IRRIGATION AUTOMATION BASED ON SOIL ELECTRICAL CONDUCTIVITY AND LEAF TEMPERATURE

by

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PROJECT REPORT

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DECLARATION

We hereby declare that this project report entitled **Irrigation automation based on soil electrical conductivity and leaf temperature** is a bonafide record of project work done by us during the course of project and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellow-ship or other similar title of any other University or Society.

Place: Tavanur

Date : 11-6-1998

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CERTIFICATE

Certified that this project report entitled **Irrigation automation based on soil electrical conductivity and leaf temperature** is a record of project work done jointly by Hema. P.S, Saritha. E.K. and Shinoj Subramannian under my guidance and supervision and that it was not previously formed the basis for the award of any degree, diploma, fellow-ship or associateship to them.

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Hema P. S.

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SYMBOLS AND ABBREVIATIONS

atm. - atmosphere

C - capacitor

cm - centimeter

CTF - Canopy Temperature Function

CWSI - Crop Water Stress Index

D - Diode

ET - Evapotranspiration

et al - and others

etc. - et cetera

Fig. - Figure

IC - Integrated Circuit

i. e. - that is

K.C.A.E.T - Kelappaji College of Agricultural Engineering and Technology

Kg - Kilogram

KΩ - Kilo ohm

L - litres

L/hr - litres per hour

m - metre

mm - millimetre

Mha - Million hectares

N - neutral

No. - number

Op - amp	Operational amplifier
P	phase
PVC	Poly Vinyl Chloride
R	Resistance
RTH	Thermistor
SDD	Stress Degree Day
TR	Transistor
TTT	Temperature Time Threshold
V	Volt
viz.	namely
VR	Variable Resistance
ΔT	Leaf - air temperature differential
μ	micro
°C	Degree Celsius
Ω	ohm
%	percentage

Chapter I

INTRODUCTION

Agriculture is the source of perpetual creation on which civilization depends. It provides raw materials for most of our industries. It also accounts for sizable share of the country's foreign exchange earnings and has a dominant role in the Indian economy. It contributes nearly half of the national income and provides employment to about 70% of the working population in India. Apart from these material considerations, it is a way of life, unique and irreplaceable in human values. Agriculture cannot be considered in isolation from the life of the people. Being the largest component of India's economic life, agriculture is of utmost importance for the vast number of people. Yet it is the most backward sector of the economy inhabited by large many poor and the very poor. It's development, essential and urgent, involves innumerable challenges, which if handled carefully offers extra ordinary opportunities of progress in this land of abundant nature.

The unfortunate facts of Indian agriculture are the low productivity of land, predominance of tiny farmers, low level of operations, iniquitous land ownership, little commercialised farming, too uncertain water supplies etc. A feature of utmost importance for agriculture and perhaps one of the greatest draw backs is in respect of it's basic input. i.e. water, which is little in many places, almost nonexistent in others, too much in some places, and uncertain in it's occurrence in most of the areas. It is because three fourth of land under crops depends on rainfall, which in India is very much unevenly distributed through time and space. As a consequence in many places and during most of the time, rainfall is either deficient, scantly, or in excess.

Water is commonly taken for granted as nature's gift. Lack of water rather than land area may become the principal constraint on efforts to increase food output and to keep the world in peace. However if land and water are used optimally and if there can be unrestricted movement of produce, there will be food for all for many years to come. While the land resources remain constant, the average annual precipitation, inspite of regional variations, also remain nearly constant. The gross cropped area, however can be increased many fold by increasing the intensity of cultivation. This would necessitate the development and application of the technology to conserve the water resources and increase the efficiency of their utilization.

India on an aggregate basis is now a moisture sufficient state. Perpetuity of this envious position is however being subjected to scrutiny as it is predicted that by 2025 India may become a moisture deficit state, if the water for irrigation is used with 40% efficiency. If that happens, sustainability of agriculture will be seriously imperilled and India may become a net importer of food to feed its population.

Currently the water use efficiency by arable crops is around 40%. Raising the efficiency of irrigation water is a *do or die* task. If the war against hunger has to be won and India has to remain self reliant in its food needs, there is no choice except to save every drop of water and use it prudently. The country's irrigation potential has increased from 26 Mha in the pre-plan period to about 90 Mha at the end of 1996-'97. The irrigation potential created at the end of 1993-'94 was 84.8 Mha but the utilization was only 76.2 Mha leaving a gap of about 9 Mha.

Human effort to fight nature's niggardliness in the supply of water to agriculture takes the form of irrigation in the first attempt. Major function of irrigation is to mitigate the impact of irregular, uneven and inadequate rainfall with wide fluctuations from year to year. It averts serious and semi-famine conditions. It also supplements supply of rain water, particularly in a country like India, where rainfall is concentrated in most regions in the monsoon months of June to September. This additional supply of water makes possible the harvesting of two or three crops or cultivation of crops requiring perennial water supply. Irrigation has assumed an increasing significance under Indian agriculture in the context of new technology where high yielding varieties and multiple cropping patterns are being practised.

Any irrigation system should convey water from a source to the field and deliver it to the root zone of the crop. Different irrigation methods are adopted because of variation in soil types, topography, water supply, crops and other management practices. The check basin and border strip methods may be adopted on well irrigable lands while sprinkler on duny and hummocky areas and drip on marginally irrigable areas.

An efficient method of irrigation should fulfil five major objectives namely, (i) Water is distributed uniformly over the field according to crop needs; (ii) Maximum fraction of applied water is stored in the root zone for plant use; (iii) Crop growth is favourably affected; (iv) Soil transport or loss is negligible; and (v) The technique used is economically sound and adaptable at farm.

Inorder to achieve better productivity, it is important to work out an efficient and economic irrigation schedule for water use under any given set of agroclimatic conditions. There are several approaches for scheduling irrigation based on crops, soil, atmosphere and plant water relations. When no rainfall is likely to be received and soil is not saline, net quantity of water required to be applied is equal to the moisture deficit in the soil. i.e. the quantity of water to fill the root zone to field capacity level.

Irrigation scheduling based on soil moisture levels measures available soil water depletion at certain depth (zone of maximum root activity). The magnitude of available soil water depletions at which irrigation is to be scheduled may be 25, 50,75 percent etc.

An ideal irrigation scheduling technique should use the plant as the indicator of water stress since the plant responds to both the aerial and soil environments. One of the most non-invasive techniques to assess plant water stress, utilizes the measurement of canopy temperature. Its usefulness is based on the principle that water lost through transpiration cools the leaves much below the temperature of surrounding air under well watered conditions. As soil water becomes limiting, transpiration is reduced and leaf temperature increases. Irrigation scheduling based on the canopy -air temperature differential has been suggested by many researchers. Remote measurement of plant canopy temperatures combined with ground-based air temperature measurements, appears to be a sound practical tool for assessing water requirement of plants. The amount of water to be applied may also be ascertained.

Farmers have always sought ways to supply crops with the water necessary for their development where rainfall is inadequate. The most recent irrigation techniques introduce a new concept in irrigation, because it is now possible using very sophisticated equipment to supply water to the plant as soon as they need it, even daily, if not necessarily continuously.

The water extracted by the crop should be constantly replenished and the soil moisture reserve should neither be depleted nor increased. An automatised irrigation system can ensure saving of work, time and precise application without the risk of forgetfulness or of too early shut off when the irrigator is anxious to return home after a hard day in the field. The level of automation achieved, render the advantage of both automation and scheduling of irrigation. An automated irrigation system is applicable to farm use, particularly in humid areas where unpredictable and unevenly distributed summer rainfall disrupts fixed irrigation schedules. Hence a study with the following objectives is taken up.

Objectives of the study

1. To establish a relationship between soil moisture content and electrical conductivity of soil; and soil moisture content and leaf - air temperature differential.
2. Development of an automated drip irrigation system based on electrical conductivity of soil.
3. Development of an automated drip irrigation system based on leaf - air temperature differential.
4. Testing of the newly developed automated systems and their comparison.

Chapter II

REVIEW OF LITERATURE

Agricultural production need to be accelerated due to the ever increasing demand of the growing population. This has led to rapid expansion in the field of irrigation. To obtain highest productivity with minimum water and least disturbance to the ecosystem, scientific irrigation systems are to be practised. Studies have shown that 45-65% of the irrigation water is lost due to seepage and runoff. Water used should be based on crop needs, especially at critical growth stages. So the efficient management of water is the need of the hour. The primary objective of any irrigation method is to supply moisture to the crop in the readily available condition, without producing water stress in the crop and by minimising wastage of water due to losses.

2.1. Automated irrigation systems

Scheduling irrigation so as to maintain uniform moisture content in the root zone would have been too tedious when watering in the conventional way. Automation is the procedure used to regulate an irrigation system by a mechanical or electronic device. It avoids frequent human supervision by controlling itself, thus reducing the human effort involved. Automatic irrigation ensures saving of work, time and precision application of water depending on the requirement of crop, thus reducing plant water stress conditions.

Garton made the first attempt to automate open ditch irrigation systems. He used automated irrigation through a lever mechanism causing collapse of check dams and thus sending water down the ditch. Butchbaker described automated control systems as open or closed loop control systems. The main feature that distinguishes these systems is the ability of a closed loop system to adjust its operation to optimise one or more performance parameters on a real time basis. Humphrey classified farm automated systems on the basis of the tasks that are automated as fully automatic and semi automatic. Fully automatic systems not only control and operate the farm irrigation structures but also make decisions about when to irrigate. Semi automatic systems normally must be started by operator who also makes the decision about when to irrigate. (Geetha et al, 1996)

Kazakov et al (1981) designed an installation for automatic irrigation of plants in vegetative pots according to a pre-selected programme. Malano (1982) suggested that some of the existing timer controlled systems fitted with multiple cycle controllers have the potential to be adopted for use in surge irrigation. Humphrey (1983) used butterfly valves in gravity pipe line irrigation system, which could be operated by springs or pneumatic method. He suggested using solenoid pivot valves in conjunction with double acting air cylinder. Bradbury and Manges (1984) developed microcomputer control of surge irrigation using wire telemetry. Receivers detected the appropriate signals and turned power on to a solenoid valve to switch the flow of water. Ismail and Westesen (1984) developed and tested an automatic drop gate. The field experiments showed that surge flow produced by the gate was more efficient than conventional continuous flow.

