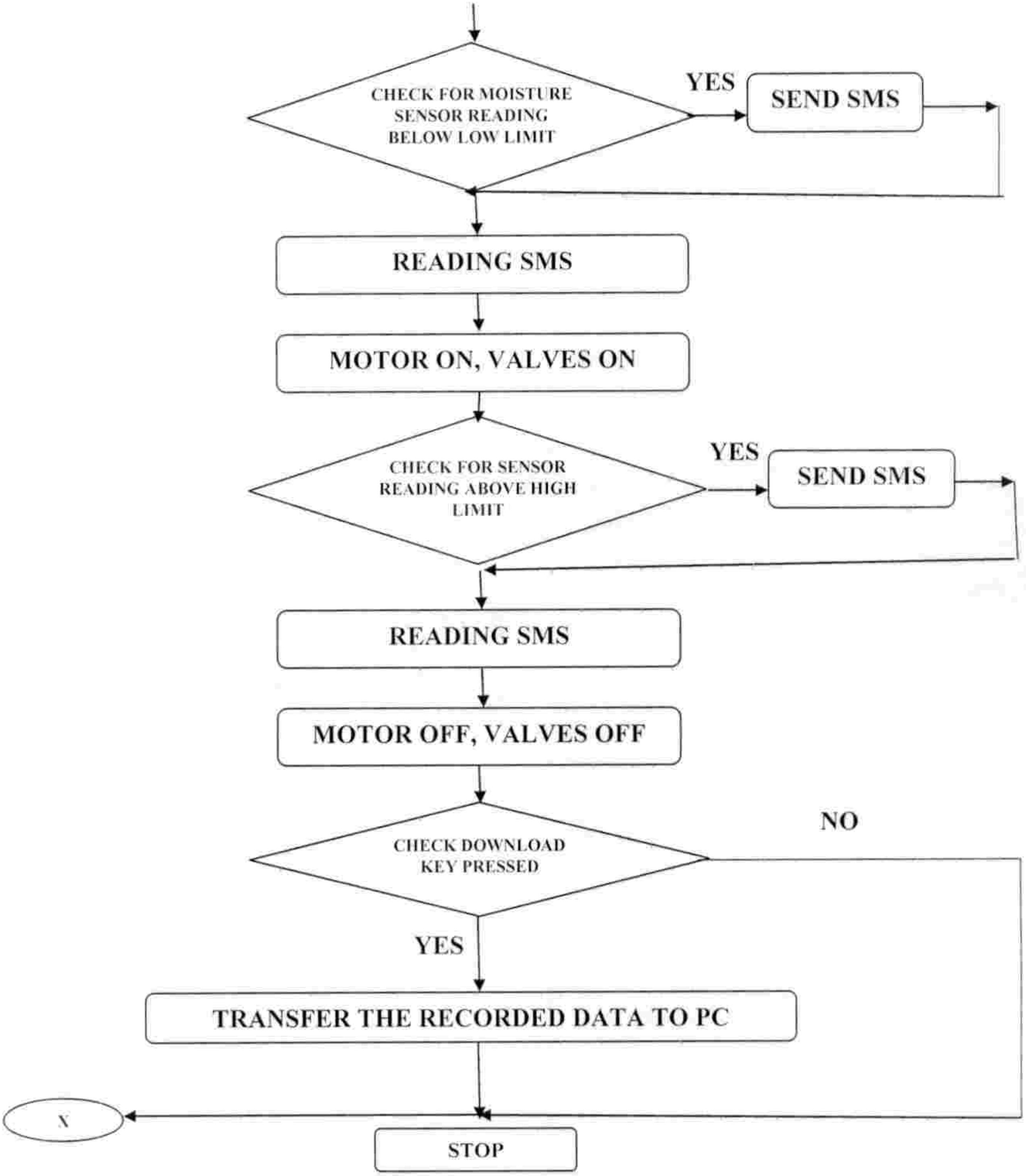


Fig. 12. Flow chart of the simulation program

3.3 DESIGN OF DRIP AUTOMATION UNIT

The system is fabricated and designed with less expensive materials and chips with the consideration of corrosiveness, portability, ease of handling sensitivity to physical parameters, ease of installation, quick response and durability etc. The program of the automation system simulated using MPLAB software. The software is very effective and it can be handled easily. The system is combined with microcontroller, which collects the reading from the capacitor type and conductive type sensors and the data are stored in the space allocated in the microcontroller.

The two sensors capacitor and conductive type gives quick response to the moisture content in which conductive type sensor has two electrodes that are connected to power supply for measuring the electrical conductivity of the soil. Capacitor type sensor has a long leg around 200 mm length and 3mm thick wire made up of Teflon material senses the capacitance of soil and calculate the volumetric moisture content. The system contains sim900 GSM modem used for sending and receiving output data and input commands respectively. A macro SIM is inserted in to the modem for the operation of the drip irrigation system. A water flow sensor was used to check the amount of water used for irrigating the entire plot. The LCD screen used to display the sensor readings, average of four sensor, reading of water flow sensor and the present status of the motor. Control keys are arranged near to the display section to set up upper and lower limits of the sensors. The up key used for adding the limit and down key used to decrease the limit. The upload key used to transfer the reading to the PC.

The sensors are inserted in to each bed to sense the moisture content. When the moisture content goes down the lower limit of sensor value then the microcontroller read it and sends as SMS to the number of authority already set in to it. So the motor will turn ON by return SMS from the user and LED will be glow. For scheduling irrigation to each bed, solenoid valves are also connected to the lateral line. The valves open by sending suitable commands to the system and the valves are opened by reading the SMS. When the moisture limit goes high then the system send SMS and motor and valves will turn OFF with the return command by.

The stored data in the microcontroller unit can be downloaded using PC by upload key and connector. The drip automation system is shown in the Plate 11.

Plate 11. Drip automation system

The real term software was used for the listing of sensed data. The data are grouped as files in .txt format and it is used for study. The software is very easy and quick. Fig. 13, Fig. 14 and Fig. 15 show the software details.

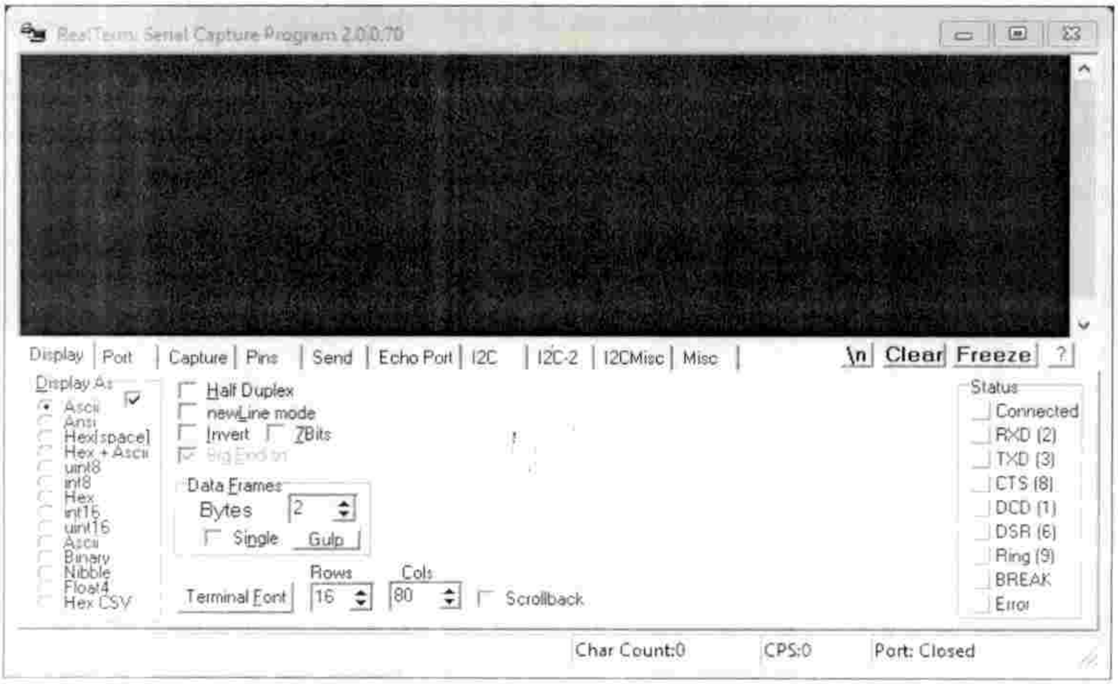


Fig. 13. Real Term software display

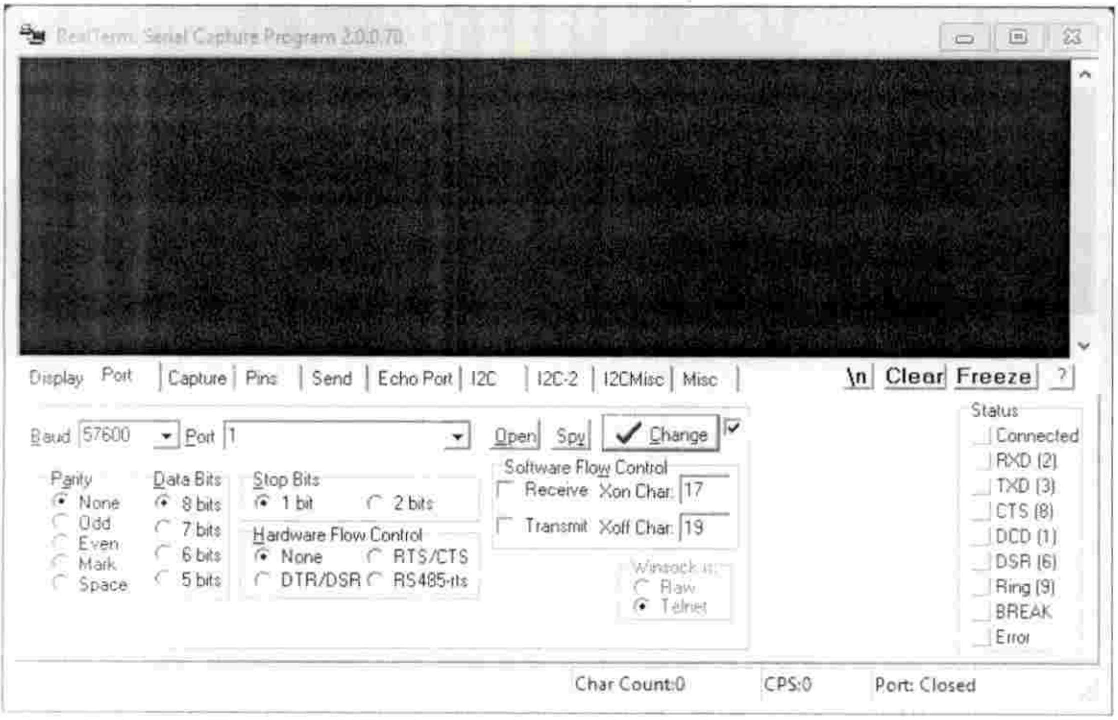


Fig. 14. Function of port

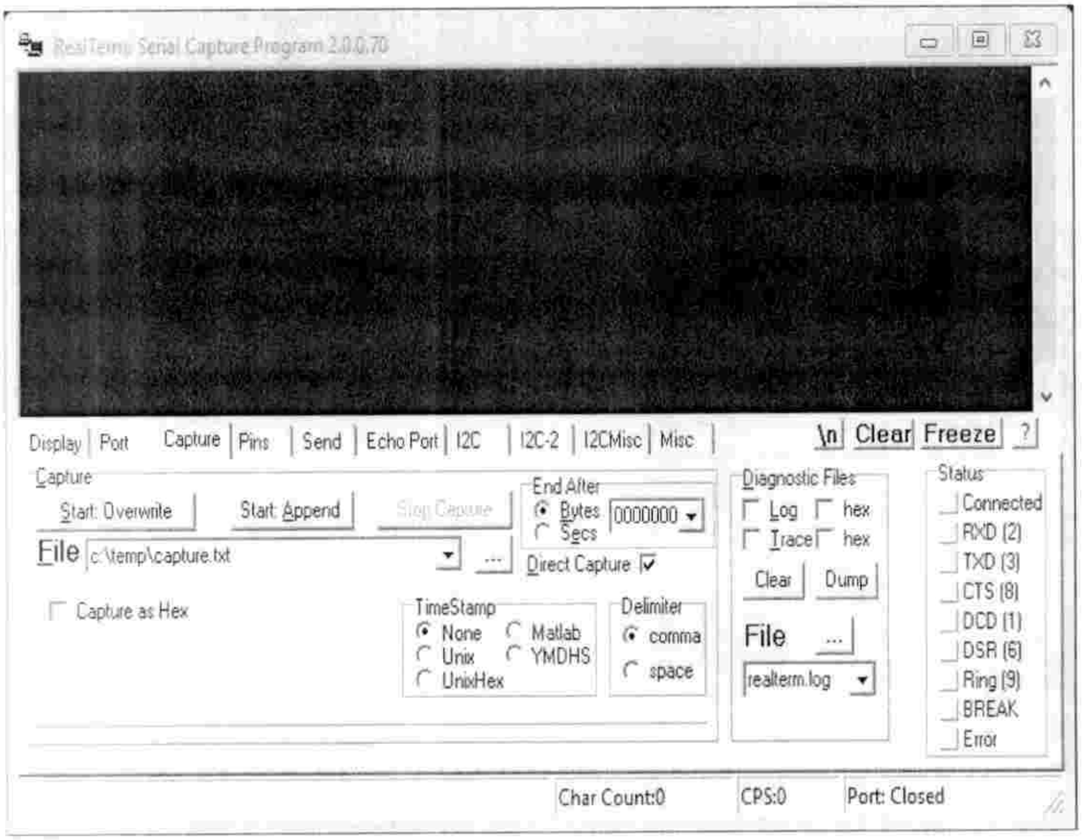


Fig. 15. Function of capture

3.4 CALIBRATION OF SOIL MOISTURE SENSOR FOR DIFFERENT CONCENTRATIONS OF SALT SOLUTION

Salt solutions were prepared by the addition of different amount of sodium chloride in 200 ml of distilled water to get the different concentration solution as shown in Table 1. Calibration of sensors is carried out with these solutions having different EC.

Table 1. Electrical conductivity at different salt concentrations

Sl. No.	Quantity of NaCl added (g)	Concentration in (ppm)	Electrical conductivity (dS/m)
1	0.0	0	0.147
2	0.25	1250	2.790
3	0.5	2500	5.480
4	0.75	3750	7.580
5	1	5000	9.630

The method of evaluation of electrical conductivity of different concentration of salt solution is carried out by dipping capacitor type, conductive type sensors and EC probe of water quality analyzer as shown in Plate 12 to Plate 14. Calibration charts are then prepared using the readings obtained from the test.

Plate 12. Calibration of capacitor type moisture sensor in salt solution

Plate 13. Calibration of conductive type moisture sensor in salt solution

Plate 14. Electrical conductivity by EC probe in salt solution

3.5 DETERMINATION OF PHYSICAL PROPERTIES OF SOIL

Laboratory tests were conducted for determining the physical properties of the soil and its particle distribution. The samples were collected from 5 different locations such as costal part of Ponnani, forest region of Malappuram, riverine part of Malapuram, Chittur and KCAET, Tavanur. Litter or debris from surface of each plot is removed and divided to an area of 0.5x0.5 cm^2. A thick slice of soil cut in to V shape using cutting tools up to a depth of 15 cm and is collected in clean bags by spade.

3.5.1 Particle size analysis

The size of particles in the selected 5 type of soils such as coastal alluvium, riverine alluvium, forest loam, black soil and laterite soil were checked using sieve analysis and sedimentation analysis.

3.6 CALIBRATION OF SOIL MOISTURE SENSOR WITH DIFFERENT SOILS

The performance evaluation of soil moisture sensors like capacitor and conductive type were done in Soil and water Conservation Engineering laboratory. Five different types soil samples, black soil, coastal alluvium, forest loam, laterite soil and riverine alluvium were tested and calibration curves were developed. The moisture content variations of each soil collected from different locations are determined using the sensors and is compared for the calibration.

Circular containers made up of polyvinylchloride (PVC) are used for the laboratory experiments. More than 15 holes are provided in the bottom side of containers for drainage. Each soil samples was taken twice in numbers into the 10 containers and soil moisture sensors were inserted in the centerline of soil collected in each container.

The conductive type sensors have two electrodes which measure the electrical conductivity of soil, as a function of moisture content of soil. The soil moisture levels corresponding to soil electrical conductivity are checked till it reaches constant moisture level. Electrical conductivity across the electrodes of the sensors differs according to the variation in the soil moisture. The capacitor type sensors have touch screen principle while soil ions contact with sensor and it shows reading corresponding to the moisture content of the soil.

Five trials were carried out using 10 samples every 24 hours interval. The soil with different texture and structure were observed at 10.30 am every day. Field capacity and wilting points were also noted while testing.

3.6.1 Determination of soil moisture content

The experiment was conducted to compare and relate the electrical conductivity and soil moisture content. The performance of the sensors is evaluated corresponding to the moisture variation of the different soil samples. Plate 15 shows the soil moisture measurement.

Plate 15. Determination of wet weight

The procedure adopted is as follows

- Weight of soil moisture sensor taken as W
- Weight of soil moisture sensor + Empty plastic pot recorded as W_0
- Weight of the oven dry soil sample was filled in the plastic pot contained with soil moisture sensor as $W_{dry}+W_0$
- Saturate the soil by pouring water to the plastic pot contained with soil moisture sensor and record the weight as $W_{wet}+W_0$

Dry weight basis, soil moisture content is estimated using the certain formula as follows (Jackson M.L., 1968)

$$\text{Moisture content} = [(W_{wet} + W_0) - (W_{dry} + W_0)] / [W_{dry}]$$

3.7 WORKING OF DRIP AUTOMATION UNIT

The system controlled by microcontroller unit has four output connectors in which one was connected to switch board, Two 12V adaptors one for developing potential difference to solenoid valve and next for the GSM modem and last connector for transferring data to the computer. The capacitor type sensors are connected in the same board of microcontroller whereas conductive type sensors connected just in the side of MCU. Water sensor is also attached to calculate the total quantity of water supplied to the crop. The LCD screen is set such a way that it displays the reading of four sensors, average of four sensors, amount of water supplied and the condition of motor. Control keys are attached with the system for adjusting the limits of soil moisture sensors, reading interval and uploading of data to the computer. Steps of operation of system are as follows

- The macro SIM was inserted into the GSM modem and the GSM modem was switched ON. Then the system was switched ON and 12V adaptor was connected with the mother board of the system.

- The LCD screen lightens and it shows "sending SMS", so it sends initial reading of all the sensors, its average, amount of water supplied and the motor status i.e. ON/OFF to the mobile number fed into the MCU (User).
- The higher limit and lower limit of each sensor was set by adjusting control keys. 'Up key' increases the limit and 'down key' decreases the limit and the intervals of monitoring were also set. After setting limits, press 'Exit key'.
- ON message was sent to the SIM inserted in to the GSM modem for starting the motor. The message will read and it gives reply as OK. Then send messages for opening each solenoid valves like CO1 ON, CO2 ON, CA1 ON and CA2 ON.
- The water sensor transfers reading to the MCU which corresponds to water applied to the field.
- When the sensor reading exceeds higher limit or decreases below the lower limit, then the system sends the SMS to the mobile number, which is already fed on it.
- Valves are closed by messages corresponding to the sensor readings and present status of the soil moisture can be got by messaging "STATUS" to the SIM.
- The system can go OFF by sending OFF message to the SIM.
- After pressing the run command, the microprocessor processes the data and displays the actual conductivity value of the soil.

3.7.1 Range of the soil moisture sensors

The conductive type sensor measures the EC value by the potential difference in the adjacent electrodes. The probe read electrical conductivity in the range of 0 mS/m to 250 mS/m. In the case of capacitor type sensor measures the capacitance and it reads a range of 0 F to 100 F. The readings of each sensor were utilized for daily examination of stability of soil sensor and determination of soil moisture content.

3.7.2 Proper maintenance

System can operate effectively and efficiently by proper planning and maintenance. The important steps for proper operations of the system are given below.

- Ensure that the system is fully covered for the prevention of water and check all the parts of system are connected into the board securely.
- The sensor terminals such as positive and negative are connected properly into the ports provided in the system.
- Ensure the GSM modem is connected correctly and the modem turns ON/OFF properly.
- Insert the sensors into the soil accurately to avoid gap between the soil moisture sensor and bed of soil.
- The ON/OFF terminals of the motor interface and relay should connect properly to the system and the motor.

3.8 FIELD EXPERIMENTS USING AUTOMATION SYSTEM

The drip automation system was designed and fabricated at research workshop and calibration experiments for soil moisture sensors were done in the Soil and water laboratory at KCAET, Tavanur, Malappuram. The field experiments were carried out in the polyhouse near to the instructional farm of KCAET, Tavanur during the March to June 2016.

3.8.1 Climatic conditions

The study area was selected inside the poly house located in eastern part of the instructional farm. The location of the experiment lies in the border of central zone and north zone of Kerala and near to the Bharathapuzha river. The region gets rainfall mainly from the contribution of south west monsoon. The total area of the polyhouse is 292 m^2 in which the drip irrigation was done with four beds with single row plantation. The land preparation was done before the installation of the system in the field.

3.8.2 Crop and variety

Salad cucumber (Cucumis sativas L.) variety Hilton FI was used for the field experiment. The crop has 90 days duration and it is good variety with high productivity and growth in the lateritic soil under polyhouse cultivation.

3.8.3 Crop water requirement

The drip irrigation in poly house was controlled using the different parameters and it can be calculated with different approaches. The crop water requirement was calculated by irrigation scheduling method (Jadhav et al., 2002).

$$WR = E_{pan} x\ K_p\ x\ K_c\ x\ W_p\ x\ A$$

3.8.4 Field layout

The field for cultivation of salad cucumber using automatic drip irrigation was prepared inside the polyhouse of PFDC, Tavanur. The plot was arranged as four beds having 30 cm length and 1 m width and plastic mulching was laid out to reduce weeds. Water source for the irrigation was supplied through 60mm diameter PVC pipe and it moves through sub mains of 40 mm. The entire water irrigates the bed through 16 mm lateral lines made up of LDPE pipes arranged centerline of each bed. The water was pumped from well located 90 m away from the poly house using 3 hp three phase motor. Seedlings were planted on the centerline of the bed and the lateral line having 35 m length with 21 emitters having 4 lph capacities were laid out. Plate 16 shows the field layout of the experiment.

Plate 16. Field layout with drip laterals

3.8.4.1 Field preparation

The plot inside the poly house was ploughed thoroughly using manual tools and the field was leveled for making ridges and furrows. Fumigants were applied to the prepared bed before planting for controlling soil-borne diseases and weeds. Basal dose of fertilizer was applied to the soil bed. The beds were prepared with a top width of 90 cm, height 40 cm, and bottom width 100 cm and laterals were laid on it. The four sensors were inserted in to the beds and drip irrigation system was installed. Salad cucumber seeds were sown in plastic trays and seedlings were planted in to each bed to reduce virus attack. Foggers were provided for giving cooling when the inside temperature is high. The arrangement of plot is shown in Plate 17.

Plate 17. Planted condition of salad cucumber

3.8.5 Irrigation and fertigation treatment

Seedlings were transplanted and irrigation was given to each bed through emitters using automated drip system. Seedlings were planted 1.5 m apart on each bed and drippers were fitted near to each plant. Four laterals were placed and 21 emitters with 4 lph capacity were fitted in each lateral. Irrigation was given in accordance with the treatment. Fig. 16 shows the treatment and replication of the experiment.

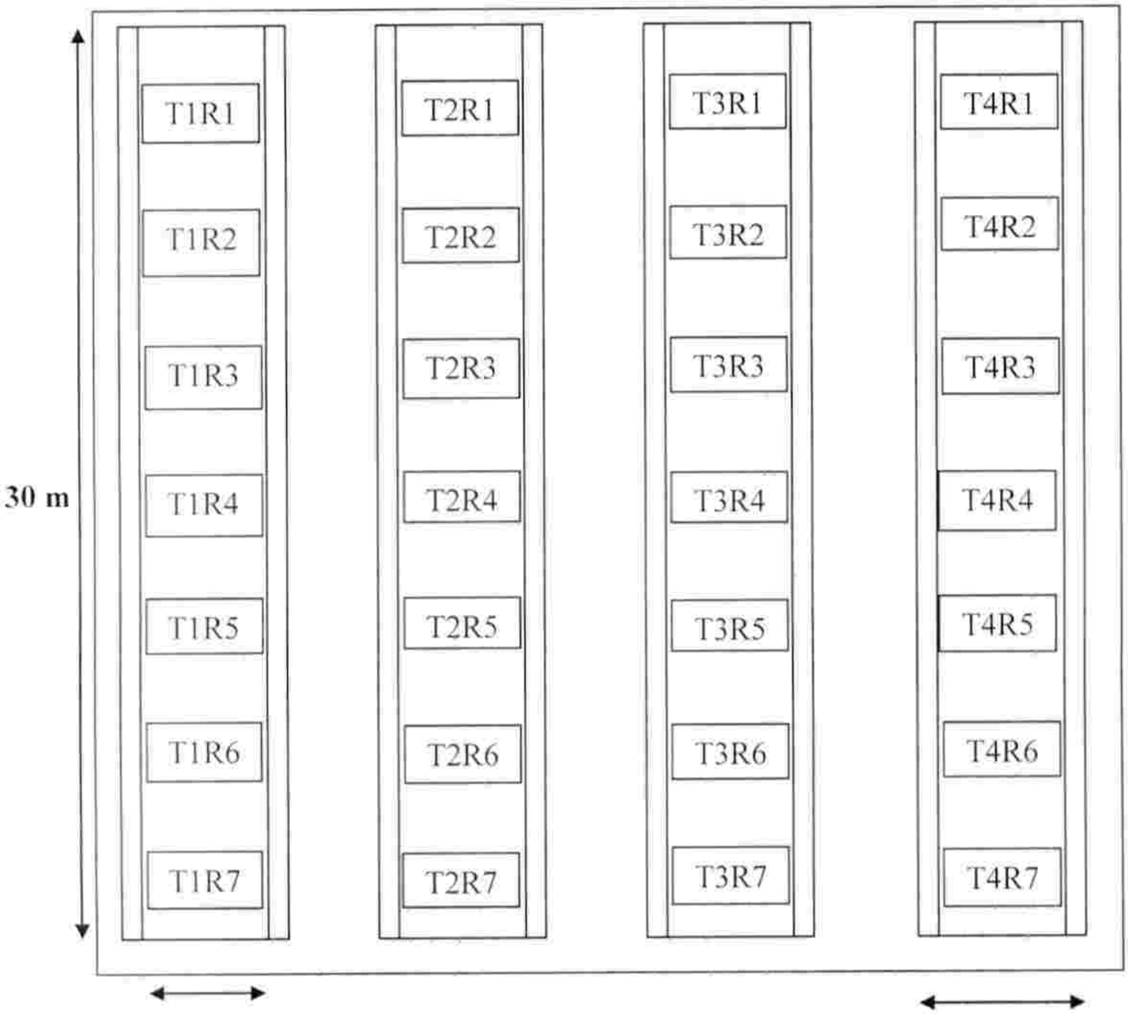


Fig. 16. Field layout

Water was applied based on the conductivity and dielectric permittivity values given by the conductive and capacitor type sensors respectively. Four treatments were used.

- T1-100 percent fertigation and 100 percent irrigation
- T2-100 percent fertigation and 70 percent irrigation
- T3-70 percent fertigation and 70 percent irrigation
- T4-70 percent fertigation and 100 percent irrigation.

The upper and lower limits of the sensor were set to identify the level of the water in each bed separately. The motor was ON/OFF by messaging corresponding to the difference in limits. The solenoid valves were operated according to the moisture level in the bed. When the moisture content came to lower limit then the motor was ON by message and water flows through the emitters via solenoid valve with the lighting of LED. When the moisture content reaches upper limit motor gets OFF by another message and the flow stops.

Recommended fertilizers for Hilton FI variety of salad cucumber were suppied every three day interval. Mono-ammonium phosphate (12:61:0), 19:19:19, Potassium Nitrate (13:0:45) and urea were used as the source of NPK. Fertigation treatments in each bed are given in Table 2.

Table 2. Fertigation treatments

Days of fertigation	Water soluble Fertilizer	T1-100% fertigation (Kg)	T2-100% fertigation (Kg)	T3-70% fertigation (Kg)	T4- 70% fertigation (Kg)
	Basal dose P	0.456	0.456	0.080	0.080
3-18	19:19:19	0.080	0.080	0.014	0.014
	13:00:45	0.069	0.069	0.012	0.012
	Urea	0.062	0.062	0.011	0.011
	12:61:oo	0.002	0.002	0.000	0.000
21-90	19:19:19	0.040	0.040	0.007	0.007
	13:00:45	0.146	0.146	0.026	0.026
	Urea	0.026	0.026	0.004	0.004
	12:61:oo	0.015	0.015	0.003	0.003

Results and discussion

CHAPTER 4

RESULTS AND DISCUSSION

This study emphasized on the modification and evaluation of existing automated drip irrigation system coupled with different types of soil moisture sensors for better irrigation efficiencies. Calibration of sensors with different concentration of salt solution and different types of soils were carried out in the Soil and Water Engineering laboratory, KCAET, Tavanur. Field study of automated drip irrigation system was conducted in the polyhouse using Hilton FI variety of salad cucumber. Results of the calibration of sensors and field evaluation are discussed in detailed in this chapter.

4.1 CALIBRATION OF SOIL MOISTURE SENSOR FOR DIFFERENT CONCENTRATIONS OF SALT SOLUTION

Sensors were calibrated in the laboratory using salt solutions prepared at different concentrations. The results of performance evaluation of sensors are given below.

4.1.1 Performance evaluation of soil moisture sensor using different salt solutions

Experiments were conducted with salt solution prepared by adding different quantity of NaCl to distilled water. Reading of conductive type and capacitor type sensors were taken by dipping the electrodes in to the sample. These readings were then compared with EC value checked by the water quality analyzer and prepared calibration curves. Calibration results of conductive type sensors are shown in Table 3 and the calibration curves are shown in Fig. 17 and Fig. 18.

Table 3. Conductive type sensors calibrated using different salt concentration

Sl. No.	Concentration in ppm	Electrical conductivity (dS/m)	Temperature (^{0}C)	Electrical conductivity (dS/m)	
				Sensor 1 reading	Sensor 2 reading
1	0	0.147	35.6	19.5	17.3
2	1250	2.790	34.6	20.6	20.8
3	2500	5.480	39.7	22.4	22.4
4	3750	7.580	39.5	23.0	23.3
5	5000	9.630	38.5	23.6	23.8