Automated irrigation systems can increase crop yields (by about 3%), save water usage (15%), save energy (20%) and save labour costs (35%) as compared with manual systems (Mulas, 1986). Automated systems are used in glass houses and in open fields.

In the operation of level basin irrigation systems the electric signalling was either directed to solenoid operated valves or to relays used to switch the main power (Dedrick, 1987). A wide array of mechanisms have been developed to control the opening and closing of outlet structures. Powered mechanisms such as electromechanical linear actuators, electric motors and compressed air are commonly used.

Latimer et al. (1989) described about an intelligent surface irrigation system that can automatically sense the advance of water at two known distances down the field. The sensing system consisted of two water advance sensors in each furrow. Kazakov et al (1989) developed an installation for programmed irrigation of plants, which consisted of a control unit, rack and actuator and may operate either automatically or manually.

Byrlev (1990) developed a semiautomatic hydraulic system for pipelines of stationary and semi-stationary systems of furrow irrigation. Cuming (1990) developed an irrigation control system which includes a soil moisture sensor that controls the common lines of various irrigation systems. Valves are controlled by a conventional irrigation time based controller. The sensor is in the first zone of primary shallow rooted plant. A timer is activated whenever the soil moisture sensor allows the first zone to be watered. When the irrigation in the first zone is completed the irrigation valve feeding the second zone of primary deep rooted plants are activated by the action of a counter.

Continuous control of irrigation can be done based on soil moisture tension as determined by tensiometers (Kubik et al, 1990). Latimer et al (1990) developed an experimental advance rate feed back surface irrigation system composed of an intelligent system, a water sensing system, a flow control system and a telemetry system. Shah et al (1990) suggested canal automation as a necessary one for Sardar Sarovar project, which is the biggest multipurpose project in India. The working of the proposed system is based on the computer aided remote control and monitoring of the canal systems.

Stombaugh et al (1990) developed an automated pulsating irrigation system which makes irrigation control decisions using artificial intelligence techniques. Sturcel et al. (1990) developed a digital control automation system which worked on the basis of an algorithm for irrigation requirements. Yoder et al (1990) developed a programmable irrigation controller which can be used to signal and activate the solenoid valve. Electrically operated three way solenoid pilot valve controls air flow into or out of the brake actuator diaphragm to open or close the normally closed irrigation valve.

Bancroft et al (1991) reported about an irrigation control apparatus for use in controlling an irrigation valve includes a soil moisture sensor for generating an output signal indicative of the soil moisture level. Bianchi (1991) reported that further development of irrigation systems in Italy may lead to *total automation systems* using the latest media networks (television, computers, telephones and sensors etc.) to substitute man in all phases of management.

Cavazza (1991) assessed the value of automated irrigation systems in reducing labour and water consumption costs. Francovitch et al (1991) developed an automatic plant watering system consisted of an electronic switching system that controls pumping time of water pump. The flow rate of water is controlled by a valve system. The electronic switching system is actuated by an electronic humidity sensor. Piccolo (1991) reported three levels of automatic irrigation scheduling methods in Italian catchment areas; local control of pump or sluice gate; remote control at district level and control programming.

Automated irrigation has a number of advantages including greater precision, more efficient use of water, reduction in man power required and no human error (Castanon, 1992). Hibbs et al (1992) developed a furrow irrigation automation system utilising an *adaptive control algorithm.* Malano et al (1992) suggested that for an automatic border irrigation equipment, correct sensor placement and timer setting are critical factors to achieve high hydraulic performance. Kolev et al (1994) developed a microcomputer system for irrigation control; which uses soil moisture, rainfall and other microclimatic data. water application is controlled by a specialized microprocessor that operates electromagnetic and hydraulic valves.

2.1.1. Automation in Sprinkler irrigation

In the sprinkler method of irrigation, water is sprayed into the air and allowed to fall on the ground surface some what resembling rainfall. The spray is developed by the flow of water under pressure through small orifices or nozzles. The pressure is usually obtained by pumping. With careful selection of nozzle sizes, operating pressures and sprinkler spacings, the amount of irrigation water required to refill the crop root zone can be applied nearly uniformly at a rate to suit the infiltration rate of the soil, thereby obtaining efficient irrigation.

Maticic (1975) described about a tensiometer control apparatus which consisted of mercury tube tensiometer and automatic relays and conduits. This was used to control stationary sprinkler irrigation system according to soil water deficit.

Hollis and Dylla (1980) evaluated a fully automated soil moisture sensing plot sprinkler irrigation system using gypsum resistance block soil moisture sensors. Irrigation was initiated when soil moisture levels averaging 3mm below the preset irrigation thresholds. A digital electronic controller provided independent plot irrigation control. A 60 second delay period was added to the controller during the first year of operation after irrigation had been initiated by lightening noise from nearby storms. Lamb et al (1985) developed a low cost microprocessor based irrigation control system which monitored and controlled sprinkler sets. The system measured water pressure, flow rate, wind velocity and rainfall intensity and produced automatic control at a remote location. Chernilevski et al (1989) developed an automatic sprinkling system in green houses. The entire system is controlled by a computer in relation to the soil temperature and pH, solar radiation and the crops grown. Thomas et al (1989) developed an electronic timer for center pivot irrigation system. The timer provides greater timing accuracy than electromechanical timers.

Indu et al (1993) evaluated the performance of different pop-up sprinklers and master control unit was developed for controlling irrigation by various system of pop-up sprinklers, micro sprinklers and drip system. The unit has separate controls for the *on* and *off* periods which could be adjusted as per requirement. Udayakumar (1994) modified an automatic control unit to control the drip and sprinkler irrigation systems. The *on* and *off* periods of the systems can be individually controlled, by means of an electronic timer having *on* and *off* delay adjustments. Solenoid valve was used to deliver water, when required.

2.1.2. Automation in drip irrigation

Drip or trickle irrigation is one of the latest methods of irrigation which is becoming increasingly popular in areas with water scarcity and salt problems. It is a method of watering plants frequently and with a volume of water approaching the consumptive use of plant thereby minimising such conventional losses as deep percolation, run off and soil water evaporation. In this method irrigation is accomplished by using small diameter plastic lateral lines with devices called *emitters* or *drippers* at selected spacings to deliver water to the soil surface near the base of the plants. The system applies water slowly to keep the soil moisture within the desired range for plant growth.

Automatic drip irrigation systems using *soil moisture potential sensor controls* were developed and tested for the crops millet (Phene et al 1976) Potatoes (Phene and Sanders 1976), maize (Montonnet et al 1981,Phene and Beale,1976) and for tomatoes (Phene and Howell,1984). Phene et al (1983) improvised a method for control of high frequency irrigation system using soil moisture sensors. An electronic feed back soil moisture sensor installed in the root zone of crop was used for control. The experimental results showed that the control method can be used successfully to improve crop yield and quality and provide precise automatic control of trickle irrigation system.

Ornstein (1985) developed a moisture sensitive self regulating water valve for drip irrigation systems. It consists of a *polyacrylamide gel* as it's moisture sensing element that expands when moist and causes a piston to compress a thin walled rubber tube, thus cutting off the water supply. Bambuch and Malkroth (1986) compared four automatic irrigation systems. i.e. drip irrigation of individual pots; mat irrigation; flooded benches with 12-15mm water depth; and channels on a 1% gradient. Irrigation was controlled by tensiometer placed on plant pots. The drip irrigation system gave the most even water distribution. Porras et al (1986) introduced a system for automatic control of drip irrigation in olive, using photovoltaic panels. Commercially available magnetic switching tensiometers were installed with irrigation timer controllers (Smajstrla and Koo, 1987). The tensiometers initiated irrigation when soil water potential dropped to preset levels and controllers applied a pre-determined amount of water. But regular inspection and calibration were necessary. Asaaf et al (1988) conducted studies on the optimisation of water for fruit trees by a computerised irrigation system. Duret (1988) developed an automated irrigation system with tensiometer as sensor.

Wilham (1988) discussed the importance of precise water volume metering in bed cultivation and the importance of automatic control systems including volume and time limiters, solar radiation meters and tensiometers. Anitha et al (1990) designed and developed an automatic drip irrigation system and tested the performance of the system on pot grown tomatoes. Mercury manometer tensiometers, switching circuit and electrically controlled solenoid valve were used to automatize the system. The scheduling and controlling of irrigation was done based on soil moisture potential measurement provided by the tensiometer connected to U-tube manometer. Changes in soil suction with time and depth was analysed by an array of tensiometers placed at various depths.

Jamal et al. (1991) designed and developed a solar powered automatic drip irrigation system for areas with low as well as high water requirements and tested the system performance. Mercury manometer tensiometer, switching circuit and electrically operated solenoid valve (for areas with low water requirement) or solarpower operated pump motor unit (for areas with high water requirements) were used for automatising drip irrigation system.

2.2. Soil moisture sensors

Intelligent management of soil, water and plant resources requires an understanding of how soils and plants react to different stresses. Where water is limiting plant growth, as it does in many parts of the world, the measurement of soil and plant water status is of fundamental importance. Soil and plant water status is influenced by a complex of climatic and management conditions. Not only does soil and plant water status influence plant growth, but other processes such as soil flow, leaching, soil evaporation and transpiration are influenced. The key to understanding and simulating these processes is knowledge of how to measure the appropriate soil and plant properties that influence these processes.

Thus there is always a need for good methods for measuring soil and plant water status. Measurements are a challenge because of soil spatial and temporal variability and the fragile nature of the growing plant in a changing climatic environment. The most important and basic component of a measurement system is the sensor. The efficiency of various management decisions depends on accurate measurements which in turn depends on the accuracy of the sensor.