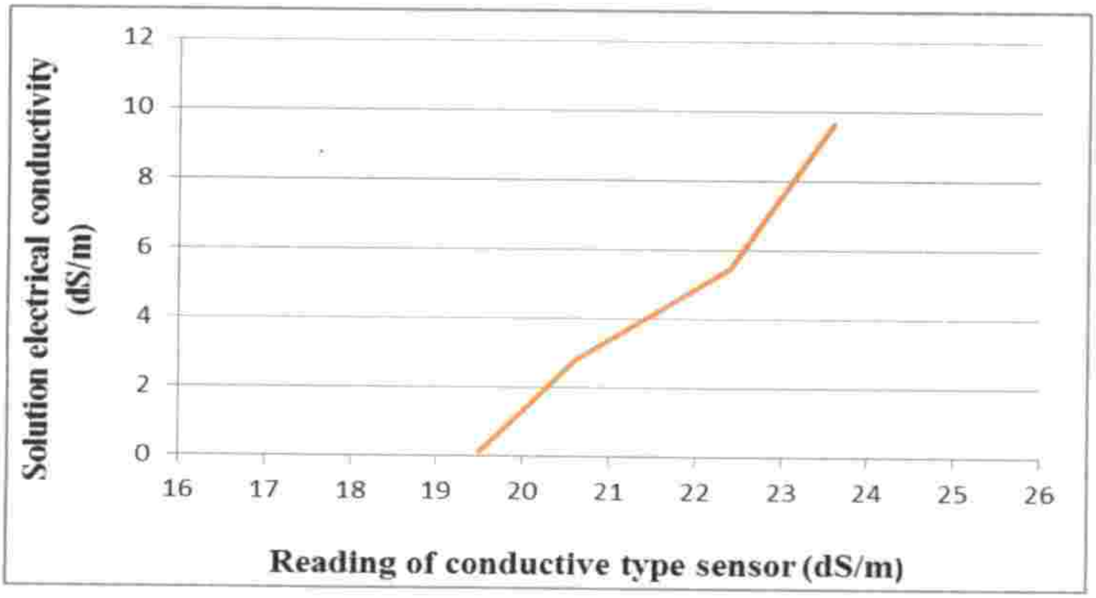


Fig. 17. Calibration curve of conductive sensor 1

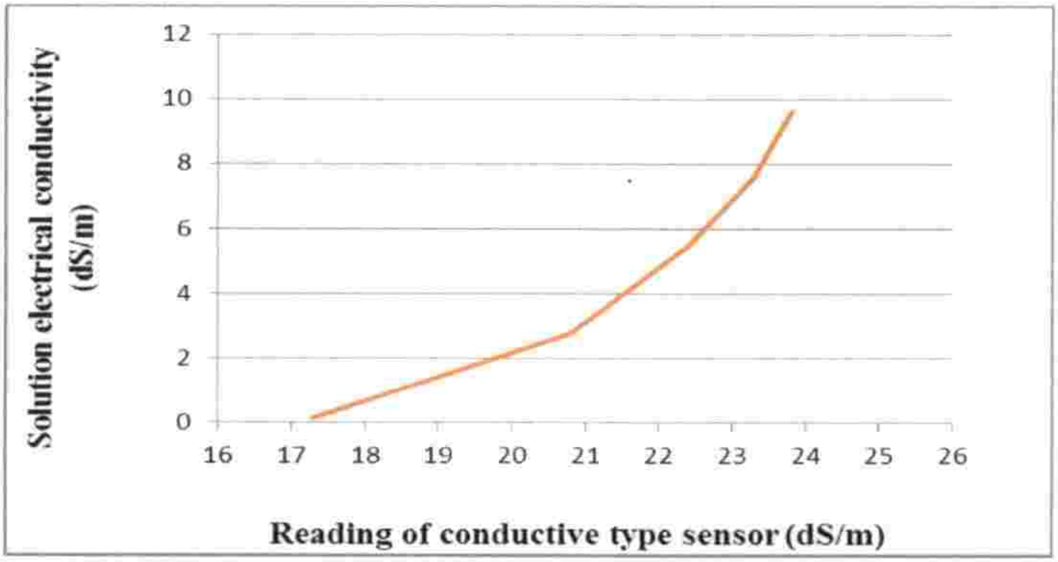


Fig. 18. Calibration curve of conductive sensor 2

Sensor readings changes with respect to the electrical conductivity of the salt solution. It showed that a linear relationship in existed in initial stage and the slope of curve increased slightly for higher salt concentration. The conductivity value of conductive type moisture sensor showed increasing trend with the increase of electrical conductivity of solution. Conductivity of the sensors showed 18 dS/m based on EC of 0.01 dS/m, because of the purity of water. The material and shape of the sensor affects the deviation of the reading, hence determined the range of the measurement. However, when a very high concentration of salt added to water which make electrical conductivity of the solution higher and the conductivity value of the sensor also varied proportionally. Conductivity turns to be linear at diminishing rate with increasing concentration of salt. At this stage addition of a small quantity of salt could increase the electrical conductivity of solution, which cause change in the conductivity value of the sensor. The sensor gave accurate measurements at higher electrical conductivities and the calibration results of capacitor type sensors are shown in Table 4 and calibration curves are shown in Fig. 19 and Fig. 20

Table 4. Capacitor type sensors calibrated using different salt concentration

Sl. No.	Concentration in ppm	Electrical conductivity (dS/m)	Temperature (^{0}C)	Capacitance (F)	
				sensor 1 reading	sensor 2 reading
1	0	0.147	35.6	36	36
2	1250	2.790	34.6	40	41
3	2500	5.480	39.7	47	47
4	3750	7.580	39.5	50	49
5	5000	9.630	38.5	54	54

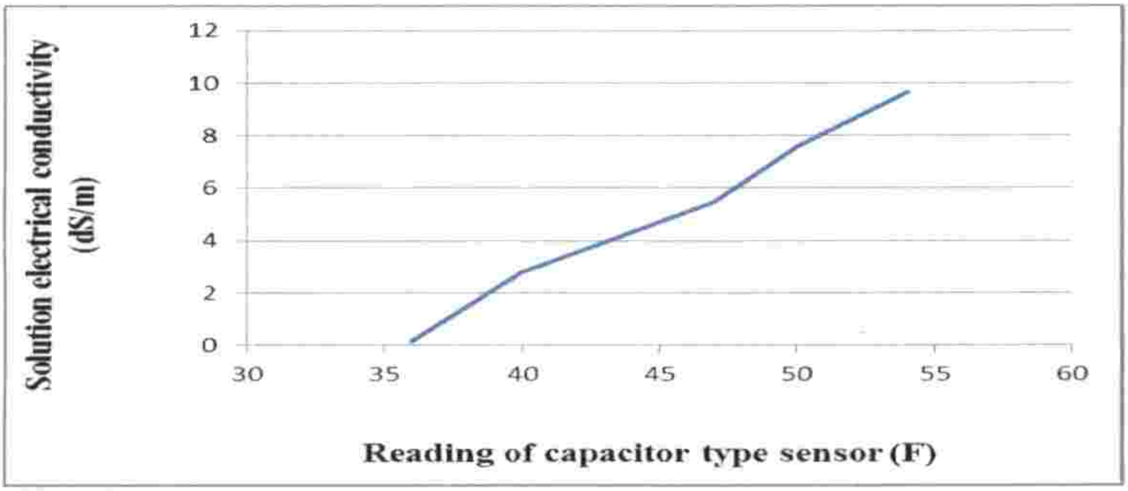


Fig. 19 Calibration curve of capacitor sensor 1

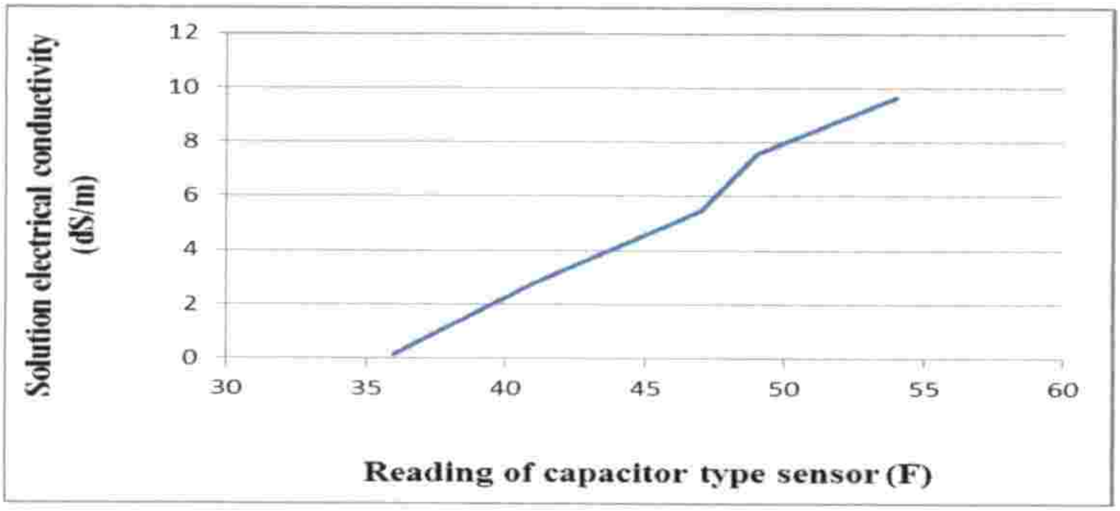


Fig. 20. Calibration curve of capacitor sensor 2

In case of the capacitor sensor, the electrical conductivity value of salt solution showed linear trend with the capacitance. The water molecules consist of hydrogen and oxygen atom bonded tightly and which moves freely based on its medium. Test with capacitor sensor and EC probe of water quality analyzer not and it showed the capacitance value as 30 F with EC of 0.01 dS/m, because of the insulating nature of water. The nature of the water changes completely when NaCl is added to it. Salt molecule breaks to form sodium and chloride ions and thus the water shows conductive nature. Due to the presence of ions that comes from salt, capacitance of the pure water changes fast.

4.2 PARTICLE SIZE ANALYSIS

For the particle size analysis, soil samples were collected from five different locations of different types of soils, viz. coastal alluvium, riverine alluvium, black soil, laterite soil and forest loam and it was carried out in the laboratory. Particle size distribution was found out by sieve analysis and sedimentation analysis.

4.2.1 Sieve analysis

Soil samples retained on each sieve (2 mm, 1 mm, 600 μm, 425 μm, 300 μm, 212 μm, 150 μm, and 75 μm) sizes arranged one below the other were collected and weighed and the process was repeated for each soil sample collected from five locations. Particle size distribution curves of each sample were drawn and are shown in Appendix I.

4.2.2 Sedimentation analysis (hydrometer method)

The particles finer than 75 μm in each sample weighing as 30 g using weighing balance was made as solution with distilled water in a measuring jar of capacity 1000 ml and tested using hydrometer. The readings at several intervals were noted and particle distribution curves were drawn for laterite soil, black soil, forest loam, riverine alluvium and coastal alluvium etc. The calculation part and calibration curves are given in Appendix II.

Particle size distribution of laterite soil and black soil showed same trend, which indicate clayey loam texture. The riverine alluvium showed a loamy nature. Coastal alluvium having linear increase but the finer percentage was very less compared to other soils.

4.3 CALIBRATION OF SENSORS IN DIFFERENT SOILS

Calibration of sensors was carried out with five different types of soils collected from different locations. Moisture content of each type of soil was measured using gravimetric method and corresponding electrical conductivity values of each sensor were also noted. The reading was noted in succeeding 5 days continuously. The soil moisture content and corresponding EC values of 5 different types of soils are given in Table 5 to 9. Calibration curves plotted with EC value (mS/m) against moisture content (%) of different types of soils are shown in Fig. 21 to Fig. 25.

Table 5. Calibration data of conductive sensors in black soil

Days	Moisture content (%)		Electrical conductivity (mS/m)			
			Conductive sensor 1		Conductive sensor 2	
	container 1	container 2	container 1	container 2	container 1	container 2
1	40.08	41.03	236	238	235	239
2	35.74	36.72	218	222	216	214
3	32.34	33.44	209	217	211	219
4	22.85	24.06	193	200	187	196
5	18.62	19.82	176	182	169	181

Table 6. Calibration data of conductive sensors in laterite soil

Days	Moisture content (%)		Electrical conductivity (mS/m)			
			Conductive sensor 1		Conductive sensor 2	
	container 1	container 2	container 1	container 2	container 1	container 2
1	37.98	36.60	227	219	231	223
2	31.69	30.62	221	210	219	213
3	27.02	26.80	216	213	211	208
4	23.68	23.14	198	203	194	201
5	20.77	20.59	193	186	189	183

Table 7. Calibration data of conductive sensors in forest loam

Days	Moisture content (%)		Electrical conductivity (mS/m)			
			Conductive sensor 1		Conductive sensor 2	
	container 1	container 2	container 1	container 2	container 1	container 2
1	29.44	28.43	220	215	217	213
2	23.93	24.20	209	212	206	208
3	18.66	17.88	198	179	188	178
4	18.05	17.22	193	181	190	183
5	14.11	12.41	181	173	176	164

Table 8. Calibration data of conductive sensors in coastal alluvium

Days	Moisture content (%)		Electrical conductivity (mS/m)			
			Conductive sensor 1		Conductive sensor 2	
	container 1	container 2	container 1	container 2	container 1	container 2
1	34.62	33.29	227	219	223	217
2	27.52	26.25	218	216	216	212
3	24.15	20.65	208	201	205	200
4	21.96	17.95	192	184	188	176
5	21.01	15.06	188	179	185	170

Table 9. Calibration data of conductive sensors in riverine alluvium

Days	Moisture content (%)		Electrical conductivity (mS/m)			
			Conductive sensor 1		Conductive sensor 2	
	container 1	container 2	container 1	container 2	container 1	container 2
1	19.48	18.96	188	184	185	179
2	16.36	16.82	182	176	178	165
3	15.22	13.84	177	172	170	162
4	11.02	10.35	163	160	160	157
5	9.941	9.14	155	152	151	146

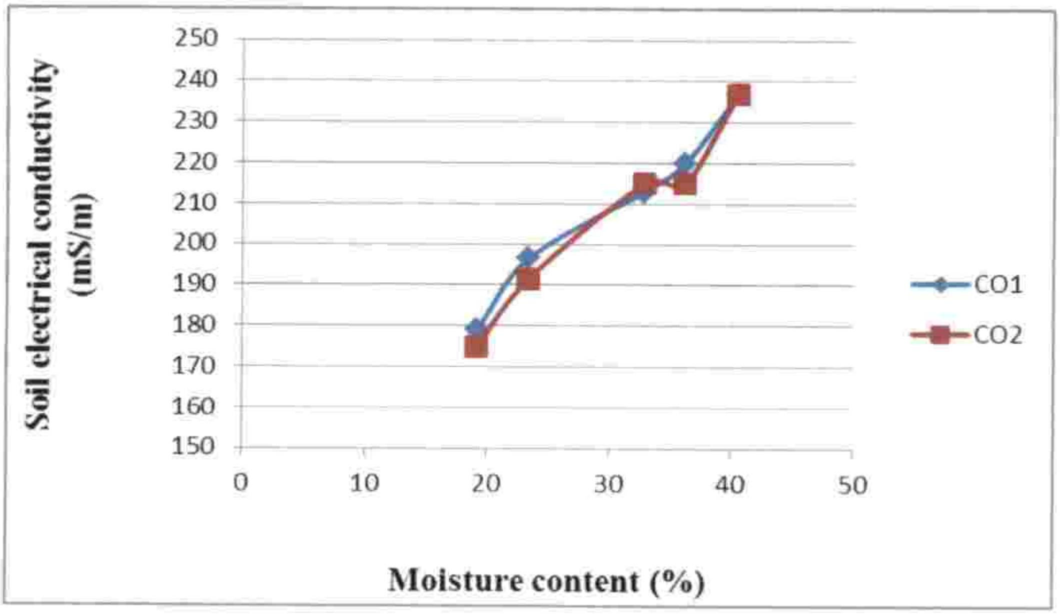


Fig. 21. Calibration curve of conductive sensors in black soil

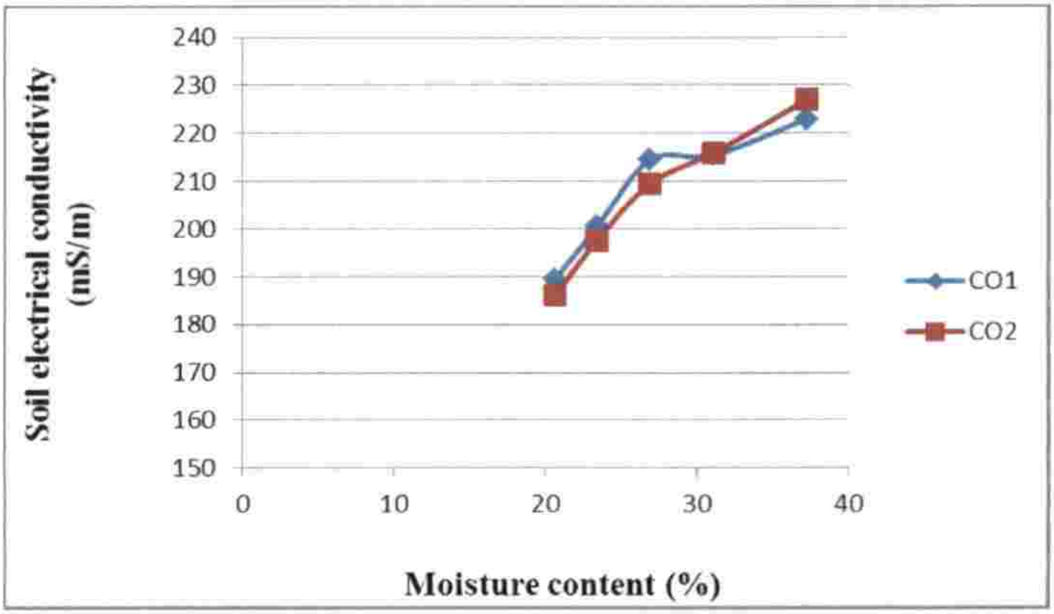


Fig. 22. Calibration curve of conductive sensors in laterite soil

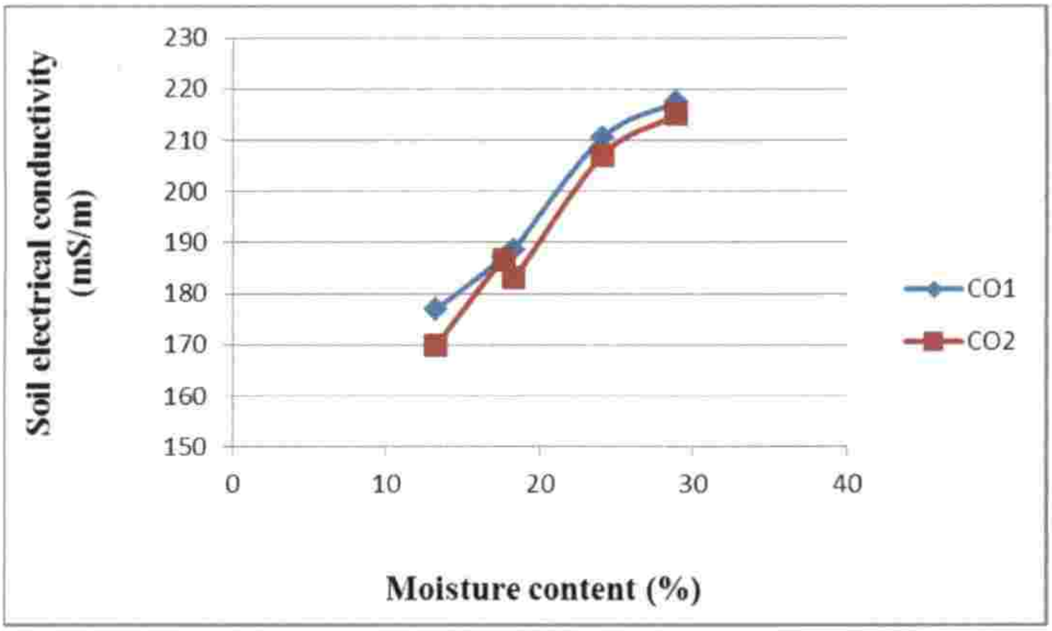


Fig. 23. Calibration curve of conductive sensors in forest loam

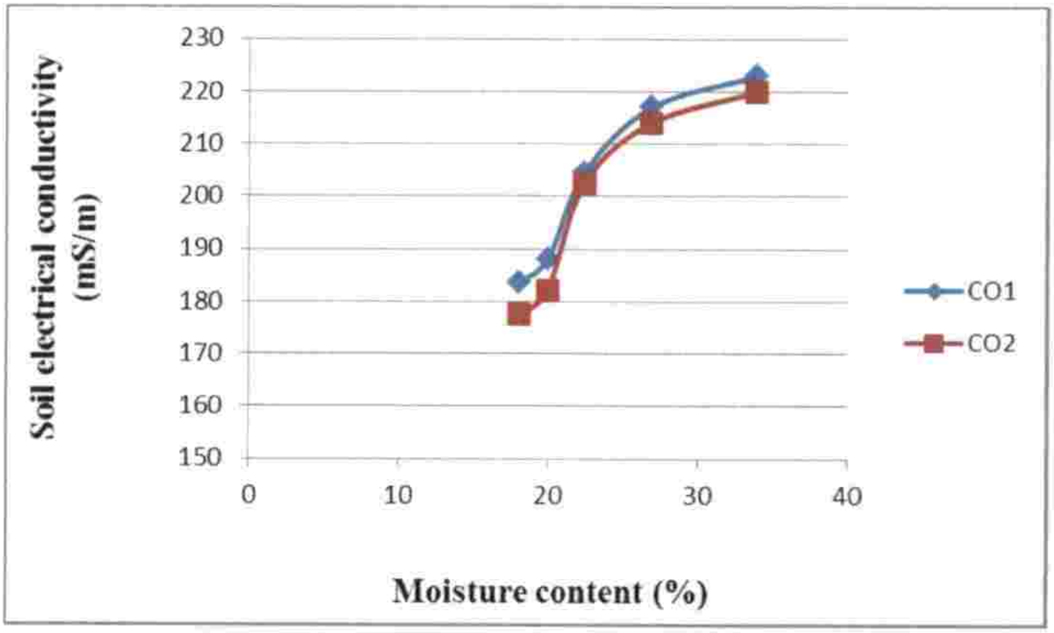


Fig. 24. Calibration curve of conductive sensors in coastal alluvium

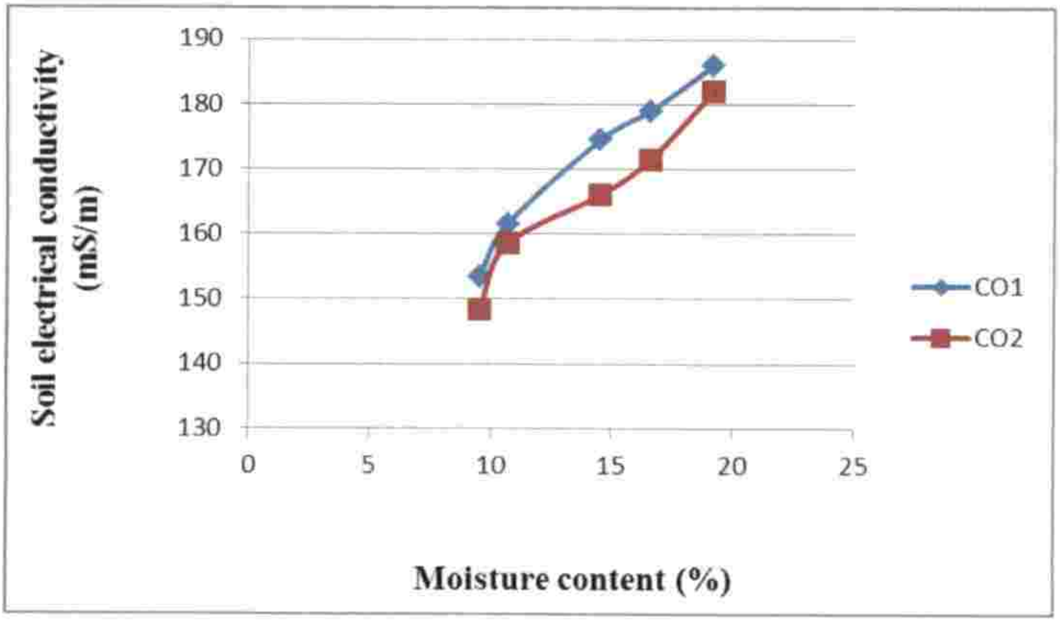


Fig. 25. Calibration curve of conductive sensors in riverine alluvium

EC value of conductive type sensor decreased with the decrease of moisture content. Maximum and minimum values of electrical conductivity indicated wet and dry conditions of soil respectively. It was observed that as soil got dried up, the electrical conductivity gets decreased. The maximum and minimum values of electrical conductivity of black soil were 237 mS/m and 177 mS/m at moisture contents of 40.55 and 19.22 per cent respectively. In laterite soil the values were 225 mS/m and 188 mS/m at moisture contents of 37.29 and 20.68 per cent respectively. In forest loam values were 216 mS/m and 174 mS/m at moisture contents of 28.93 and 13.26 per cent respectively. In coastal alluvium values were 222 mS/m and 180 mS/m at moisture contents of 33.95 and 18.03 per cent respectively. In riverine alluvium values were 184 mS/m and 151 mS/m at moisture contents of 19.22 and 9.54 per cent respectively.

Riverine alluvium showed small reduction of electrical conductivity in relation to moisture content, while forest loam showed minor variations after the soil moisture reached field capacity. Similarly the relationship between capacitance and moisture content were determined and are given in Table 10 to 14. Calibration curves are shown in Fig. 26 to Fig. 30.

Table 10. Calibration data of capacitor sensors in black soil

Days	Moisture content (%)		Capacitance (F)			
			capacitor sensor 1		capacitor sensor 2	
	container 1	container 2	container 1	container 2	container 1	container 2
1	40.08	41.03	36	37	35	38
2	35.74	36.72	33	34	34	32
3	32.34	33.44	29	30	31	30
4	22.85	24.06	20	23	21	23
5	18.62	19.82	17	17	16	17

Table 11. Calibration data of capacitor sensors in laterite soil

Days	Moisture content (%)		Capacitance (F)			
			Capacitor sensor 1		Capacitor sensor 2	
	container 1	container 2	container 1	container 2	container 1	container 2
1	37.98	36.60	35	34	36	34
2	31.69	30.62	29	30	29	29
3	27.02	26.80	26	25	24	25
4	23.68	23.14	18	22	19	21
5	20.77	20.59	17	18	17	19

Table 12. Calibration data of capacitor sensors in forest loam

Days	Moisture content (%)		Capacitance (F)			
			Capacitor sensor 1		Capacitor sensor 2	
	container 1	container 2	container 1	container 2	container 1	container 2
1	29.44	28.43	27	25	26	25
2	23.93	24.20	21	22	22	23
3	18.66	17.88	18	16	17	16
4	18.05	17.22	17	14	15	16
5	14.11	12.41	11	11	13	12

Table 13. Calibration data of capacitor sensors in coastal alluvium

Days	Moisture content (%)		Capacitance (F)			
			Capacitor sensor 1		Capacitor sensor 2	
	container 1	container 2	container 1	container 2	container 1	container 2
1	34.62	33.29	32	33	33	31
2	27.52	26.25	26	24	26	25
3	24.15	20.65	22	18	22	19
4	21.96	17.95	20	21	19	21
5	21.01	15.06	19	18	19	17

Table 14. Calibration data of capacitor sensors in riverine alluvium

Days	Moisture content (%)		Capacitance (F)			
			capacitor sensor 1		capacitor sensor 2	
	container 1	container 2	container 1	container 2	container 1	container 2
1	19.48	18.96	16	15	16	15
2	16.36	16.82	13	12	14	13
3	15.22	13.84	11	14	13	13
4	11.02	10.35	9	8	8	10
5	9.94	9.14	6	8	7	8