A new commercial version of electronic sensor developed by Phene et al (1971) was tested to determine its ability to monitor the matric potential of soil water and to control high frequency irrigation systems. It was found that these sensors have large measurement sensitivity in the soil matric potential range of interest of irrigation control and a rapid response to changes in soil matric potential. Austin et al (1977) reported that tensiometers fitted with mercury manometers and an optoelectronic level detector can be used as soil moisture sensors for an automated irrigation system. Shull et al (1980) suggested the use of gypsum resistance block as soil moisture sensor. The controller of an automated irrigation system could be used on larger fields by extending the soil moisture sensing area. A network of gypsum resistance blocks was made by connecting them in series and in parallel with a resistance range the same as that provided by one block.

Usually in border irrigation automation, the pneumatic sensors are being superseded by electronic water sensors due to the blocking of air transmission line by debris. Augustin et al (1984) investigated the feasibility of basin irrigation by using soil moisture sensors rather than traditional time clock scheduling. They found that sensor treatments had received only 26% of the water applied by daily treatments.

Alharthi et al (1987) suggested a method of assessing the water saturations by the measurements of composite dielectric constant. A case study using gypsum blocks for improved irrigation scheduling was described by Stenitzer and Lergn (1988) and it was proved to be practicable for use by farmers with minimum water and nitrate losses during irrigation.

Tension measurements by tensiometers are generally limited to matric suction values of below 1 atm. They do not satisfactorily measure the entire range of available moisture in all soil types. Tensiometers are less well suited to use in fine textured soils in which only a small part of available moisture is held at a tension of less than 1atm. If air enters the unit through any leaks at the rubber connections , measurements are not reliable. After an irrigation or rain , it is desirable to fill the instruments with water (Michael,1995).

2.3. Leaf temperature as an indicator of crop water stress

Observations of plant water status probably were the first plant physiological observations ever made. Before the beginning of recorded history farmers and gardeners observed the water status of plants in order to know when to irrigate. Those early farmers used visual indicators such as wilting, leaf rolling and change in colour which remain useful even today. Generally all the farmers' or gardeners' need is an early indicator of water stress, and this can be provided by the observation of plant leaf temperature. Many researchers have contributed to the subject. Plant temperature may be a valuable qualitative index of water availability (Tanner, 1963 and Gates,1964). The status of water in the plant represents an integration of the atmospheric demand, soil water potential, rooting density and distribution as well as other plant characteristics (Kramer, 1969). Therefore to obtain a true measure of the plant water deficit, the measurement should be made on the plant and not on the soil or atmosphere.

Clark and Hiler (1973) correlated the leaf air temperature differential with crop water deficit. They found that in almost every case the leaves were cooler than the air above the canopy, when the crop was well watered. Once a water deficit occurred in the stressed treatment, the ΔT became positive and was usually 2-3°C warmer than the non-stressed treatment. William and Ehler (1973) investigated the relation between moderate soil water depletion and early temperature difference for feasibility of measurement and possible use as a guide to irrigation scheduling. They found that the method is restricted to regions with sunny climate.

Jackson et al (1977) reported that water stress causes partial stomatal closure, thus reducing transpiration and allowing sunlit leaves to warm above ambient air temperature. In the same and in another paper they introduced a new term called *stress degree day (SDD)* which is the summation of canopy-air temperature difference measured over a specified time period. The SDD concept shows as a promising indicator for determining the times and amounts of irrigations . Idso et al(1981) showed that through out greater portion of day light period, plots of *canopy-air temperature differential* with *air vapour pressure deficit* yielded linear relationships for plants transpiring at the potential rate irrespective of other environmental parameters except cloud cover. From this plot they developed a term called *crop water stress index (CWSI)* which can be used for scheduling irrigations.

Jackson (1982) found that an ideal irrigation scheduling technique should use the plant as the indicator of water stress, since the plant response to both the aerial and soil environments. The use of canopy temperature to detect water stress is based on the principle that water lost through the transpiration process cools the leaves below the temperature of the surrounding air under well watered conditions. Irrigation scheduling based on the canopy-air temperature differential has been suggested by many researchers. (Reginato,1977, Reginato and Idso,1977, Walker and Hatfield, 1979).

Throssel et al (1987) found that the plant canopy-ambient air temperature difference is a good indicator of the water status of a plant. Gaitan et al (1990) found that the location of a cotton plot on the block had an effect on the *canopy* *temperature function (CTF)* of well watered and water stressed cotton and plot location had a major effect on the mean irrigation seasonal CWSI of water stressed cotton. Asher et al (1992) concluded that implementation of the infrared thermometer using both CWSI and transpiration estimation could not improve the efficiency of high frequency irrigation.

Kadam et al (1994) found that *stress degree day* provides a valid indicator of crop water stress . The canopy air temperature difference is also related to leaf water potential and CWSI and can be utilised for irrigation scheduling. Pushkala (1994) found that leaf temperature seems to be a function of both soil temperature as well as water content. The relationship of stomatal resistance with gravimetric moisture content, relative humidity and leaf water potential for summer cowpea showed that relative humidity and leaf water potential are strongly related to stomatal resistance. Wanjura et al (1995) scheduled irrigation of cotton using a minimum 3 day irrigation cycle which was adjusted by *temperature time thresholds (TTT)*. These TTT were measured as the amount of time that canopy temperature exceeded 28°C during one day.

Bhosale et al (1996) found that the canopy air temperature differential *(ΔTc)* is a good indicator of water status of the plants. The cumulative SDD, CWSI and ΔTc just before irrigation have linear relationship with grain yield. Of these three approaches ΔTc concept is simple and practicable. Olufayo et al (1996) evaluated the plant water stress using canopy temperature measurements on sorghum.

2.3.1 Leaf temperature sensors

Until infrared thermometers became available, most plant temperature measurements were made with contact sensors on, or embedded in, leaves (Ehrler, 1973). He used thermocouples embedded in cotton leaves to determine leaf temperatures. He concluded that using leaf-air temperature differences for scheduling irrigations in cotton has merit and should be developed. Misra and Ahmed (1990) described the method of measuring leaf temperature with thermocouples. The thermocouple junction must be in perfect thermal contact with the leaf, and the lead wire conduction and radiation must not affect the sensor. The sensor should be attached tightly to the under side of the leaf. A strain relief loop at the petiole is made to prevent wind from tearing the thermocouple from the leaf.

2.3.2 Automation based on leaf temperature

Jackson et al (1977) suggested the possibility of development of a totally automated irrigation system in which instruments monitor the canopy temperature of plants for signs of water stress and signal devices that automatically provide required amounts of irrigation water.

Wanjura et al (1992) developed an automated drip irrigation system based on threshold canopy temperature. Irrigation was applied only when average canopy temperature exceeded predetermined threshold values. The length of irrigation cycles was shortest and amount per irrigation event was highest for all threshold temperatures during the early growth stage because canopies were small and warm bare soil contributed to measured canopy temperature. Automating irrigation has a number of advantages including greater precision, more efficient use of water, reduction in man power required and no human error (Castanon, 1992) .

Eldin and Al-Amond (1993) developed a micro computer based real time data acquisition and controlled system and used for automatic irrigation scheduling of centre pivots. The system operation involves collecting continuous soil-water data from field stations using tensiometers equipped with transducers distributed through out the area, via an infrared telemetry system.

Chapter III

MATERIALS AND METHODS

A study was conducted to evaluate the soil electrical conductivity and leaf-air temperature differential as indicators for irrigation automation. Relationships between soil moisture content and electrical resistance and soil moisture content and leaf - air temperature differential were established. Two automated irrigation systems with soil electrical conductivity and leaf-air temperature respectively as indicators for irrigation automation were developed. Testing and performance evaluation of these automated systems were conducted. A soil moisture sensor was also developed. This chapter deals with different materials used in this study and methods adopted to compare the irrigation systems.

3.1. Location

The experiment was conducted at the Kelappaji College of Agricultural Engineering and Technology premises, Tavanur, in Malappuram district of Kerala. The place is situated at 10° 52′ 30″ North Latitude and 76° East Longitude.

3.2. Climate

The area falls within the boarder line of northern zone, central zone and kole zone. Climatologically the area is in the high rainfall zone (2500mm to 3000 mm). The area receives the rainfall mainly from South West monsoon and a certain extent from North East monsoon.

3.3. Land preparation

Two experimental plots (plot 1 and plot 2) were selected, each with an area of 2m × 2m.The site was cleared and seed bed was prepared as per the Package of Practices, Kerala Agricultural University. A pretreatment was given for soil with Neem cake powder and pre-sowing irrigation was done.

3.4. Experimental set up

The automated irrigation system based on electrical conductivity of soil was installed in plot 1 and the other system based on leaf-air temperature differential was installed in plot 2.

3.4.1. Crop

The crop planted was Bhindi *(Abelmoschus esculentus*) of variety Arca Anamika for which one of the main planting season is February-March. It has an excellent rooting pattern and good canopy, with moderately strong and thick leaves. Being a summer crop, the seeds were soaked in water for 24 hours before sowing. A spacing of 60 cm between rows and 30 cm between plants were given.

3.4.2. Water supply

An overhead plastic tank of 100 L capacity was provided for supplying water for irrigation. The water level in the tank was maintained constant using a float valve connected at the inlet of the tank. An effective head of 5.5m was available for the irrigation system.

3.4.3. Soil moisture sensors

A soil moisture sensor was fabricated to sense the soil moisture content in the root zone of the plant. The sensor was placed at required depth in the root zone and based on the signal from the sensor the switching circuit in the control board was activated.

The soil moisture sensor consists of two electrodes with a porous medium in between. When the sensor is embedded in the soil, the moisture content of the porous medium comes in equilibrium with soil moisture. The electrical resistance between the two electrodes varies with moisture of porous medium which is in equilibrium with soil moisture.

3.4.3.1. Selection of soil moisture sensor

In order to find the suitability of the electrode material, three sensors were made with different electrode materials. i.e. copper, stainless steel and brass. The three sensors were placed in a pot filled with soil of the field and the soil was saturated. Moisture contents and corresponding resistances were continuously monitored at regular intervals to find the relationship of soil moisture content with electrical resistance between the electrodes. To find the suitability of porous medium between the electrodes, five soil moisture sensors with different porous medium in between electrode plates were evaluated . Among the five sensors, four of them had brass plate of size 3cm× 2.5cm as electrodes with a gap of 1cm between them. The porous media used were soil at the site, washed sand, sponge and nylon for first, second, third and fourth sensors respectively. A gypsum block was the fifth sensor used for evaluation.

A pit of size 1m × 1m with a depth of 15cm was made at the experimental site. All the five moisture sensors were placed at the bottom of the pit and is covered with soil up to 12cm height. The rest 3cm is used to pond water over the pit. Initially the pit was saturated with water. Soil samples were taken from the pit, from the time of saturation and corresponding electrical resistance values of all the five sensors were measured using a multimeter. The moisture content of the soil sample was found by gravimetric method. This procedure was continued till a nearly constant moisture content value was maintained in the soil. After this, the pit was laid as such for two days and the above procedure was repeated four times. Soil moisture content- electrical resistance relationship for all the five sensors were obtained. The selection of appropriate sensor was made on the basis of the uniformity of soil moisture content-electrical resistance relationship for all the four replications. The resistance corresponding to the field capacity of soil was also determined. The soil moisture sensor used in this study is shown in Plate No. 1.

3.4.4. Leaf- air temperature differential

Previous studies have clearly shown the importance of canopy temperature of crop as an effective indicator of crop water stress. Sometimes, plant may not be able to extract water even if the soil is in a saturated condition as in saline soils. Moreover, the moisture measurement in certain soils like Laterite which is having large gravels may not be accurate. This idea substantiated the use of canopy temperature as an indicator for irrigation scheduling in recent studies.

Remote sensing of canopy temperature was done in order to schedule irrigation in previous studies. The canopy temperature was measured using infrared thermometers, which is very costly. Instead of taking canopy temperature as the indicator, leaf emperature is taken in this study to indicate plant water stress. The leaf-air temperature differential is used to quantify the plant water stress.

A mercury in glass thermometer is used to measure the temperature of air as well as leaf. The thermometer bulb is placed underside of the leaf, keeping the leaf in shade to prevent solar radiation effects.

3.4.4.1. Temperature sensor

In order to sense the leaf and air temperature for converting it into a signal acceptable to the switching circuit, a thermistor is used. Thermistor is a contraction of a term *thermal resistor.* They are generally composed of semiconductor materials. Most thermistors have a negative coefficient of thermal resistance. i.e. their resistance decreases with increase of temperature. The negative temperature coefficient of resistance can be as large as several percent per degree Celsius and this makes the thermistor very sensitive. i.e. to detect very small changes in temperature. In some cases the resistance of thermistor at room temperature may decrease as much as 5% for each 1°C rise in temperature. The resistance of thermistors ranges from 0.5Ω to 0.75 MΩ. Thermistors are widely used in applications which involve measurements in the range of -60 °C to 115°C. The thermistor exhibits a highly non linear characteristics of resistance verses temperature. They are composed of sintered mixture of metallic oxides such as manganese, nickel, cobalt, copper, iron and uranium. It has two leads to connect to the circuit. The thermistor is shown in Plate No. 2.

Thermistors are extremely delicate components and heat should be passed through them quickly. Button type thermistors were used as temperature sensors, whose effective surface area in contact with the leaf is very less. So the thermistor attached in between the leaf and an aluminium foil of 2cm × 1cm size constitutes the leaf temperature sensor. The aluminium foil will make a rigid contact with leaf and thermistor and maintain quick flow of heat from leaf to thermistor. The temperature sensor attached to the leaf is shown in Plate No. 3.

Small holes should be provided on the aluminium foil in order to aid smooth transpiration. Otherwise water may accumulate in between leaf and aluminium foil, causing a rapid reduction in temperature during windy conditions, which is not a function of plant characteristics.

Similar button type thermistor can be used as the air temperature sensor. This thermistor was hung freely in atmosphere in the micro climate of the plant to sense the air temperature. The placement of temperature sensors to sense the leaf as well as atmospheric temperature is shown in Plate No.4.

3.4.5. Control system for automation

Two different circuits were used for automation based on electrical conductivity of soil and automation based on leaf-air temperature differential. The working of both circuits are explained below.

3.4.5.1. Automation based on electrical conductivity of soil

The circuit used for automation based on electrical conductivity of soil is shown in Fig. 3.1. Variation of moisture in soil causes variation in electrical resistance across the electrode of the sensor. The electrical signal obtained by variation in electrical resistance is inverted with the help of IC1, CD4011. It is then applied to the triggering input of IC2, NE555, which is a monostable multivibrator. Here, a single output pulse of preset magnitude and period is produced for a single input trigger pulse. The period of the output pulse is determined by the series resistor VR2 and capacitor C1. When triggered by pin 2, IC2 drives IC3, NE555, which is wired as an astable multivibrator.

The relay contacts are connected to an electrically operated solinoid valve whose input is connected to the pipe line from water source and output of valve is connected to main line of drip system. Thus when the soil gets dry and its resistivity increases, the valve operates and water flows to the plants. When water content in soil reaches the required level set by the variable register VR1, the valve stops the flow of water. The circuit is powered by an eliminator, which rectified 230V ac supply to 9V dc supply.

3.4 5.2. Automation based on leaf-air temperature differential

When the temperature of the leaf decreases with the supply of water, the resistance of the thermistor RTH1 (attached to the leaf) increases. Thermistor RTH1 along with the variable resistance VR1 constitutes a potential divider across the supply, resulting in a voltage at pin 2 of the Op-amp IC1 741. This voltage rises as the temperature decreases. Thermistor RTH2 (exposed to atmosphere) along with

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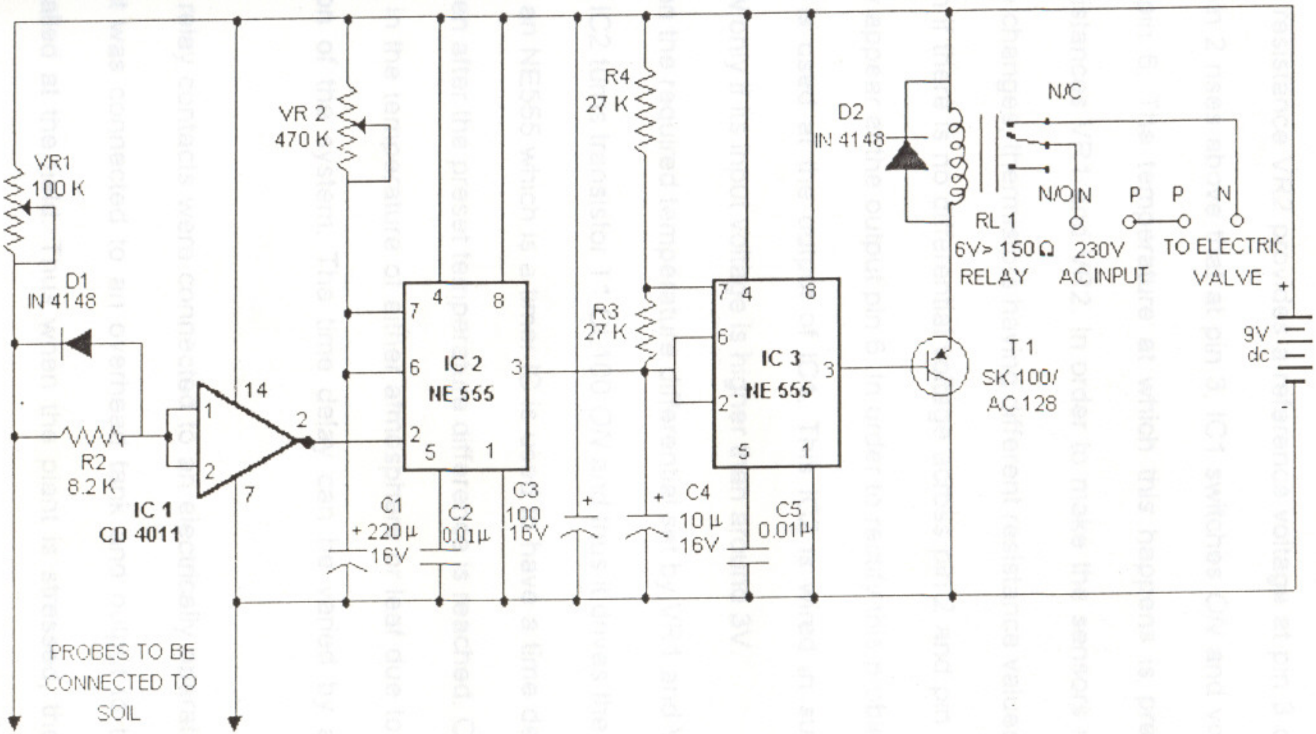


Fig. 3.1. Switching circuit for automation system based on soil electrical conductivity.

the variable resistance VR2 provides a reference voltage at pin 3 of IC1. When the voltage at pin 2 rises above that at pin 3, IC1 switches *ON* and voltage appears at the output pin 6. The temperature at which this happens is preset by adjusting variable resistances VR1 and VR2. In order to make the sensors more sensitive to temperature changes, thermistors having different resistance values were used.

Even if there is no differential voltage across pin 2 and pin 3 of IC1, a small voltage may appear at the output pin 6. In order to rectify this problem IC2, CD 4011 (CMOS IC) is used at the output of IC1. This IC2 is wired in such a way that it switches *ON* only if its input voltage is higher than around 3V.

When the required temperature differential set by VR1 and VR2 reaches, the output from IC2 turns transistor T1 CL100 *ON* and thus it drives the relay.

IC3, an NE555 which is a timer IC is used to have a time delay for operating the relay even after the preset temperature difference is reached. Otherwise sudden fluctuations in the temperature of either atmosphere or leaf due to wind may affect the operation of the system. The time delay can be varied by adjusting VR3, if needed.

The relay contacts were connected to an electrically operated solinoid valve whose input was connected to an overhead tank and output to the drip irrigation system installed at the field. Thus when the plant is stressed, the temperature of leaf increases with respect to atmosphere, the valve operates and water flows to the plants. Then the plant leaves begin to cool and when the temperature reaches the preset value, the valve stops the flow of water. The circuit was powered by an eliminator, which rectified 230 V ac supply to 9V dc supply. The switching circuit used for automation based on leaf - air temperature differential is shown in Fig. 3.2.