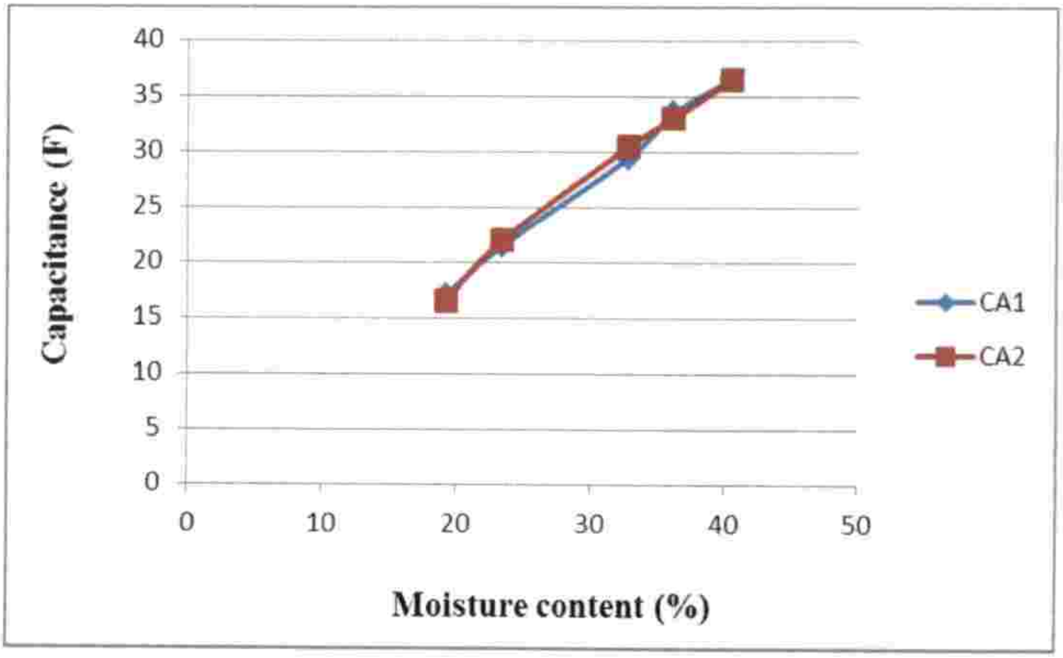


Fig. 26. Calibration curve of capacitor sensors in black soil

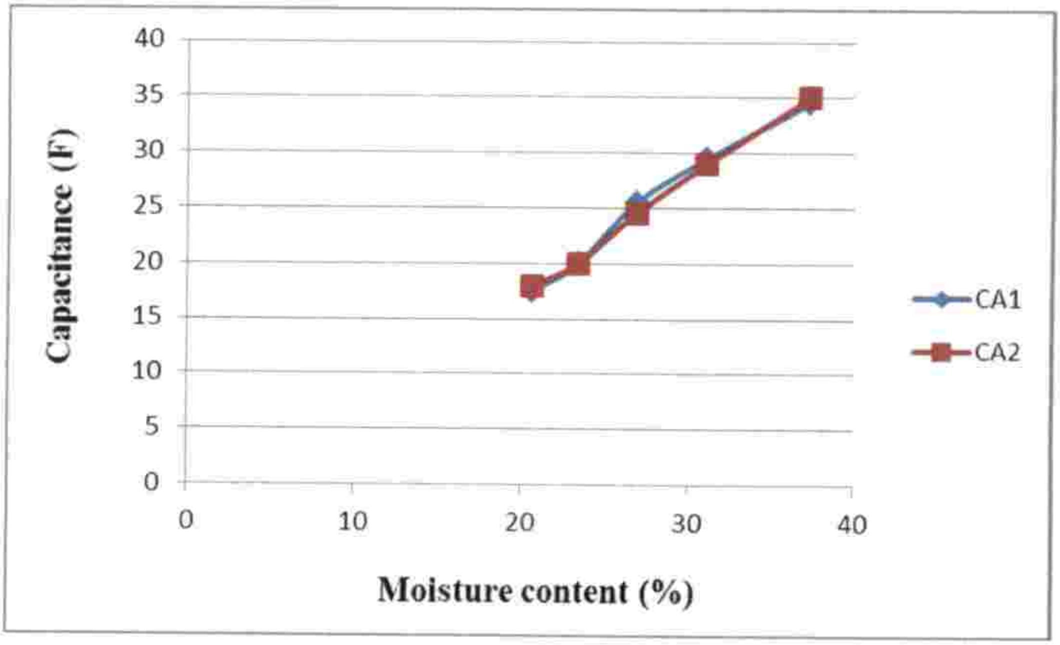


Fig. 27 Calibration curve of capacitor sensors in laterite soil

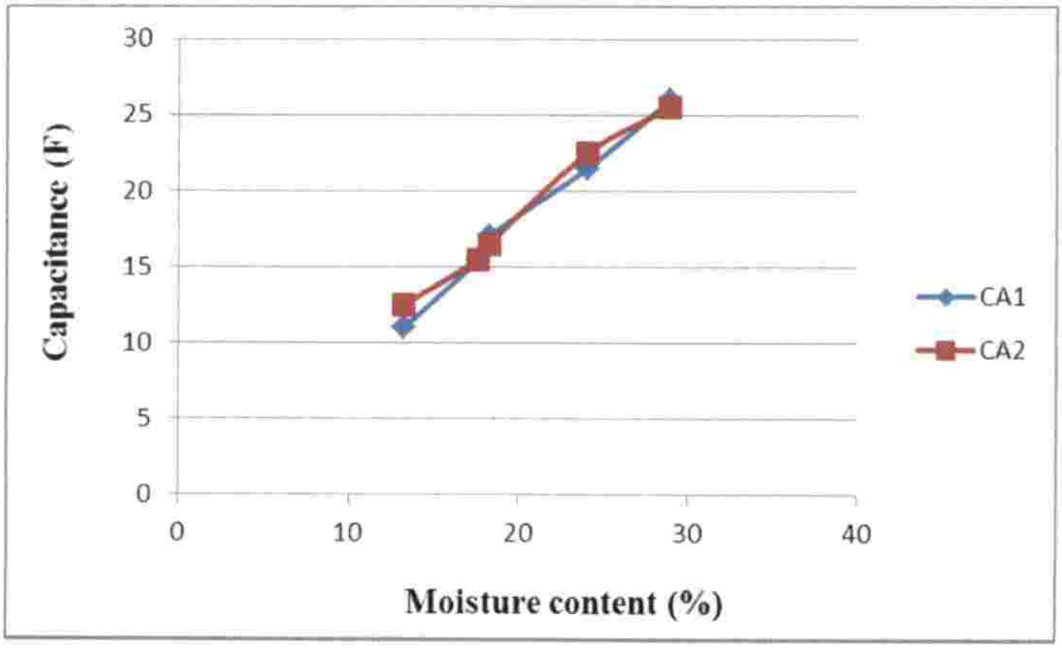


Fig. 28 Calibration curve of capacitor sensors in forest loam

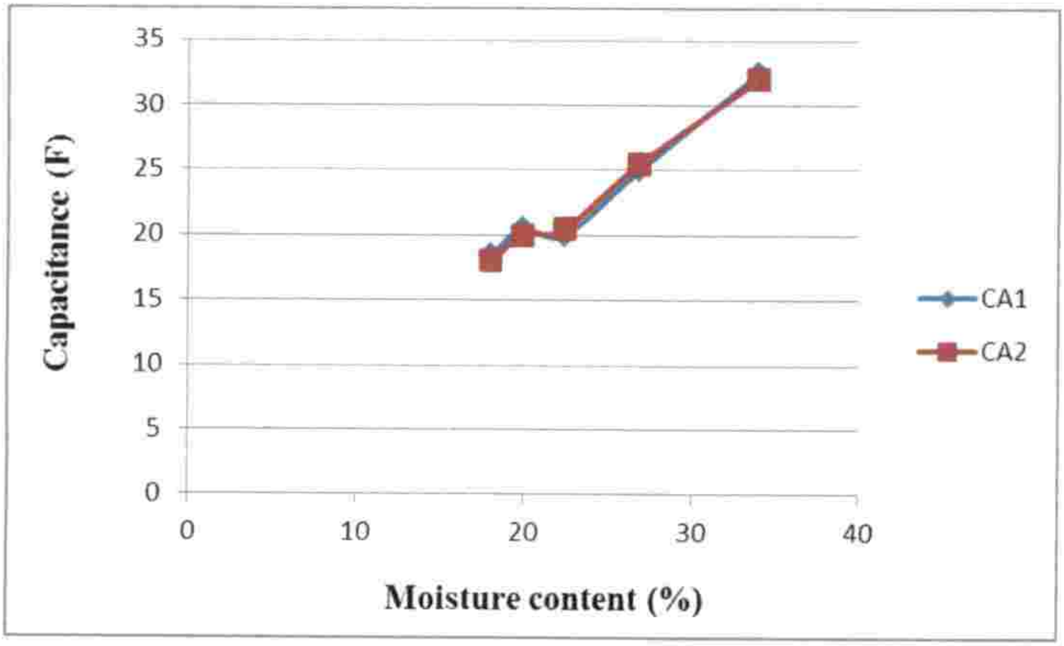


Fig. 29. Calibration curve of capacitor sensors in coastal alluvium

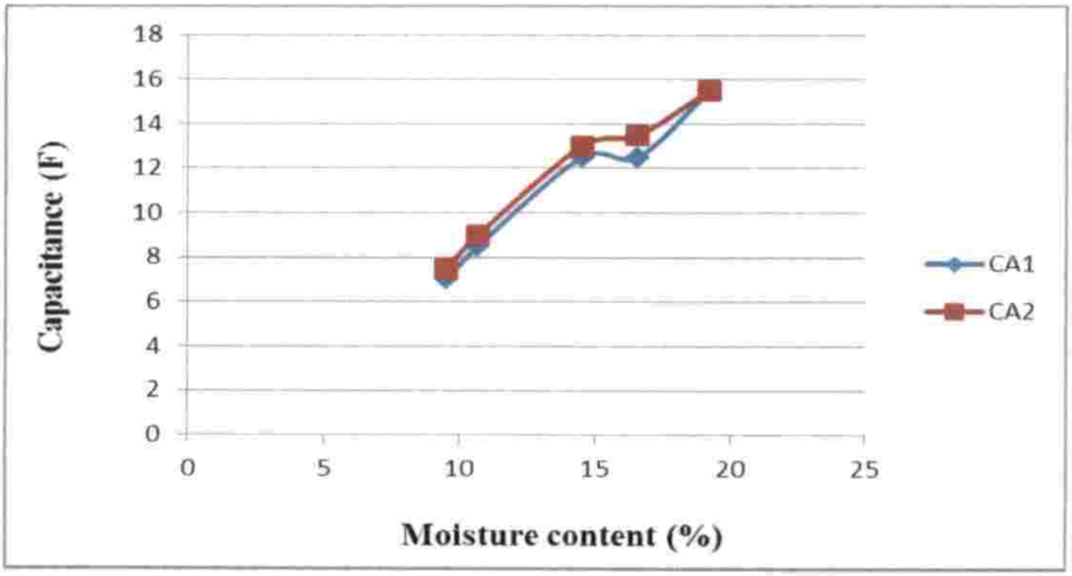


Fig. 30. Calibration curve of capacitor sensors in riverine alluvium

All the soil samples tested showed fluctuation in the value of capacitance because of its dielectric property. The capacitance of sensor decreases gradually with the decrease of moisture content. It was observed that the maximum and minimum values of capacitance of black soil was 36 F and 17 F corresponding to moisture content of 40.55 and 19.22 per cent respectively. In laterite soil values were 35 F and 18 F corresponding to moisture content of 37.29 and 20.68 per cent, in forest loam it was 26 F and 12 F corresponding to moisture content of 28.93 and 13.26 per cent, in coastal alluvium it was 32 F and 18 F corresponding to moisture content of 33.95 and 18.03 per cent and in riverine alluvium it was 16 F and 7 F corresponding to moisture content of 19.22 and 9.54 per cent respectively.

Riverine alluvium showed sudden decrease of capacitance after field capacity and in coastal alluvium, the value gradually decreased after field capacity. Laterite soil and forest loam showed a linear relationship of moisture content and capacitance value of the sensor. Black soil showed irregular variation in the capacitance of sensor value when moisture content decreased below the field capacity. The variation was such a way that from saturated condition to field capacity, capacitance value of sensor decreased slightly and after that every small reduction in moisture content, capacitance value of sensor decreased very fast.

4.3.1 Statistical analysis

4.3.1.1 Moisture content

Variation of soil moisture content value of each soil in continuous five days interval was analyzed statistically with OPSTAT (one factor analysis) software. The mean and C.D. values of the moisture content are given in Table 15. The relative percentage decreases on different days were found out using formula, [(Day1- Day 2)/Day1]* 100. Relative percentage reduction of moisture content is given in Table 16.

Table 15. Mean value and C.D of moisture content

Soil type	Moisture content (%)				
	Mean				
	Day 1	Day 2	Day 3	Day 4	Day 5
Black soil	40.55	36.23	32.8	23.4	19.22
Laterite soil	37.29	31.16	26.91	23.41	20.68
Forest loam	28.94	24.07	18.27	17.63	13.26
Coastal alluvium	33.95	26.88	22.40	19.96	18.03
Riverine alluvium	19.22	16.59	14.53	10.68	9.54
C.D.	2.01	1.65	3.32	3.62	5.28

Table 16. Relative percentage decrease of moisture content

Soil type	Moisture content (%)			
	Relative % decrease			
	Day 2	Day 3	Day 4	Day 5
Black soil	10.65	9.21	28.70	18.03
Laterite soil	16.43	13.63	13.01	11.66
Forest loam	16.82	24.09	3.50	24.78
Coastal alluvium	20.82	16.66	10.89	9.66
Riverine alluvium	13.68	12.41	26.49	10.67

Moisture content value declined gradually with time. But the forest loam soil showed an irregular deviation in the moisture reduction after reaching field capacity. Coastal alluvium showed steady reduction in moisture content with time.

4.3.1.2 Conductive sensor reading

The variations of electrical conductivity with time of five different types of soils tested were analyzed statistically using OPSTAT (one factor analysis) software. The mean values and C.D values are given in Table 17 and the relative percentage reduction of conductivity are given in Table 18.

Table 17. Mean value and C.D of conductive sensor reading

Soil type	Conductive sensor reading (mS/m)				
	Mean				
	Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**
Black soil	237.00	217.50	214.00	194.00	177.00
Laterite soil	225.00	215.75	212.00	199.00	187.75
Forest loam	216.25	208.75	185.75	186.75	173.50
Coastal alluvium	221.50	215.50	203.50	185.00	180.50
Riverine alluvium	184.00	175.25	170.25	160.00	151.00
C.D.	10.748	11.111	15.801	14.377	16.270

Table 18. Relative percentage decrease of conductive sensor reading

Soil type	Conductive sensor reading (mS/m)			
	Relative % decrease			
	Day 2	**Day 3**	**Day 4**	**Day 5**
Black soil	8.22	1.60	9.34	8.76
Laterite soil	4.11	1.73	6.13	5.65
Forest loam	3.46	11.01	-0.53	7.09
Coastal alluvium	2.70	5.56	9.09	2.43
Riverine alluvium	4.75	2.85	6.02	5.62

4.3.1.3 Capacitor sensor reading

The variation of capacitance values of all the soils with respect to time was analyzed statistically. The mean and C.D value are given in Table 19 and the relative percentage reduction is given in Table 20.

Table 19. Mean value and C.D of capacitor sensor reading

Soil type	Capacitor sensor reading (F)				
	Mean				
	Day 1	Day 2	Day 3	Day 4	Day 5
Black soil	36.50	33.25	30.00	21.75	16.75
Laterite soil	34.75	29.25	25.00	20.00	17.75
Forest loam	25.75	22.00	16.75	15.50	11.75
Coastal alluvium	32.25	25.25	20.25	20.20	18.20
Riverine alluvium	15.50	13.00	12.75	8.75	7.25
C.D.	2.595	1.811	3.401	3.599	2.238

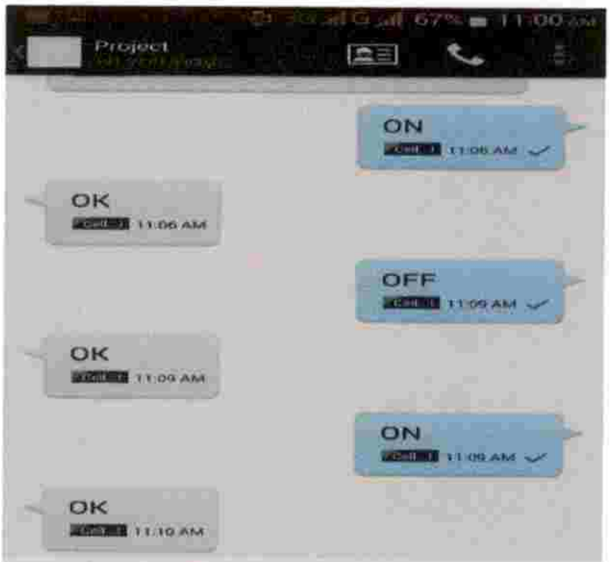
Table 20. Relative percentage decrease of capacitor sensor reading

Soil type	Capacitor sensor reading (F)			
	Relative % decrease			
	Day 2	Day 3	Day 4	Day 5
Black soil	8.90	9.77	27.50	22.98
Laterite soil	15.82	14.52	20.00	11.25
Forest loam	14.56	23.86	7.46	24.19
Coastal alluvium	21.70	19.80	0.24	9.90
Riverine alluvium	16.12	1.92	31.37	17.14

4.4 PERFORMANCE EVALUATION OF DRIP AUTOMATION SYSTEM

The system is very economical and portable when compared with other automation systems. Capacitor type sensor showed high linearity between capacitance and moisture content, while conductive type sensor showed less linearity between EC and soil moisture content. Both types of sensors are highly sensitive and light weight. The conductive type sensor electrodes may get corroded slightly while operating in the field condition, whereas capacitor type sensors are made with Teflon coating, hence it is durable than conductive type. The sensors and valves can be operated easily and installation of system is easy. There is scope for further modification of shape and precision of sensors.

When the system is switched ON, the present status of EC value and capacitance value of soil sensed by sensors and the status of motor are sent from the GSM modem to the mobile phone of user (which was already fed into the GSM modem). Solenoid valves of each bed are also controlled by the direction of users as messages like CO1 ON, CO2 ON, CA1 ON and CA2 ON etc to the modem. System shuts down by the OFF message. The display of status and messaging setup in the mobile phone are shown in Fig. 31, Fig. 32 and Fig. 33.



ON
11:06 AM

OK
11:06 AM

OFF
11:09 AM

OK
11:09 AM

ON
11:09 AM

OK
11:10 AM

Fig. 31. ON/OFF messages to the system

STATUS
2:49 PM

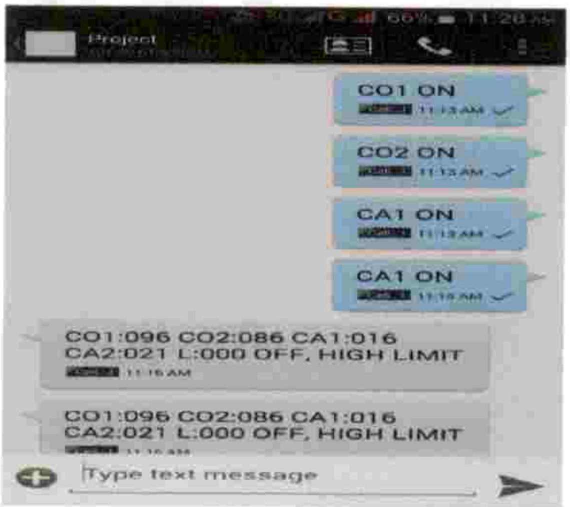
CO1:000 CO2:039 CA1:065
CA2:067 L:020 OFF
2:49 PM

CO1:000 CO2:031 CA1:065
CA2:090 L:020 OFF, HIGH LIMIT
2:50 PM

CO1:000 CO2:023 CA1:065
CA2:090 L:020 OFF, HIGH LIMIT
2:51 PM

CO1:000 CO2:000 CA1:065
CA2:090 L:020 OFF, HIGH LIMIT
2:54 PM

Fig. 32. Status messages to the system



CO1 ON
11:13 AM

CO2 ON
11:13 AM

CA1 ON
11:13 AM

CA1 ON
11:16 AM

CO1:096 CO2:086 CA1:016
CA2:021 L:000 OFF, HIGH LIMIT
11:16 AM

CO1:096 CO2:086 CA1:016
CA2:021 L:000 OFF, HIGH LIMIT
11:16 AM

Fig. 33. Solenoid valve operation messages to the system

4.5 FIELD EVALUATION OF AUTOMATED DRIP SYSTEM

Field study was carried out inside the polyhouse located in the instructional farm of KCAET, Tavanur. The Hilton FI variety of salad cucumber having 90 days crop period were planted in four beds with four treatments and seven replications.

Automated drip system was placed in front of the beds and sensors were fixed to each bed (total 4 sensor and 4 beds) as shown in Plate 18.

Plate 18. Evaluation of conductive and capacitor type sensor

Soil moisture sensors in each bed sense the moisture content in terms of electrical conductivity and capacitance and are transferred to microcontroller unit. This data are processed by MCU as per the lower limit and upper limit value fed on it. The lower limit and upper limit value of capacitance and EC were calculated with moisture content at wilting point and field capacity respectively (on the basis of calibration curves). In this study the soil type is laterite and the moisture content corresponding to wilting point and field capacity of laterite soil are 10 to 15% and 35 to 45% respectively.

The capacitance and EC values, obtained from the calibration curve of laterite soil, corresponding to the moisture content at wilting point and field capacity were used to set the lower and upper limit of capacitor and conductive type sensors respectively. This value was 10 F and 42 F for capacitor sensor (Fig. 45) and 168 mS/m and 234 mS/m for the conductive type sensor (Fig. 40). All the data were stored using microcontroller unit and transferred to the PC via real term software. Overall view of experimental plot is shown in the Plate 19.

Plate 19. Experimental plot

4.5.1 Growth parameters

Growth parameters such as plant height, number of leaves, number of flowers and stem girth were taken 14, 21, 28, 35, 42 and 49 days after planting (DAP) and are given in Table 21 to 24. Weekly observation readings are given in Appendix III.