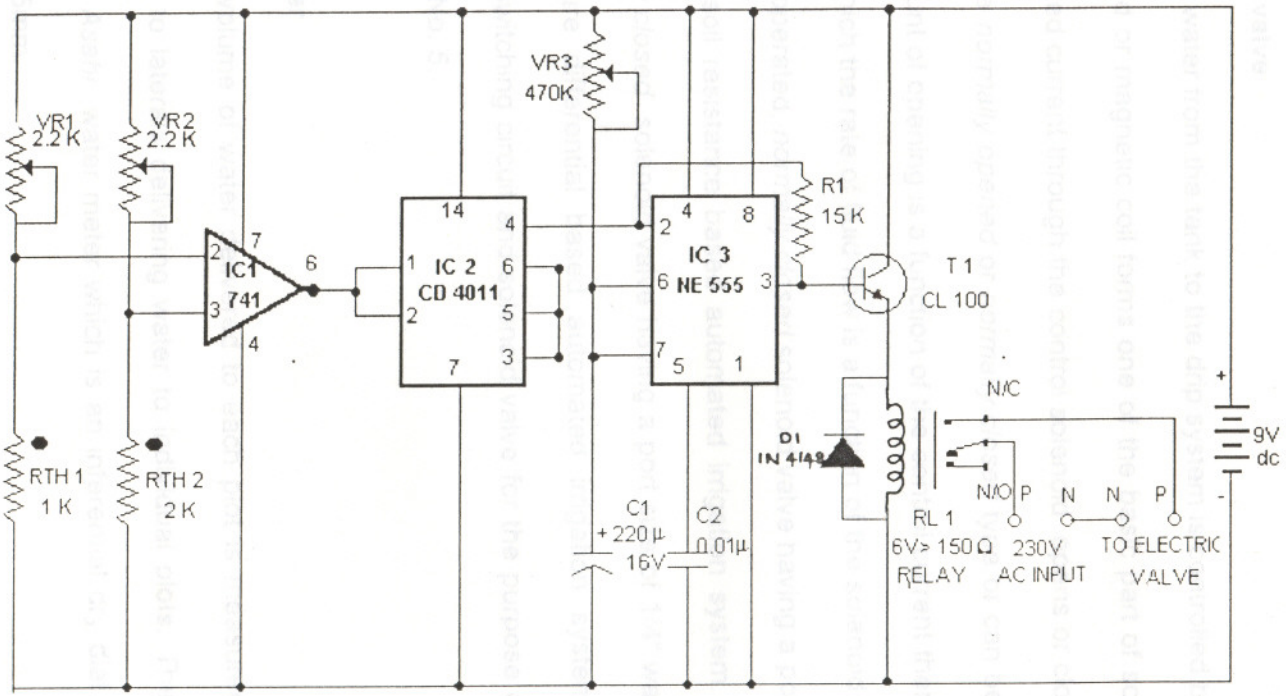


Fig. 3.2. Switching circuit for the automation system based on leaf-air temperature differential

3.4.5.3. Solenoid valve

The flow of water from the tank to the drip system is controlled by a solenoid valve. The solenoid or magnetic coil forms one of the basic part of solenoid valve. Passage of the rated current through the control solenoid opens or closes a valve. They can be of the *normally opened* or *normally closed* type or can be constructed such that the amount of opening is a function of the control current thereby having a characteristic in which the rate of fluid flow is a function of the solenoid current.

A 12 V dc operated, *normally closed* solenoid valve having a port size of 1/4" was used in the soil resistance based automated irrigation system. A 230 V ac operated *normally closed* solenoid valve having a port size of 1/4" was used in the leaf-air temperature differential based automated irrigation system.The control board fitted with switching circuit and solenoid valve for the purpose of automation is shown in Plate No. 5.

3.4.6. Water meter

The total volume of water delivered to each plot is measured using water meter connected to laterals delivering water to individual plots. The water meter used was *Anand Asahi* water meter which is an inferential dry dial type and has nominal size of 15mm.

3.4.7. Installation and arrangement of drip system

Black PVC pipes of 16 mm diameter were used to deliver water from the overhead tank to each plot. A view of the experimental plots is shown in Plate No. 6 and 7. The emitters used were tap type, whose discharge can be adjusted as required. The emitters were connected to lateral pipes through micro tubes. Each plant was given one micro tube with an emitter. The layout of the system is shown in Fig. 3.3.

3.5. Performance evaluation of irrigation systems

To evaluate the performance of the two automated system, the soil moisture content was measured from each automated plot three times a day. i.e. at 8.30 am, 12.30 pm and 3.30 pm. At the same time air temperature and leaf temperature were also measured from the plot automated based on leaf - air temperature differential using a mercury in glass thermometer. The amount of water applied was also noted using two water meters.

3.5.1. Measurement of moisture content

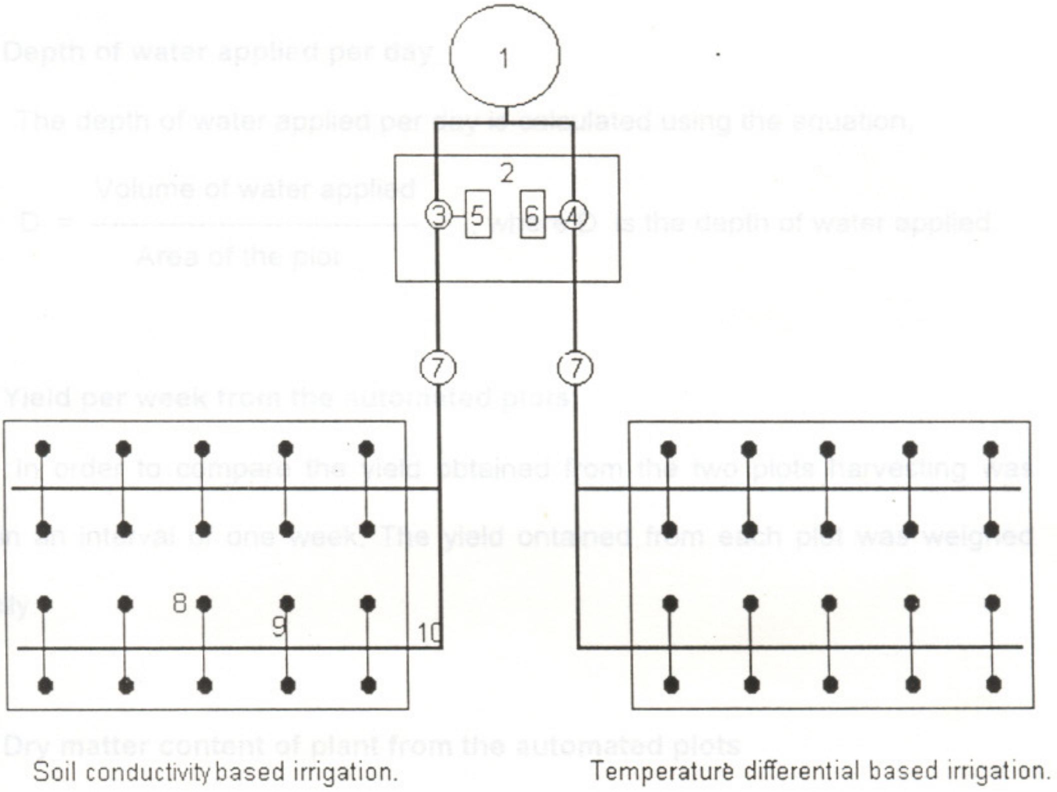
Moisture content from two plots was measured by gravimetric method. The initial weight of the sample (W1) was taken. Then the sample was dried for 24 hours at 105°C in a hot air oven and the oven dry weight of sample (W2) was taken. The weigts were taken by a tripple beam balance.The moisture content (%) was calculated using the equation,

$$\text{m.c}\ (\%) = \frac{(W1-W2)}{(W2-W)}$$

, where W is the Weight of the sample box.

3.5.2. Measurement of volume of water delivered

Volume of water delivered to each plot was obtained in litres from water meter readings.



1. Overhead tank.

2. Control board.

3. Solenoid valve delivering water to plot 1.

4. Solenoid valve delivering water to plot 2.

5. Control circuit for soil conductivity based automated irrigation system.

6. Control circuit for leaf air temperature diferential based automated irrigation system

7. Watermeters.

8. Plants.

9. micro tubes.

10. Laterals.

Fig.3.3 Lay out of the experimental arrangement.

3.5.3. Depth of water applied per day

The depth of water applied per day is calculated using the equation,

$$D = \frac{\text{Volume of water applied}}{\text{Area of the plot}}$$

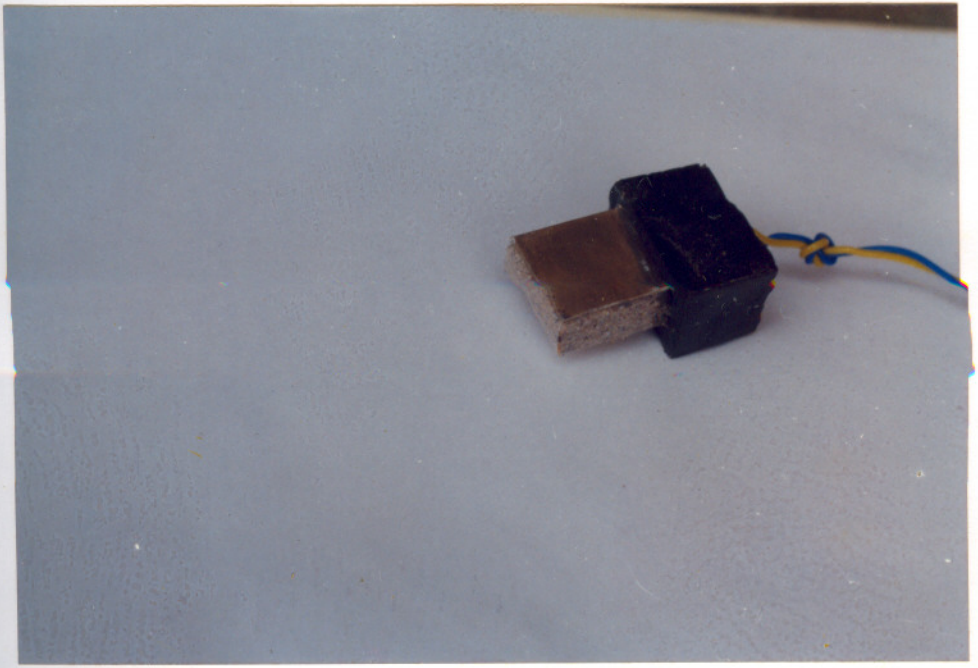
, where D is the depth of water applied.

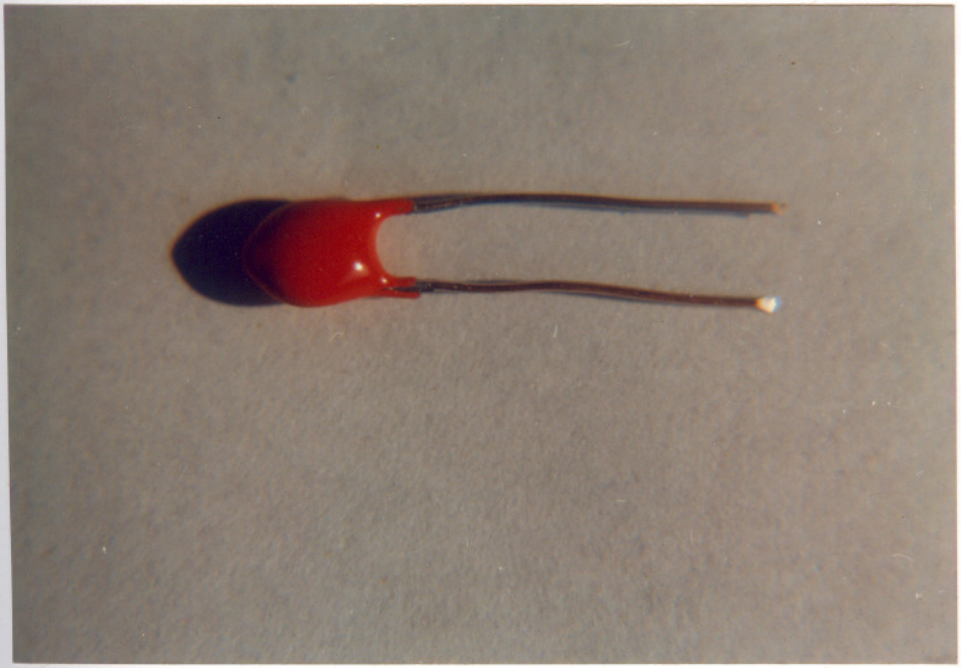
3.5.4. Yield per week from the automated plots

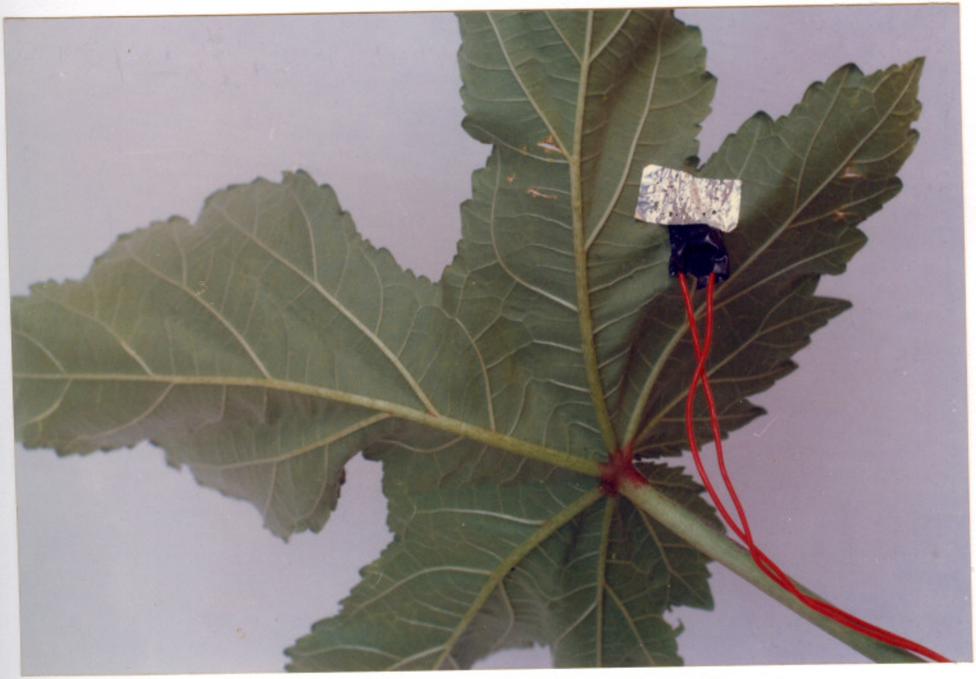
In order to compare the yield obtained from the two plots harvesting was done in an interval of one week. The yield ontained from each plot was weighed carefully.

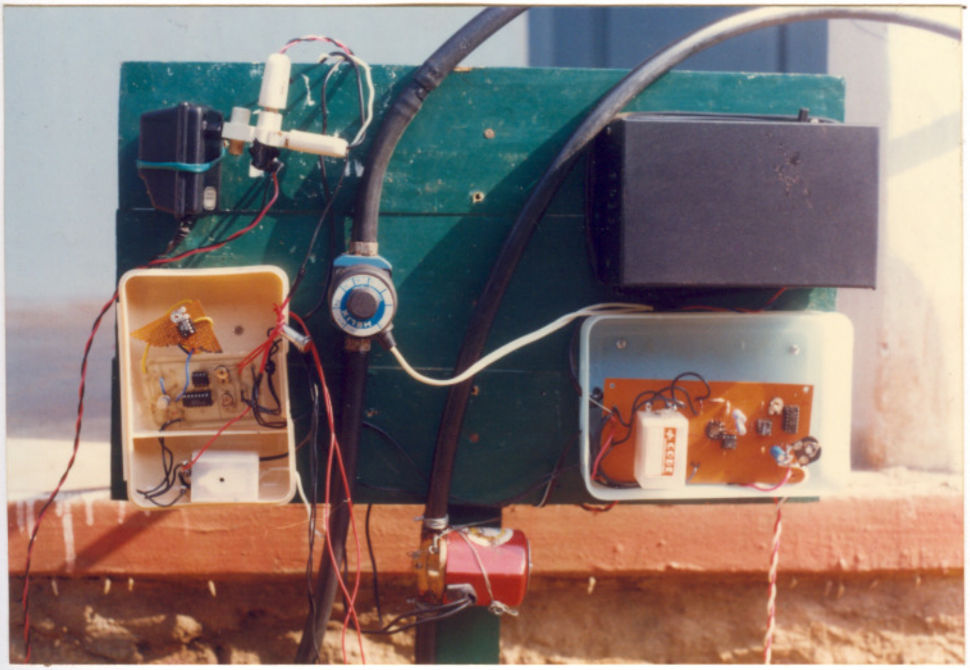
3.5.5. Dry matter content of plant from the automated plots

One plant from each of the automated plots were taken out carefully. After washing properly, the plants were dried by standard oven dry method. The dry weight of the plants were determined.









Chapter IV

RESULTS AND DISCUSSION

Automatic irrigation is a promising technique which help to apply the required amount of water when the plant needs it, thus facilitating water saving. Two automatic drip irrigation systems - one based on the electrical conductivity of the soil and the other based on the leaf-air temperature differential were developed. They were evaluated in two field plots, each of size 2m × 2m where Bhindi is grown. Different soil moisture sensors were fabricated and their performance were evaluated and based on this one was selected. The results of the experiment are explained in this chapter. A comparison between the two automatic irrigation systems were made and the results are presented in this chapter. A relationship between soil moisture content and leaf - air temperature differential for this selected crop is also presented.

4.1. Soil moisture sensors

The soil moisture sensor is an important component of the automated irrigation system based on soil electrical conductivity. Any physical or chemical changes within or around the sensor may affect the resistance across electrodes which in turn affects the sensitivity of the system. So extra care should be taken during the selection and installation of the sensor. The material for the fabrication of the electrode plate was selected after comparing the performance of three different materials. The porous medium filled between the electrodes was also selected in a similar way.

4.1.1. Selection of electrode plate material

Three different materials viz copper, stainless steel and brass were evaluated for selecting the electrode material of the soil moisture sensor. The performance curves for these materials are shown in Fig. 4.1, Fig. 4.2 and Fig. 4.3 respectively. The sensor having brass as electrode material clearly showed the desired inverse relationship of soil electrical resistance with moisture content. Copper and stainless steel showed much variation from the trend. So they were discarded and the brass was selected as the electrode material for the soil moisture sensor.

4.1.2. Selection of porous medium

Five different materials viz gypsum, soil in the field itself, sponge, nylon and washed sand were evaluated for selecting the porous medium. The material which showed a constant trend in the soil moisture content- electrical resistance relationships during the four replications was selected.

Gypsum block is used commercially for determining soil moisture content by measuring the electrical resistance across two electrodes. But the measurement of resistance in the field showed that when the polarity across the electrodes changed , the resistance readings had considerable variations. The performance curves of gypsum block for the four replications are shown in Fig. 4.4.