Table 21. Plant height during the plant growth period

Treatment	Plant height (cm)					
	14 DAP	21 DAP	28 DAP	35 DAP	42 DAP	49 DAP
T1	45.71	141.44	199.71	234.13	284.63	330.66
T2	56.57	168.98	218.07	250.18	300.86	342.71
T3	60.31	170.71	220.28	244.85	283.25	315.35
T4	58.89	172.66	226.90	253.86	281.20	308.26

Table 22. Number of leaves during the plant growth period

Treatment	Number of leaves					
	14 DAP	21 DAP	28 DAP	35 DAP	42 DAP	49 DAP
T1	9	19	33	49	65	84
T2	10	24	36	44	56	75
T3	11	29	35	40	46	60
T4	10	28	45	43	55	65

Table 23. Number of flowers during the plant growth period

Treatment	Number of flowers					
	14 DAP	21 DAP	28 DAP	35 DAP	42 DAP	49 DAP
T1	0	0	1	6	9	11
T2	0	0	2	10	11	12
T3	0	1	3	7	8	10
T4	0	2	4	11	13	15

Table 24. Stem girth during the plant growth period

Treatment	Stem girth (cm)					
	21 DAP	28 DAP	35 DAP	42 DAP	49 DAP	56 DAP
T1	1.89	2.31	2.66	2.90	3.24	3.59
T2	2.29	2.59	2.86	3.07	2.99	3.31
T3	2.42	2.51	2.65	2.84	2.55	2.15
T4	2.27	2.51	2.61	2.8	3.00	3.09

4.5.1.1 Statistical analysis

Data were collected for irrigation and fertigation having two levels of operation 100 percent and 70 percent. Statistical analysis was carried out using last day (49 DAP) observations of different growth parameters (Table 25) using OPSTAT (two factor analysis) software. The mean tables of observations on growth parameter are shown in Table 26 to 29. Methods adopted for statistical analysis are given in Appendix III.

Table 25. Growth parameters of salad cucumber plant (last observation)

Treatment		**Plant height (cm)**	**Number of leaves**	**Number of flowers**	**Stem girth (cm)**
T1	R1	335.66	85	13	3.5
	R2	340.00	84	9	3.7
	R3	370.00	104	16	3.6
	R4	374.00	106	15	3.8
	R5	313.33	81	11	3.5
	R6	316.66	84	6	3.2
	R7	265.00	55	8	3.6
T2	R1	296.66	46	8	2.3
	R2	378.33	76	16	4.0
	R3	370.66	73	15	4.0
	R4	366.66	83	10	3.8
	R5	366.66	85	15	3.9
	R6	320.00	88	10	3.8
	R7	300.00	75	13	3.7
T3	R1	353.33	85	14	4.1
	R2	228.33	47	6	3.2
	R3	290.00	56	10	3.7
	R4	340.00	23	2	4.1
	R5	325.00	44	4	3.4
	R6	338.33	78	14	3.4
	R7	332.50	83	16	3.8

Table 25. Continued

T4	R1	315.00	68	12	3.3
	R2	303.33	61	14	3.6
	R3	300.33	60	16	3.6
	R4	323.33	66	20	3.8
	R5	293.33	67	10	3.4
	R6	280.00	39	12	3.1
	R7	342.5	87	23	3.7

Table 26. Two way mean table of plant height (cm)

Factors	I 1	I 2	Mean F
F1	330.66	342.71	336.69
F2	315.35	308.26	311.80
Mean F	323.01	325.48	

C.D. for interaction of irrigation and fertigation is non-significant. C.D for fertigation and irrigation are non-significant.

Table 27. Two way mean table of number of Leaves

Factors	I 1	I 2	Mean F
F1	84.85	74.57	79.71
F2	58.85	63.57	61.21
Mean F	71.85	69.07	

C.D (0.05) for irrigation is 13.76, hence irrigation factor is significant. Fertigation factor and interaction of irrigation and fertigation are non-significant.

Table 28. Two way mean table of number of flower

Factors	I 1	I 2	Mean F
F1	10.57	12.00	11.28
F2	9.14	14.57	11.85
Mean F	9.85	13.28	

C.D for interaction of irrigation and fertigation is non-significant. C.D for fertigation is non-significant. C.D for irrigation is 3.39.

Table 29. Two way mean table of stem girth (cm)

Factors	I 1	I 2	Mean F
F1	3.59	3.29	3.44
F2	2.25	3.06	2.65
Mean F	2.92	3.17	

C.D for interaction of irrigation and fertigation is non-significant. C.D for fertigation is 0.661 and C.D for irrigation is non-significant.

4.5.2 Yield parameters

Yield parameters such as number of fruits, fruit length, circumference and weight were taken at 42, 49, 56, 63, 70, 77 and 84 days after planting.

4.5.2.1 Statistical analysis

The statistical analysis was carried out with last day (84 DAP) observations of different yield parameters (Table 30) using OPSTAT (two factor analysis) software. The mean tables of observations of yield parameter are shown in Table 31 to 34. Methods of statistical analysis are given in Appendix IV.

Table 30. Yield parameters of salad cucumber plant (last observation)

Treatment		Number of fruits	Fruit length (cm)	Fruit circumference (cm)	Fruit weight (kg)
T1	R1	16	17.5	13.1	0.158
	R2	14	16.7	11.4	0.127
	R3	12	16.7	12.0	0.132
	R4	15	21.1	14.8	0.243
	R5	10	13.1	10.7	0.069
	R6	11	17.0	12.2	0.136
	R7	9	17.5	13.1	0.158
T2	R1	17	17.6	13.1	0.165
	R2	14	17.5	13.0	0.163
	R3	12	18.2	14.0	0.202
	R4	11	20.8	14.6	0.261
	R5	14	18.0	13.0	0.155
	R6	14	17.8	13.3	0.167
	R7	11	15.2	13.1	0.106
T3	R1	12	15.7	12.8	0.132
	R2	9	16.0	12.6	0.139
	R3	9	16.3	14.0	0.164
	R4	8	15.7	14.7	0.210
	R5	11	16.2	12.8	0.165
	R6	7	15.9	13.1	0.161
	R7	8	16.9	12.5	0.137
T4	R1	12	12.8	12.5	0.115
	R2	8	16.5	13.7	0.182
	R3	11	15.5	14	0.160
	R4	9	17.7	14.5	0.208
	R5	11	16.2	11.0	0.120
	R6	10	16.3	11.6	0.130
	R7	9	18.3	14.2	0.175

Table 31. Two way mean table of number of fruit

Factors	I 1	I 2	Mean F
F1	12.429	13.286	12.857
F2	9.143	10.000	9.571
Mean F	10.786	11.643	

C.D for interaction of irrigation and fertigation is significant. C.D for irrigation is non-significant, whereas C.D for fertigation is 1.60 and it is significant.

Table 32. Two way mean table of fruit length (cm)

Factors	I 1	I 2	Mean F
F1	15.78	15.00	15.39
F2	13.92	12.50	13.21
Mean F	14.85	13.75	

C.D for interaction of irrigation and fertigation is non-significant. C.D for fertigation is 1.200. C.D for irrigation is non-significant.

Table 33. Two way mean table of fruit circumference (cm)

Factors	I 1	I 2	Mean F
F1	10.71	10.42	10.57
F2	9.35	9.21	9.28
Mean F	10.03	9.82	

C.D for interaction of irrigation and fertigation is non-significant. C.D for fertigation is 0.67. C.D for irrigation is non-significant.

Table 34. Two way mean table of fruit weight (g)

Factors	I 1	I 2	Mean F
F1	96.57	78.14	87.35
F2	51.42	42.857	47.14
Mean F	74.00	60.500	

C.D for interaction of irrigation and fertigation is non-significant and C.D for fertigation and irrigation is 13.05.

Field experiment of salad cucumber grown using drip automation system gave 112.665 kg of yield in T1. Experiment showed high yield ie. 126.535 kg obtained from T2. Lowest yield obtained was 85.635 kg in T3, whereas 96.835 kg was obtained from T4.

From the field study, it can be concluded that the combination of 100 per cent fertigation and 70 per cent irrigation (T2) is better for crop yield performance over the other treatments. The lowest yield was obtained with 70 per cent fertigation with 70 per cent irrigation levels.

4.7 DIFFICULTIES IN AUTOMATION

As the pumping system was far away from the polyhouse, the electrical connections were made with 90 meter long wire in hanging position. Voltage fluctuations in the board resulted in false reading while operation. Laterite soil beds are fully mulched so that sensors can be placed by cutting small portion of sheet. As the main valve opens only at certain pressure, more pressure is needed for the solenoid valve operation. Voltage to solenoid valves is provided with additional 12 V adaptors. The GSM modem can operate only using electricity, thus if it is switched OFF, operator has to switch it ON from the control point. Entire system needs to be fully covered with a protective cover, in order to prevent from water contact.

Summary and Conclusion

CHAPTER 5

SUMMARY AND CONCLUSIONS

Precise use of water in agriculture can be achieved only through precise control like automated drip irrigation system. This study was conducted to modify and evaluate the existing cost effective automated drip irrigation system. The system consisted of conductive and capacitor type sensors for soil moisture measurement and providing irrigation according to the requirement. Experiments were carried out both in laboratory and field. Calibration of conductive and capacitor type sensors were carried out in laboratory using different types of soils and different concentrations of salt solution. The capacitor type sensor senses capacitance related to soil ionic concentration, whereas conductive type sensor senses the electrical conductivity. For easy operation and installation, capacitor type sensors are developed in thin rod using Teflon coated wire and conductive type sensors as cylindrical rod using iron.

This automated drip irrigation system composed of water sensors, solenoid valves, microcontroller unit and LCD display. Handling the system is very simple and can be installed and uninstalled easily. The sensors were made as more sensitive and durable. Automation system was installed in front of the crop beds and sensors were fixed to each bed. Irrigation started when the moisture content of soil reached wilting point. The upper and lower limits of conductive and capacitor sensors were set by control keys. The drip automation system operated using the messaging technique and the system starts the motor according to the messages from the user through GSM modem. The solenoid valves were also opened by the messaging command from the user. The system could send a reply message to the user when the moisture content falls below the sensor lower limit or exceeds its higher limit. Present status of the sensors and motor could also send back to the user mobile phone based on his command. Moisture variation in the field was sensed using conductive and capacitor sensors and it is collected and stored in the micro controller unit. Total quantity of water used for irrigation was measured using water sensor attached with the system. The continuous data recorded in the micro controller can be transferred to PC using Real term software and upload key.

Laboratory test was conducted in the Soil and Water Engineering laboratory, KCAET, Tavanur using five different types of soils collected from different locations. Sensors were calibrated with riverine alluvium, forest loam, coastal alluvium, black soil and laterite soil. Calibration curves were plotted with moisture content against capacitance and moisture content against electrical conductivity for capacitor type and conductive type sensors respectively. Capacitor type sensor showed high linearity between capacitance and moisture content, while conductive type sensor showed less linearity between EC and soil moisture content. Sensor placed in riverine alluvium showed sudden decrease of capacitance after reaching the field capacity and that placed in coastal alluvium showed gradual variation of capacitance after field capacity. Laterite soil and forest loam showed a linear relationship between moisture content and capacitance. Riverine alluvium showed small reduction of electrical conductivity corresponding to moisture content and forest loam showed minor variation after field capacity.

Experiments were conducted with salt solution prepared by the addition of different amounts of NaCl to distilled water. Readings of conductive type and capacitor type sensors were taken by dipping the electrodes in to the sample. The readings were compared with EC value obtained from the water quality analyzer and it showed a functional relation. Calibration curves were also drawn according to the readings. Sensor readings were changed with respect to the electrical conductivity of salt solution and it showed a linear relationship in the primary readings and changed slightly when the salt concentration increased.

Field study was conducted inside the polyhouse located in the instructional farm of KCAET, Tavanur. The Hilton FI variety of salad cucumber having 90 days crop period was planted in four beds with four treatments and seven replications.

Growth parameters such as plant height, number of leaves, flowers, fruits and stem girth were taken at 14, 21, 28, 35, 42 and 49 days after planting and yield parameters were taken at 42, 49, 56, 63, 70, 77 and 84 days after planting.

The instrument operated using current and hence care should be taken to ensure the safety of the operator and also to protect the electronic device from water to avoid damage. Effort is needed for the popularization of automated drip system and creation of awareness on suitability of the system, which can help improved crop production ie, more yield from less water, energy and money.

Conclusions

- The automated drip irrigation system available in the market are costly (more than Rs.50000/-) and more complex in nature. Hence the system is not affordable by small marginal farmers having limited land area. The modified automated drip system developed in this present study costs only Rs.15000/- and simple in operation. Hence the system can be considered as a cost effective.
- The automated irrigation system consists of conductive and capacitor type sensors for the soil moisture measurement which allowed irrigating each bed according to the requirement.
- This automated irrigation system could operate with GSM technology.
- The drip automation system and motor were operated using 'SMS' from mobile phones through GSM modem.
- Total quantity of water used for irrigation was measured using water sensor attached with the system.
- Automatic drip irrigation system gave positive result in the experiments and it is suitable for different soil conditions.

- 100 % fertigation showed good result when compared to 70 % fertigation.
- The combination of 100 % fertigation and 70% irrigation showed better crop performance.
- 70% fertigation and 70 % irrigation treatment resulted in lowest crop yield.

Future recommendation

- There is scope for further modification of the system with high capacity microcontroller unit and LCD display.
- Sensors can be improved with more durable material, different geometrical shapes and sizes.
- GSM modem can be modified to use with battery charger, which will help to avoid manual switching ON/OFF of modem.
- Wireless controlled sensors and other units can be incorporated for easy handling.
- GPRS system can be used for data transfer to the network.
- Automation of foggers in the polyhouse is possible for cooling.
- Addition of more sensitive solenoid valves and water flow sensors will be useful in calculating irrigation water to the plot.
- Photovoltaic panels can be used as the power source for the modified system.

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Appendices

Appendix I: Particle size analysis of different types of soils (Sieve analysis)

Total dry weight of coastal alluvium= 5666 g

Total dry weight of Riverine alluvium= 5428 g

Total dry weight of Forest loam= 5555 g

Total dry weight of Black soil= 5900 g

Total dry weight of Laterite soil= 4250 g

Readings of sieve analysis

Sieve size	Sieve weight (g)	Weight retained (g)				
		Coastal alluvium	**Riverine alluvium**	**forest loam**	**black soil**	**laterite soil**
2 mm	360	3	1841	1826.5	3310	3766
1 mm	370	22	635	506	442.5	272
600 µm	330	4697	1637	781.5	649	416
425 µm	335	135	228	340	365	211
300 µm	340	289	418	279.5	442	295
212 µm	340	423	526	306	472	424
150 µm	335	34	43	38.5	41	44.5
75 µm	295	27	59	102	116.5	74.5
receiver	310	34	38	68	59	50

Appendix II: Particle size analysis of different types of soils (Sedimentation analysis)

Sedimentation analysis (hydrometer method)

Weight of the sample taken= 30 g

Capacity of cylinder= 1000 ml

Diameter of the cylinder= 6.8 cm

Difference in graduation of cylinder= 2.4 cm

Height of hydrometer bulb= 16 cm

$V_h/A = 2.6$ cm

<u>Sample calculation</u>

Effective depth, $He = H + 1/2(h - (V_h/A))$

$He = 8 + 1/2(16 - 2.6)$

$He = 14.7$ cm

Diameter of the particle, $D = 10^{-5} F (He/t)^{½}$

$F = 1352.97$

$D = 0.0733$ cm

$N' = [100\ G/ (W_d (G-1))] * Rh$

$N' = [267/ (30*1.67)]*8$

$N' = 42.6347$

$N = N'*(M'/M)$

$N = 42.6347*(4038/5555)$

$N = 30.9917$

Sedimentation analysis (hydrometer method) of laterite soil

Time (min)	**Reading**	**Rh**	**He (cm)**	**D (cm)**	**N'**	**N**
0.5	1.008	8	14.7	0.0733	42.6347	30.9917
1	1.0075	7.5	14.2	0.0509	39.97	29.0547
2	1.007	7	13.7	0.0354	37.3053	27.1177
4	1.0063	6.3	13	0.0243	33.5748	24.4059
8	1.0058	5.8	12.5	0.0169	30.9101	22.469
15	1.0049	4.9	11.6	0.0118	26.1137	18.9824
30	1.0037	3.7	10.4	0.0079	19.7185	14.3336
60	1.003	3	9.7	0.0054	15.988	11.6218
120	1.0019	1.9	8.6	0.0036	10.1257	7.3605