Brass plates were used as the electrode for the rest of the sensors tested. The sensor having soil in the field itself as the porous medium showed the same relationship between moisture content and electrical resistance in the first and second trials. During the third trial it showed a slight variation from the trend. The

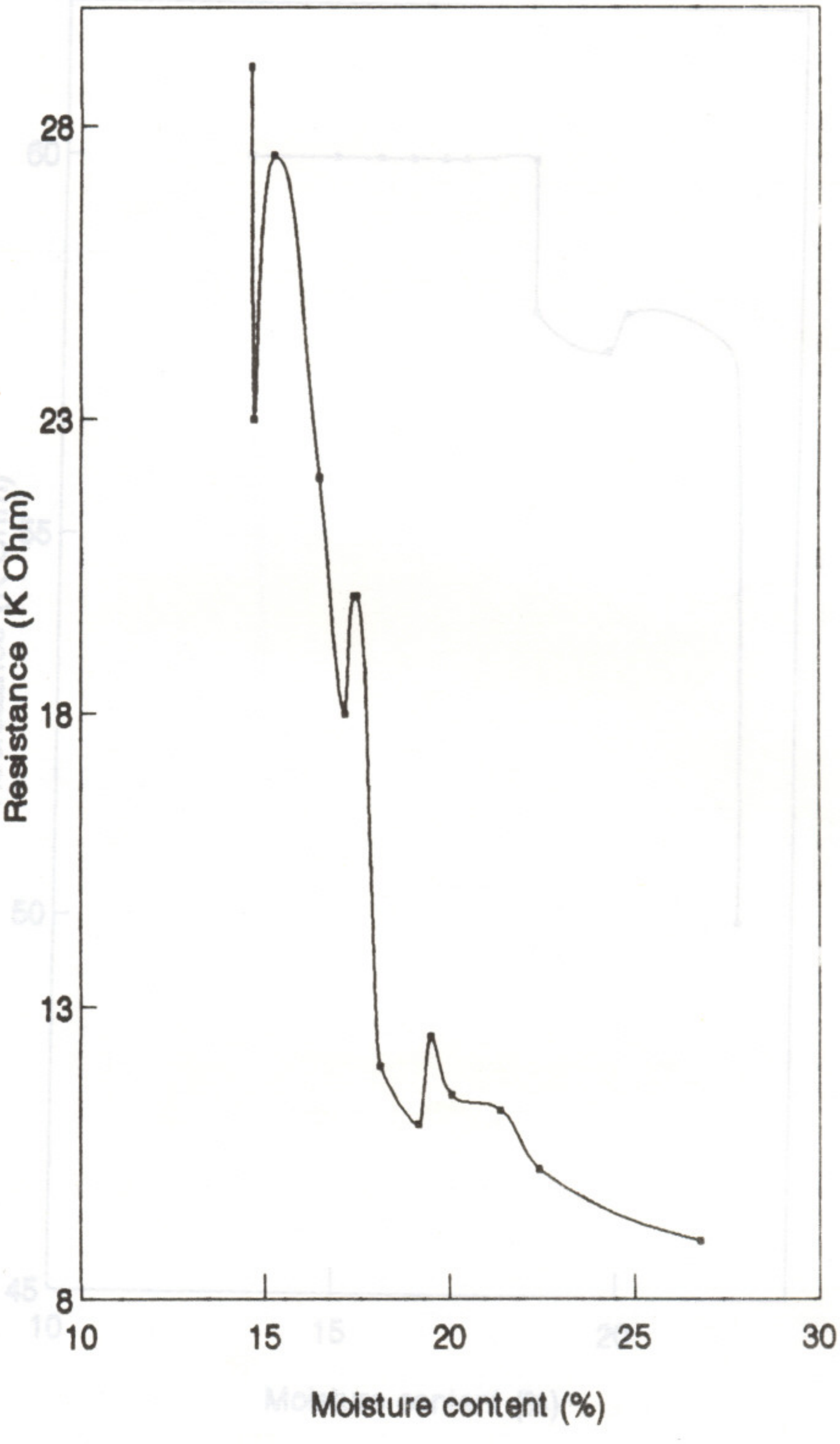


Fig. 4.1. Performance curve of copper as electrode material.

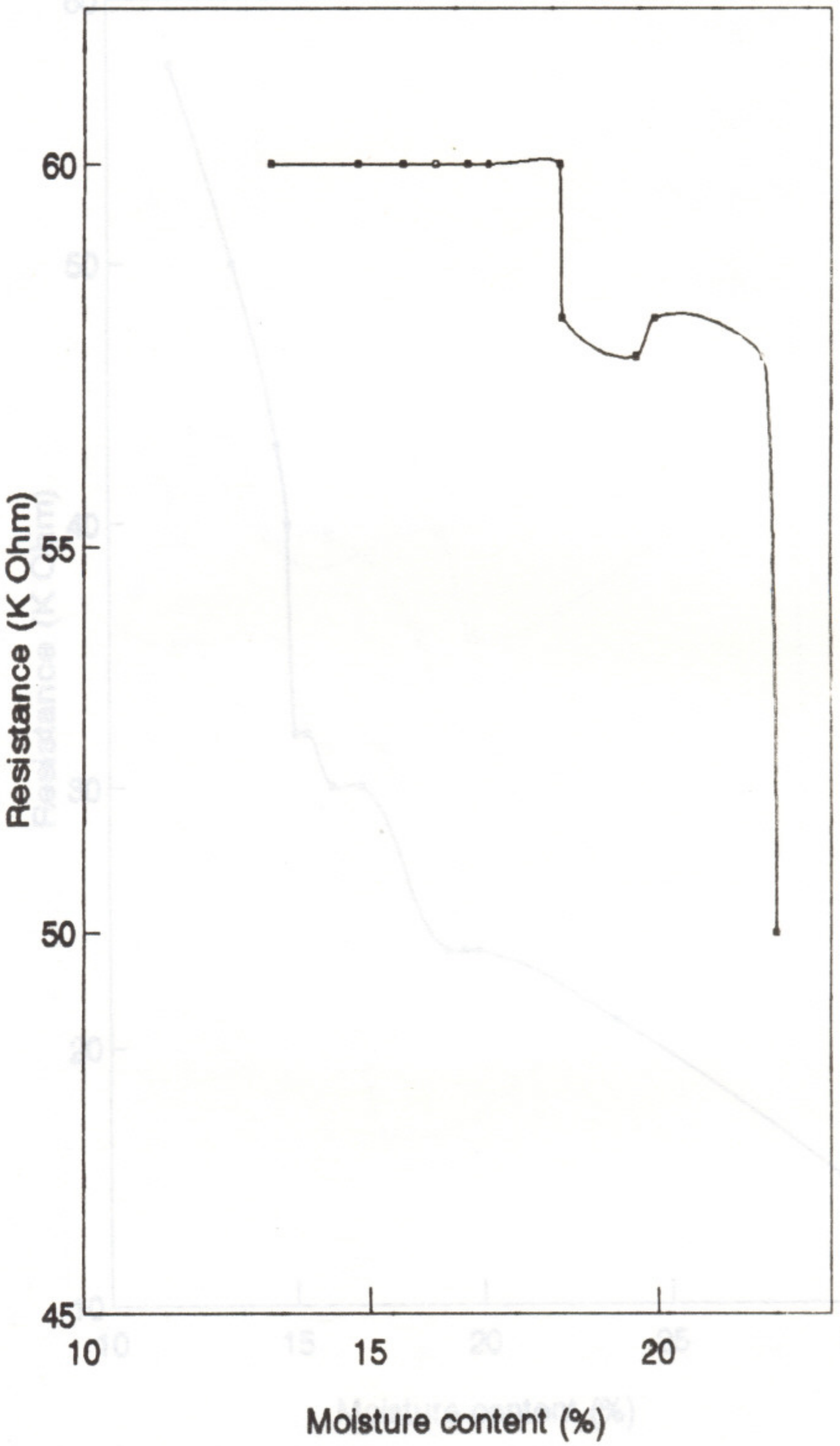


Fig. 4.2. Performance curve of stainless steel as electrode material.

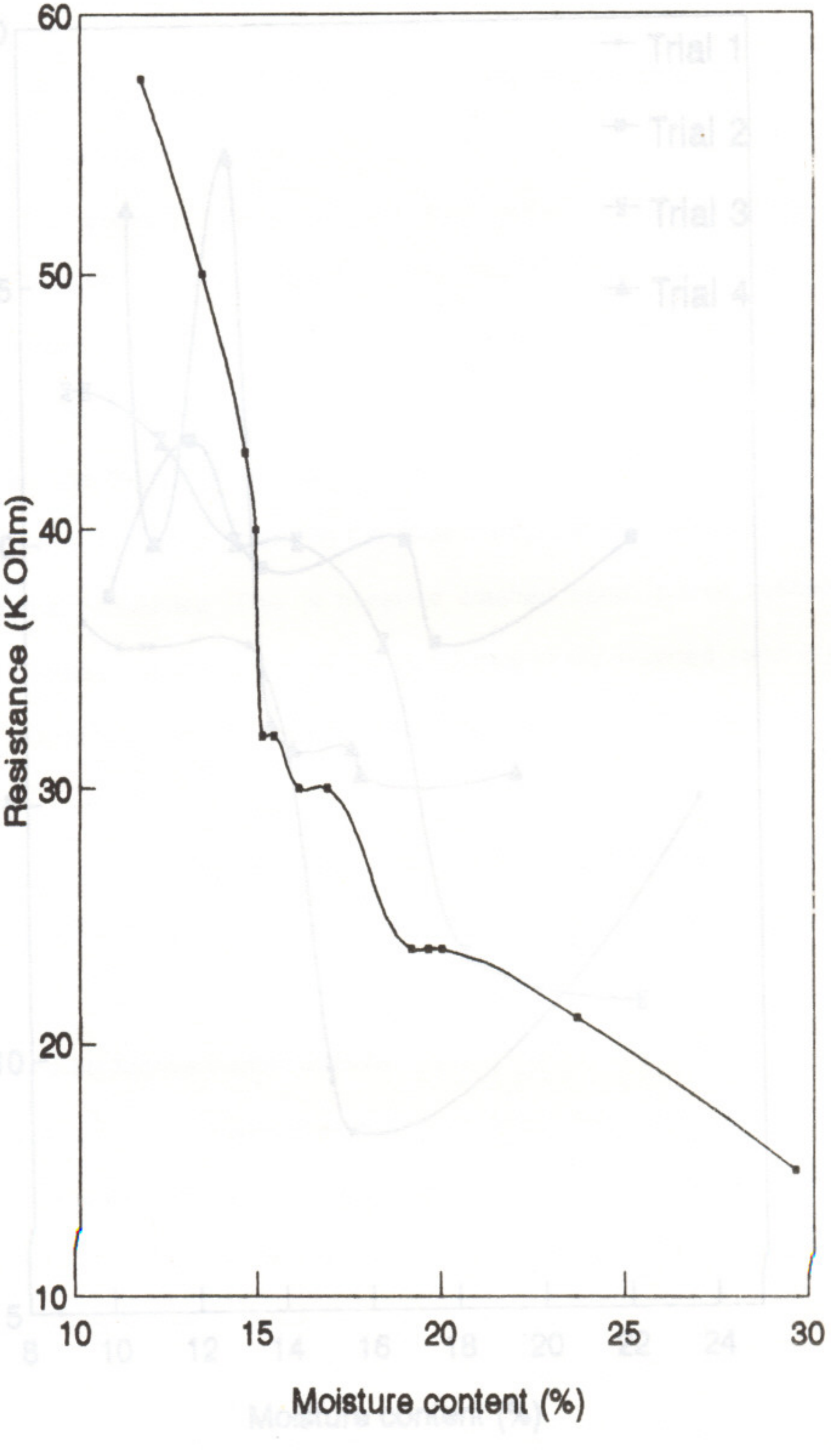


Fig. 4.3. Performance curve of brass as electrode material.