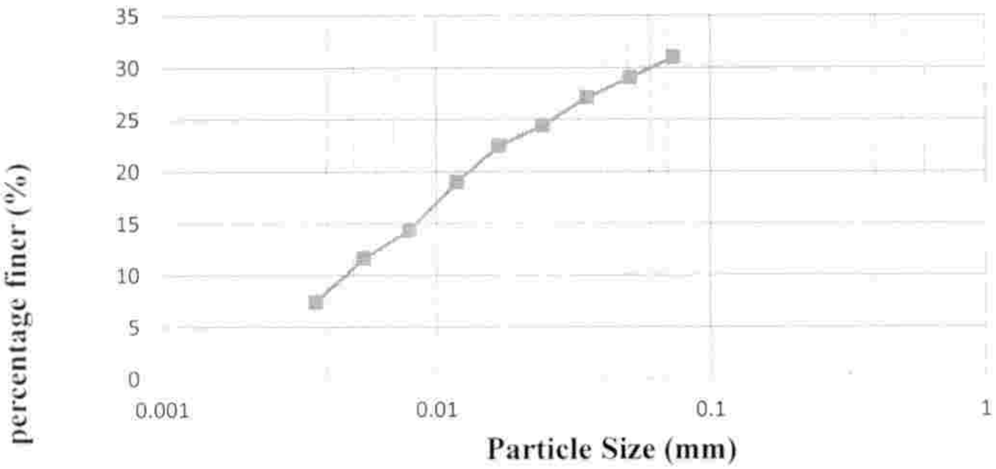
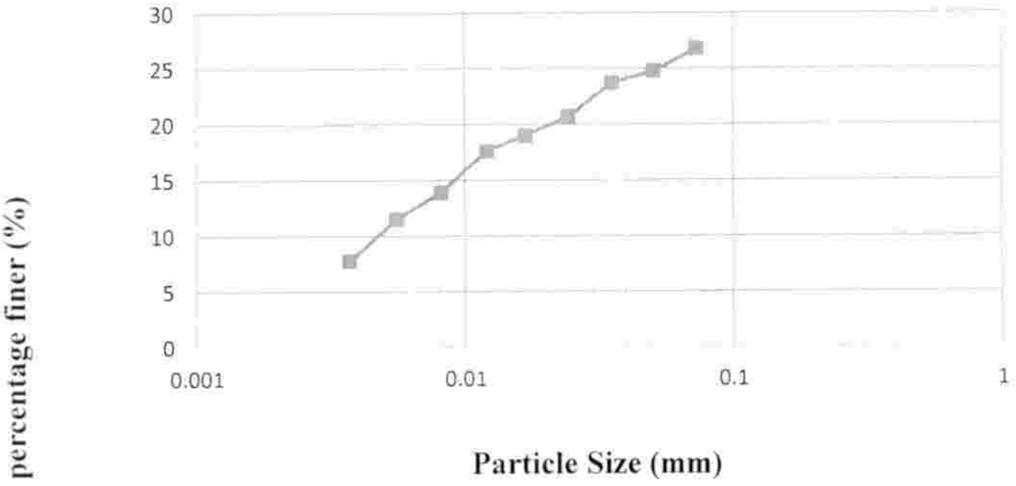


Fig. 40 Particle size distribution curve of laterite soil

Sedimentation analysis (hydrometer method) of black soil

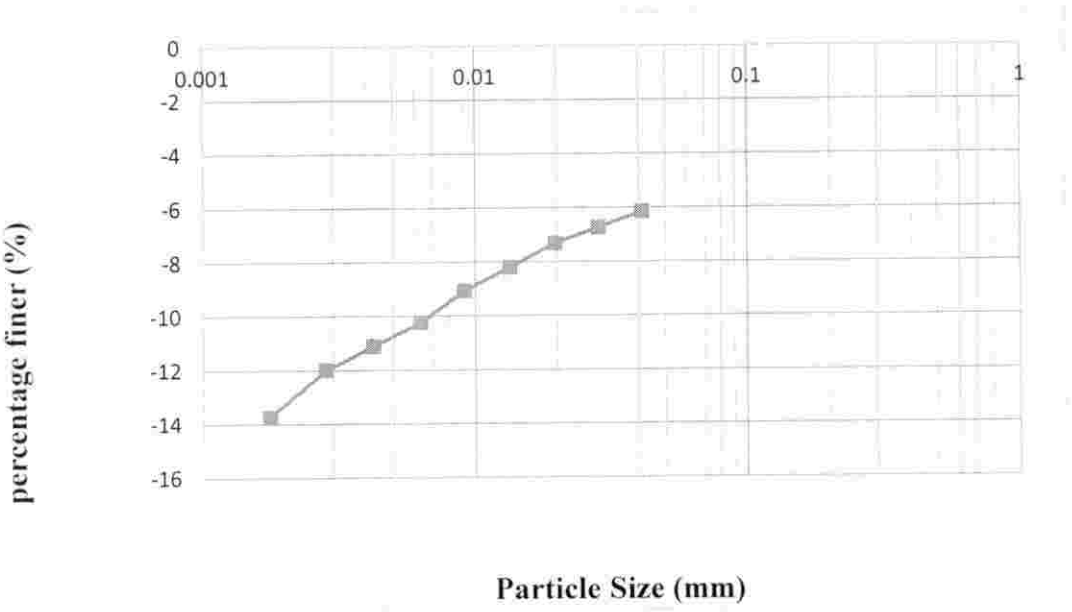
Time (min)	Reading	Rh	He (cm)	D (cm)	N'	N
0.5	1.0079	7.9	14.6	0.0731	42.1017	26.7774
1	1.0073	7.3	14	0.0506	38.9041	24.7437
2	1.007	7	13.7	0.0354	37.3053	23.7268
4	1.0061	6.1	12.8	0.0242	32.5089	20.6762
8	1.0056	5.6	12.3	0.0167	29.8443	18.9814
15	1.0052	5.2	11.9	0.0120	27.7125	17.6256
30	1.0041	4.1	10.8	0.0081	21.8502	13.8971
60	1.0034	3.4	10.1	0.0055	18.1197	11.5244
120	1.0023	2.3	9	0.0037	12.2574	7.7959



Particle size distribution curve of black soil

Sedimentation analysis (hydrometer method) of forest loam

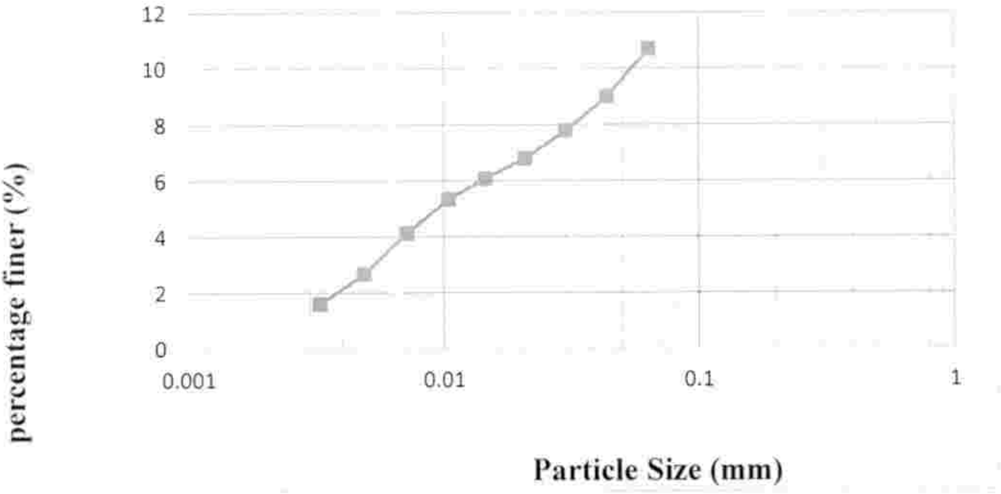
Time (min)	Reading	Rh	He (cm)	D (cm)	N'	N
0.5	0.9979	-2.1	4.6	0.0410	-11.1916	-6.1422
1	0.9977	-2.3	4.4	0.0283	-12.2574	-6.7271
2	0.9975	-2.5	4.2	0.0196	-13.3233	-7.3121
4	0.9972	-2.8	3.9	0.0133	-14.9221	-8.1896
8	0.9969	-3.1	3.6	0.0090	-16.5209	-9.0670
15	0.9965	-3.5	3.2	0.0062	-18.6526	-10.2370
30	0.9962	-3.8	2.9	0.0042	-20.2514	-11.1144
60	0.9959	-4.1	2.6	0.0028	-21.8502	-11.9919
120	0.9953	-4.7	2	0.0017	-25.0479	-13.7468



Particle size distribution curve of forest loam

Sedimentation analysis (hydrometer method) of riverine alluvium

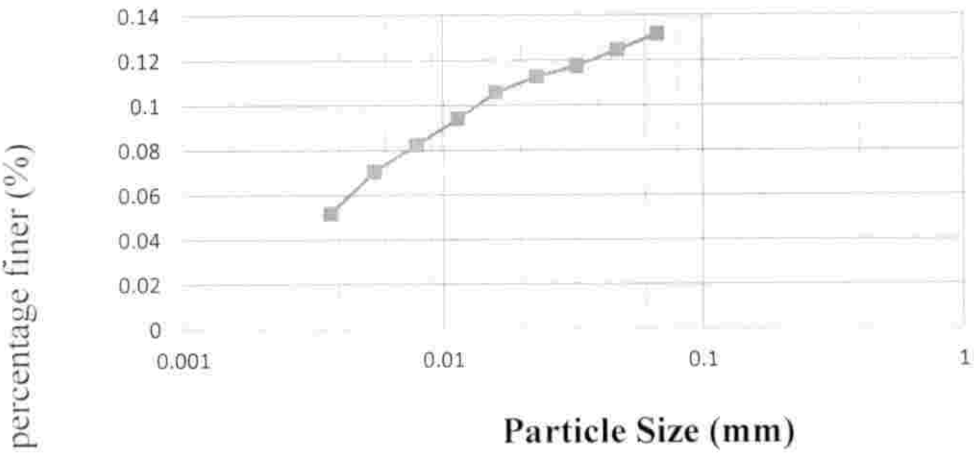
Time (min)	Reading	Rh	He (cm)	D (cm)	N'	N
0.5	1.0044	4.4	11.1	0.0637	23.4491	10.6963
1	1.0037	3.7	10.4	0.0436	19.7185	8.9946
2	1.0032	3.2	9.9	0.0301	17.0538	7.7791
4	1.0028	2.8	9.5	0.0208	14.9221	6.8067
8	1.0025	2.5	9.2	0.0145	13.3233	6.0774
15	1.0022	2.2	8.9	0.0104	11.7245	5.3481
30	1.0017	1.7	8.4	0.0071	9.0598	4.1326
60	1.0011	1.1	7.8	0.0048	5.8622	2.6740
120	1.003	3	9.7	0.0038	15.9880	7.2929



Particle size distribution curve of riverine alluvium

Sedimentation analysis (hydrometer method) of coastal alluvium

Time (min)	Reading	Rh	He (cm)	D (cm)	N'	N
0.5	1.0056	5.6	12.3	0.0671	29.8443	0.1316
1	1.0053	5.3	12	0.0468	28.2455	0.1246
2	1.005	5	11.7	0.0327	26.6467	0.1175
4	1.0048	4.8	11.5	0.0229	25.5808	0.1128
8	1.0045	4.5	11.2	0.0160	23.9820	0.1058
15	1.004	4	10.7	0.0114	21.3173	0.0940
30	1.0035	3.5	10.2	0.0078	18.6526	0.0823
60	1.003	3	9.7	0.0054	15.9880	0.0705
120	1.0022	2.2	8.9	0.0036	11.7245	0.0517



Particle size distribution curve of coastal alluvium

Appendix II: Weekly observation readings

Observation of growth parameters in March 25th

Plant no.	Plant height (cm)	Number of leaves	Number of flowers
T1R1	66.50	12	0
T1R2	26.66	8	0
T1R3	55.16	10	0
T1R4	50.33	10	0
T1R5	51.33	10	0
T1R6	33.00	8	0
T1R7	37.00	7	0
T2R1	51.66	9	0
T2R2	45.00	11	0
T2R3	56.00	12	0
T2R4	80.00	11	0
T2R5	77.33	12	0
T2R6	33.00	8	0
T2R7	53.00	10	0
T3R1	85.66	14	0
T3R2	44.66	8	0
T3R3	50.33	9	0
T3R4	78.00	12	0
T3R5	60.00	11	0
T3R6	55.33	10	0
T3R7	48.25	10	0
T4R1	88.00	14	0
T4R2	70.00	12	0
T4R3	22.16	7	0
T4R4	58.33	11	0
T4R5	65.66	11	0
T4R6	58.33	9	0
T4R7	49.75	8	0

Observation of growth parameters in April 1st

Plant no.	Plant height (cm)	Number of leaves	Number of flowers
T1R1	181.33	24	0
T1R2	137.00	17	0
T1R3	157.00	20	0
T1R4	169.00	22	0
T1R5	128.00	17	0
T1R6	126.00	17	0
T1R7	91.75	17	0
T2R1	132.66	21	0
T2R2	160.00	22	0
T2R3	185.66	28	0
T2R4	201.00	28	0
T2R5	199.33	26	0
T2R6	147.00	19	0
T2R7	157.25	23	0
T3R1	202.66	36	0
T3R2	142.33	26	0
T3R3	134.66	26	1
T3R4	193.00	37	0
T3R5	171.33	30	0
T3R6	180.00	26	0
T3R7	171.00	27	0
T4R1	204.66	39	2
T4R2	173.33	32	0
T4R3	145.66	30	2
T4R4	178.33	34	2
T4R5	165.66	25	0
T4R6	171.00	22	0
T4R7	170.00	23	0

Observation of growth parameters in April 8th

Plant no.	Plant height (cm)	Number of leaves	Number of flowers
T1R1	221.00	39	3
T1R2	208.33	36	0
T1R3	221.00	42	0
T1R4	238.33	42	0
T1R5	193.00	27	0
T1R6	193.33	27	0
T1R7	123.00	21	4
T2R1	157.33	26	3
T2R2	226.66	38	2
T2R3	246.33	35	2
T2R4	223.33	38	2
T2R5	231.66	40	2
T2R6	221.66	40	0
T2R7	219.50	33	2
T3R1	257.33	41	5
T3R2	175.33	25	5
T3R3	178.33	29	3
T3R4	239.00	37	5
T3R5	220.00	34	3
T3R6	251.00	37	2
T3R7	221.00	38	1
T4R1	225.33	57	13
T4R2	221.00	46	7
T4R3	214.00	43	6
T4R4	223.00	48	7
T4R5	244.66	44	0
T4R6	222.33	39	0
T4R7	238.00	42	0

Observation of growth parameters in April 15th

Plant no.	Plant height (cm)	Number of leaves	Number of flowers
T1R1	243.33	65	9
T1R2	235.00	48	4
T1R3	252.66	53	13
T1R4	256.66	56	10
T1R5	232.66	52	3
T1R6	243.33	41	0
T1R7	190.00	29	5
T2R1	177.66	33	6
T2R2	261.33	46	7
T2R3	266.00	40	18
T2R4	257.33	44	10
T2R5	266.33	49	14
T2R6	262.00	44	6
T2R7	258.00	46	10
T3R1	261.66	57	9
T3R2	188.66	27	5
T3R3	224.33	35	4
T3R4	263.00	13	1
T3R5	268.33	43	5
T3R6	256.66	49	8
T3R7	258.75	47	12
T4R1	264.00	46	10
T4R2	264.33	37	11
T4R3	247.66	41	14
T4R4	249.00	49	12
T4R5	251.66	43	7
T4R6	236.66	29	4
T4R7	261.25	52	16

Observation of growth parameters in April 22nd

Plant no.	Plant height (cm)	Number of leaves	Number of flowers
T1R1	289.00	73	11
T1R2	299.33	57	7
T1R3	318.66	82	14
T1R4	313.66	82	12
T1R5	272.66	66	8
T1R6	272.33	65	8
T1R7	226.75	42	7
T2R1	249.00	38	8
T2R2	321.33	60	12
T2R3	323.00	53	14
T2R4	321.66	63	9
T2R5	321.33	61	14
T2R6	293.00	62	7
T2R7	276.75	56	11
T3R1	315.66	68	12
T3R2	207.66	35	5
T3R3	255.66	42	7
T3R4	312.00	17	2
T3R5	294.50	36	3
T3R6	301.00	63	11
T3R7	296.25	60	14
T4R1	291.00	61	12
T4R2	287.33	52	12
T4R3	274.33	53	16
T4R4	281.00	57	16
T4R5	273.00	55	8
T4R6	261.50	33	9
T4R7	300.25	70	18

Observation of growth parameters in April 29th

Plant no.	Plant height (cm)	Number of leaves	Number of flowers
T1R1	335.66	85	13
T1R2	340.00	84	9
T1R3	370.00	104	16
T1R4	374.00	106	15
T1R5	313.33	81	11
T1R6	316.66	84	6
T1R7	265.00	55	8
T2R1	296.66	46	8
T2R2	378.33	76	16
T2R3	370.66	73	15
T2R4	366.66	83	10
T2R5	366.66	85	15
T2R6	320.00	88	10
T2R7	300.00	75	13
T3R1	353.33	85	14
T3R2	228.33	47	6
T3R3	290.00	56	10
T3R4	340.00	23	2
T3R5	325.00	44	4
T3R6	338.33	78	14
T3R7	332.50	83	16
T4R1	315.00	68	12
T4R2	303.33	61	14
T4R3	300.33	60	16
T4R4	323.33	66	20
T4R5	293.33	67	10
T4R6	280.00	39	12
T4R7	342.5	87	23

Observation of stem girth

plant no	Stem girth (cm)					
	April 8th	**April 15th**	**April 22nd**	**April 29th**	**May 6th**	**May 13th**
T1R1	1.5	1.9	2.2	2.5	2.9	3.5
T1R2	1.9	2.4	2.7	3	3.4	3.7
T1R3	2.1	2.4	2.6	2.9	3.3	3.6
T1R4	2.1	2.6	2.8	3.1	3.5	3.8
T1R5	1.9	2.5	2.8	3	3.3	3.5
T1R6	2	2.3	2.6	2.8	3	3.2
T1R7	1.6	2.0	2.7	2.9	3.1	3.6
T2R1	1.7	2.1	2.4	2.7	3.1	2.3
T2R2	2.6	2.9	3.2	3.4	3.7	4.0
T2R3	2.7	3	3.2	3.4	3.6	4.0
T2R4	2.3	2.6	2.8	3	3.25	3.8
T2R5	2.4	2.7	3	3.2	3.4	3.9
T2R6	1.9	2.2	2.4	2.6	2.9	3.8
T2R7	2.3	2.5	2.8	3.0	3.2	3.7
T3R1	2.5	2.8	3.35	3.6	4	4.1
T3R2	1.8	2.1	2.4	2.6	3.1	3.2
T3R3	2.4	2.8	3.2	3.4	3.6	3.7
T3R4	2.7	3.3	3.6	3.9	4	4.1
T3R5	2.2	2.7	2.8	3	3.2	3.4
T3R6	2.4	2.7	2.9	3.2	3.3	3.4
T3R7	2.7	3.1	3.2	3.4	3.7	3.8
T4R1	2.3	2.4	2.6	2.8	3	3.3
T4R2	2.5	2.6	2.8	3.1	3.4	3.6
T4R3	2.1	2.4	2.7	2.8	3	3.6
T4R4	2.5	2.8	3	3.2	3.4	3.8
T4R5	2.1	2.3	2.5	2.7	2.9	3.4
T4R6	2.1	2.2	2.5	2.7	2.9	3.1
T4R7	2.2	2.5	2.7	2.9	3.1	3.7

Observation of number of fruits

plant no	Number of fruits						
	April 22nd	**April 29th**	**May 6th**	**May 13th**	**May 20th**	**May 27th**	**June 3rd**
T1R1	3	6	8	11	9	12	16
T1R2	1	5	7	6	8	9	14
T1R3	2	6	5	8	7	8	12
T1R4	1	5	8	10	9	10	15
T1R5	1	5	7	6	8	11	10
T1R6	2	3	6	9	7	12	11
T1R7	1	2	5	8	10	8	9
T2R1	1	2	4	8	7	14	17
T2R2	2	4	4	9	7	12	14
T2R3	5	7	8	6	9	8	12
T2R4	4	7	6	10	7	9	11
T2R5	6	8	12	14	12	14	14
T2R6	1	3	4	7	5	9	14
T2R7	3	6	8	10	11	11	11
T3R1	3	9	7	6	5	8	12
T3R2	4	5	4	5	7	8	9
T3R3	3	5	6	6	8	7	9
T3R4	1	2	3	5	5	6	8
T3R5	3	5	7	8	8	12	11
T3R6	2	3	4	7	5	8	7
T3R7	4	8	5	4	6	6	8
T4R1	4	6	7	9	9	11	12
T4R2	3	6	8	7	4	6	8
T4R3	3	6	5	7	10	13	11
T4R4	7	10	8	7	9	8	9
T4R5	2	5	4	6	8	9	11
T4R6	1	3	4	5	4	7	10
T4R7	4	7	8	9	8	9	9

Observation of yield parameters in April 22rd

Plant no.	Length (cm)	Circumference (cm)	Weight (kg)
T1R1	15.0	12.4	0.117
T1R2	15.8	13.3	0.168
T1R3	14.3	13.0	0.110
T1R4	14.4	11.1	0.098
T1R5	14.7	11.5	0.120
T1R7	14.5	10.7	0.085
T2R1	15.5	12.5	0.110
T2R2	11.0	10.0	0.045
T2R3	14.2	11.8	0.116
T2R5	13.2	11.0	0.092
T2R6	13.3	10.6	0.080
T2R7	14.5	11.0	0.100
T3R1	14.0	12.5	0.110
T3R2	13.6	11.5	0.105
T3R3	14.8	13.5	0.150
T3R4	15.0	12.6	0.120
T3R6	13.5	11.5	0.100
T3R7	12.7	11.3	0.070
T4R1	12.4	10.1	0.068
T4R2	14.6	11.1	0.098
T4R3	13.8	12.2	0.128
T4R4	14.0	11.0	0.080
T4R6	11.8	9.6	0.058
T4R7	12.2	11.1	0.070

Observation of yield parameters in April 29th

Plant no.	Length (cm)	Circumference (cm)	Weight (kg)
T1R1	15.1	11.0	0.083
T1R2	15.6	10.5	0.076
T1R3	20.0	13.0	0.130
T1R4	15.5	11.0	0.085
T1R5	12.7	9.7	0.055
T1R6	17..0	12.2	0.122
T1R7	18.0	10.0	0.105
T2R1	17.0	11.7	0.122
T2R2	16.0	12.0	0.108
T2R3	13.8	9.9	0.066
T2R4	16.4	10.0	0.077
T2R5	13.3	9.7	0.063
T2R6	13.0	9.3	0.048
T2R7	16.7	11.2	0.105
T3R1	12.2	8.7	0.042
T3R2	13.0	9.4	0.056
T3R3	16.3	11.0	0.080
T3R5	13.0	9.0	0.040
T3R6	13.4	9.9	0.058
T3R7	12.7	9.5	0.048
T4R2	13.0	10.0	0.060
T4R3	13.0	9.7	0.059
T4R4	12.0	9.0	0.040
T4R5	10.5	9.0	0.030
T4R6	12.8	9.0	0.046
T4R7	12.2	9.2	0.039

Observation of yield parameters in May 6th

Plant no.	Length (cm)	Circumference (cm)	Weight (kg)
T1R1	12.5	9.7	0.058
T1R2	11.6	9.3	0.056
T1R3	16.1	10.6	0.106
T1R4	15.0	10.3	0.074
T1R5	17.0	13.5	0.175
T1R6	14.7	11.9	0.078
T1R7	14.2	10.5	0.075
T2R1	15.3	12.2	0.121
T2R2	12.2	9.7	0.060
T2R3	14.6	10.3	0.091
T2R5	14.3	10.8	0.093
T2R6	13.3	10.3	0.065
T2R7	15.7	9.7	0.082
T3R1	14.1	12.0	0.110
T3R2	12.5	9.5	0.055
T3R3	15.7	11.7	0.077
T3R4	13.0	12.2	0.087
T3R7	14.8	11.1	0.104
T4R1	13.6	11.1	0.102
T4R2	18.5	13.5	0.020
T4R3	16.2	11.8	0.122
T4R4	16.0	13.0	0.125
T4R5	12.5	10.2	0.081
T4R6	13.3	10.3	0.067
T4R7	13.5	10.1	0.080

Observation of yield parameters in May 13th

Plant no.	Length (cm)	Circumference (cm)	Weight (kg)
T1R1	15.0	12.3	0.095
T1R2	14.0	12.0	0.080
T1R3	15.6	11.7	0.123
T1R4	16.3	10.8	0.088
T1R5	14.7	12.5	0.105
T1R6	17.0	11.5	0.125
T1R7	14.3	11.1	0.091
T2R1	15.5	11.8	0.110
T2R2	13.0	10.5	0.065
T2R3	14.1	10.6	0.110
T2R5	15.4	11.1	0.106
T2R6	16.0	10.5	0.095
T2R7	16.0	10.7	0.085
T3R1	16.8	13.5	0.133
T3R2	14.3	11.2	0.080
T3R4	16.0	12.5	0.130
T3R5	12.6	10.0	0.070
T3R6	16.8	13.5	0.133
T4R1	16.0	10.0	0.090
T4R2	12.2	11.0	0.058
T4R3	15.6	11.3	0.120
T4R4	14.0	9.8	0.062
T4R5	13.3	10.8	0.095
T4R6	13.3	10.5	0.079
T4R7	16.2	11.0	0.130

Observation of yield parameters in May 20th

Plant no.	Length (cm)	Circumference (cm)	Weight (kg)
T1R1	16.1	10.6	0.100
T1R3	18.0	10.0	0.110
T1R4	14.9	11.4	0.107
T1R6	14.9	12.5	0.122
T1R7	14.6	11.6	0.101
T2R2	12.0	10.8	0.062
T2R3	15.1	12.1	0.109
T2R5	13.0	9.2	0.060
T2R6	16.0	12.6	0.148
T2R7	16.8	12.2	0.132
T3R1	16.5	11	0.12
T3R2	13.1	10.7	0.083
T3R3	16	14.5	0.145
T3R6	14.4	11.2	0.098
T3R7	26.8	11.5	0.120
T4R1	12.8	10.5	0.080
T4R2	15.4	12.4	0.103
T4R4	14.6	11.0	0.090
T4R5	16.0	15.0	0.190
T4R6	13.0	10.5	0.080
T4R7	16.5	11.5	0.102

Observation of yield parameters in May 27th

Plant no.	**Length (cm)**	**Circumference (cm)**	**Weight (kg)**
T1R1	13.6	10.2	0.059
T1R2	14.5	11.0	0.070
T1R3	16.8	11.5	0.095
T1R4	16.2	11.1	0.096
T1R5	15.5	12.3	0.083
T1R6	15.5	11.5	0.102
T1R7	15.2	10.5	0.067
T2R3	14.1	11.1	0.078
T2R4	16.7	12.2	0.110
T2R6	16.2	12.8	0.117
T2R7	13.8	10.3	0.075
T3R1	17.0	10.5	0.090
T3R2	11.0	9.8	0.048
T3R	15.0	12.1	0.100
T3R4	17.0	10.6	0.106
T3R7	15.2	11.6	0.088
T4R1	15.1	11.0	0.082
T4R3	13.1	11.8	0.081
T4R4	17.1	12.9	0.134
T4R5	15.0	11.0	0.092
T4R6	15.2	11.5	0.091
T4R7	15.3	9.6	0.070

Observation of yield parameters in June 3rd

Plant no.	**Length (cm)**	**Circumference (cm)**	**Weight (kg)**
T1R1	17.5	13.1	0.158
T1R2	16.7	11.4	0.127
T1R3	16.7	12.0	0.132
T1R4	21.1	14.8	0.243
T1R5	13.1	10.7	0.069
T1R6	17.0	12.2	0.136
T1R7	17.5	13.1	0.158
T2R1	17.6	13.1	0.165
T2R2	17.5	13.0	0.163
T2R3	18.2	14.0	0.202
T2R4	20.8	14.6	0.261
T2R5	18.0	13.0	0.155
T2R6	17.8	13.3	0.167
T2R7	15.2	13.1	0.106
T3R1	15.7	12.8	0.132
T3R2	16.0	12.6	0.139
T3R3	16.3	14.0	0.164
T3R4	15.7	14.7	0.210
T3R5	16.2	12.8	0.165
T3R6	15.9	13.1	0.161
T3R7	16.9	12.5	0.137
T4R1	12.8	12.5	0.115
T4R2	16.5	13.7	0.182
T4R3	15.5	14	0.160
T4R4	17.7	14.5	0.208
T4R5	16.2	11.0	0.120
T4R6	16.3	11.6	0.130
T4R7	18.3	14.2	0.175

Appendix III: Method of statistical analysis of growth parameters

Analysis of variance table (Plant height (cm))

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Factor A	1	4,333.352	4,333.352	3.497	0.07372
Factor B	1	42.938	42.938	0.035	0.85389
Interaction A X B	1	641.360	641.360	0.518	0.47881
Error	24	29,737.625	1,239.068		
Total	27	34,755.275			

Analysis of variance table (Number of leaves)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Factor A	1	2,395.750	2,395.750	7.786	0.01016
Factor B	1	54.321	54.321	0.177	0.67811
Interaction A X B	1	393.750	393.750	1.280	0.26915
Error	24	7,385.143	307.714		
Total	27	10,228.964			

Analysis of variance table (Number of flowers)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Factor A	1	2.286	2.286	0.122	0.73010
Factor B	1	82.286	82.286	4.386	0.04698
Interaction A X B	1	28.000	28.000	1.492	0.23371
Error	24	450.286	18.762		
Total	27	34,755.275			

Analysis of variance table (stem girth (cm))

Source of Variation	**DF**	**Sum of Squares**	**Mean Squares**	**F-Calculated**	**Significance**
Factor A	1	4.329	4.329	6.098	0.02104
Factor B	1	0.445	0.445	0.627	0.43626
Interaction A X B	1	2.178	2.178	3.068	0.09261
Error	24	17.040	0.710		
Total	27	23.993			

Appendix IV: Method of statistical analysis of yield parameters

Analysis of variance table (Number of fruits)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Factor A	1	75.571	75.571	18.137	0.00027
Factor B	1	5.143	5.143	1.234	0.27758
Interaction A X B	1	-0.000	-0.000	-0.000	0.00000
Error	24	100.000	4.167		
Total	27	180.714			

Analysis of variance table (fruit length (cm))

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Factor A	1	33.223	33.223	14.202	0.00094
Factor B	1	8.580	8.580	3.668	0.06746
Interaction A X B	1	0.723	0.723	0.309	0.58334
Error	24	56.143	2.339		
Total	27	98.670			

Analysis of variance table (fruit circumference (cm))

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Factor A	1	11.571	11.571	15.490	0.00062
Factor B	1	0.321	0.321	0.430	0.51809
Interaction A X B	1	0.036	0.036	0.048	0.82877
Error	24	17.929	0.747		
Total	27	29.857			

Analysis of variance table (fruit weight (g))

Source of Variation	**DF**	**Sum of Squares**	**Mean Squares**	**F-Calculated**	**Significance**
Factor A	1	11,320.321	11,320.321	40.897	0.00000
Factor B	1	1,275.750	1,275.750	4.609	0.04212
Interaction A X B	1	170.036	170.036	0.614	0.44084
Error	24	6,643.143	276.798		
Total	27	19,409.250			

MODIFICATION AND EVALUATION OF AUTOMATED DRIP IRRIGATION SYSTEM

By

ARJUN PRAKASH K.V.

(2014 - 18 - 107)

ABSTRACT OF THE THESIS

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Faculty of Agricultural Engineering & Technology

Kerala Agricultural University

DEPARTMENT OF LAND & WATER RESOURCES AND CONSERVATION ENGINEERING
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ABSTRACT

Water is the most valuable resource in the world and is playing a crucial role in daily activities of living beings on the earth. To meet the ever increasing demand, conservation and management of water resource is very important. Conventional methods of irrigation, like surface and subsurface flooding leads to scarcity of water, which can be reduced by adopting drip or trickle irrigation. Drip irrigation system can be controlled through different automation techniques. The present study was focused on the modification and evaluation of the existing cost effective automated drip irrigation system. In this study, calibration of capacitor type and conductive type moisture sensors were carried out in different soil types viz. black soil, coastal alluvium, forest loam, laterite soil and riverine alluvium. Field study was carried out with Hilton FI variety of salad cucumber under different irrigation and fertigation levels using solenoid valves and GSM modem technique. The automated drip irrigation system consists of two capacitor type and two conductive type soil moisture sensors, solenoid valves and water flow sensors. Total yield and crop growth parameters showed better performance under 100 per cent fertigation when compared with 70 per cent fertigation. Combination of 100 per cent fertigation with 70 per cent irrigation also showed good results, whereas production was less in the case of 70 per cent fertigation with 70 per cent irrigation. The modified automated drip irrigation system is cost effective, portable, durable and can perform better.