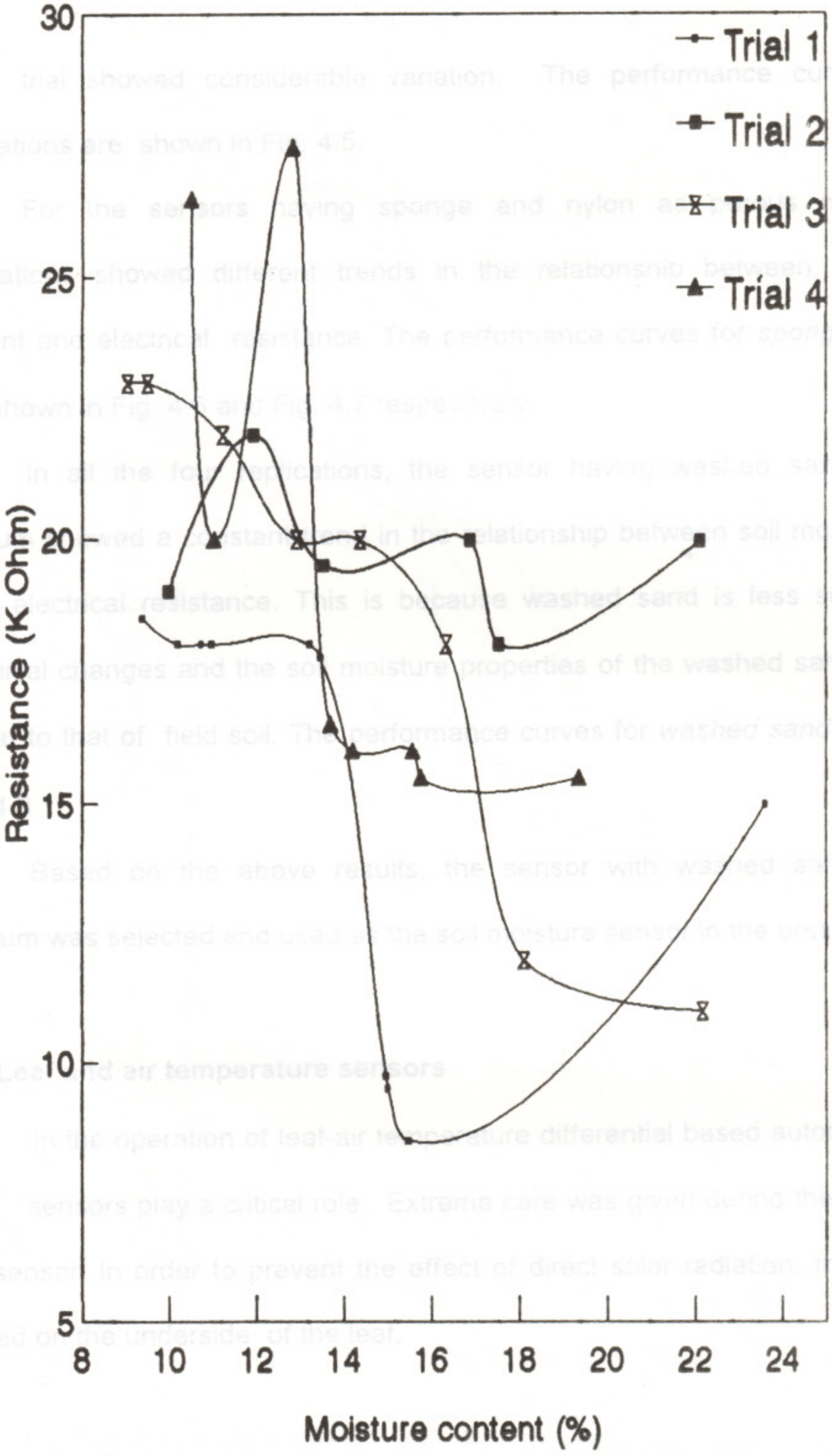


Fig. 4.4. Performance curve of gypsum as porous medium between electrode plates.

fourth trial showed considerable variation. The performance curves for four replications are shown in Fig. 4.5.

For the sensors having sponge and nylon as porous medium, four replications showed different trends in the relationship between soil moisture content and electrical resistance. The performance curves for *sponge* and *nylon* are shown in Fig. 4.6 and Fig. 4.7 respectively.

In all the four replications, the sensor having washed sand as porous medium showed a constant trend in the relationship between soil moisture content and electrical resistance. This is because washed sand is less susceptable to chemical changes and the soil moisture properties of the washed sand is probably similar to that of field soil. The performance curves for *washed sand* are shown in Fig. 4.8.

Based on the above results, the sensor with washed sand as porous medium was selected and used as the soil moisture sensor in the present study.

4.2. Leaf and air temperature sensors

In the operation of leaf-air temperature differential based automation system also, sensors play a critical role . Extreme care was given during the installation of the sensor. In order to prevent the effect of direct solar radiation, the sensor was placed on the underside of the leaf.

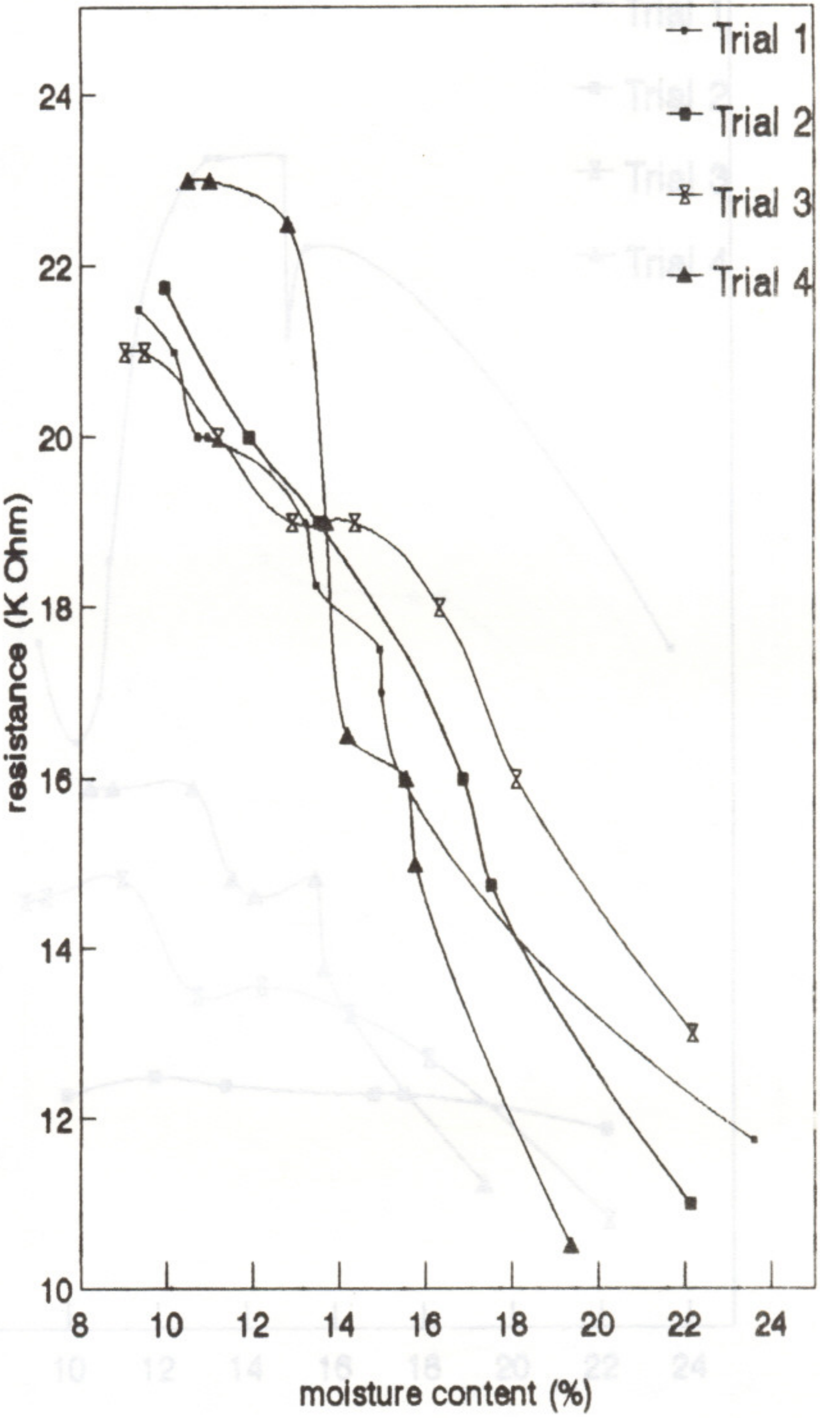


Fig. 4.5. Performance curve of Soil at field as porous medium.

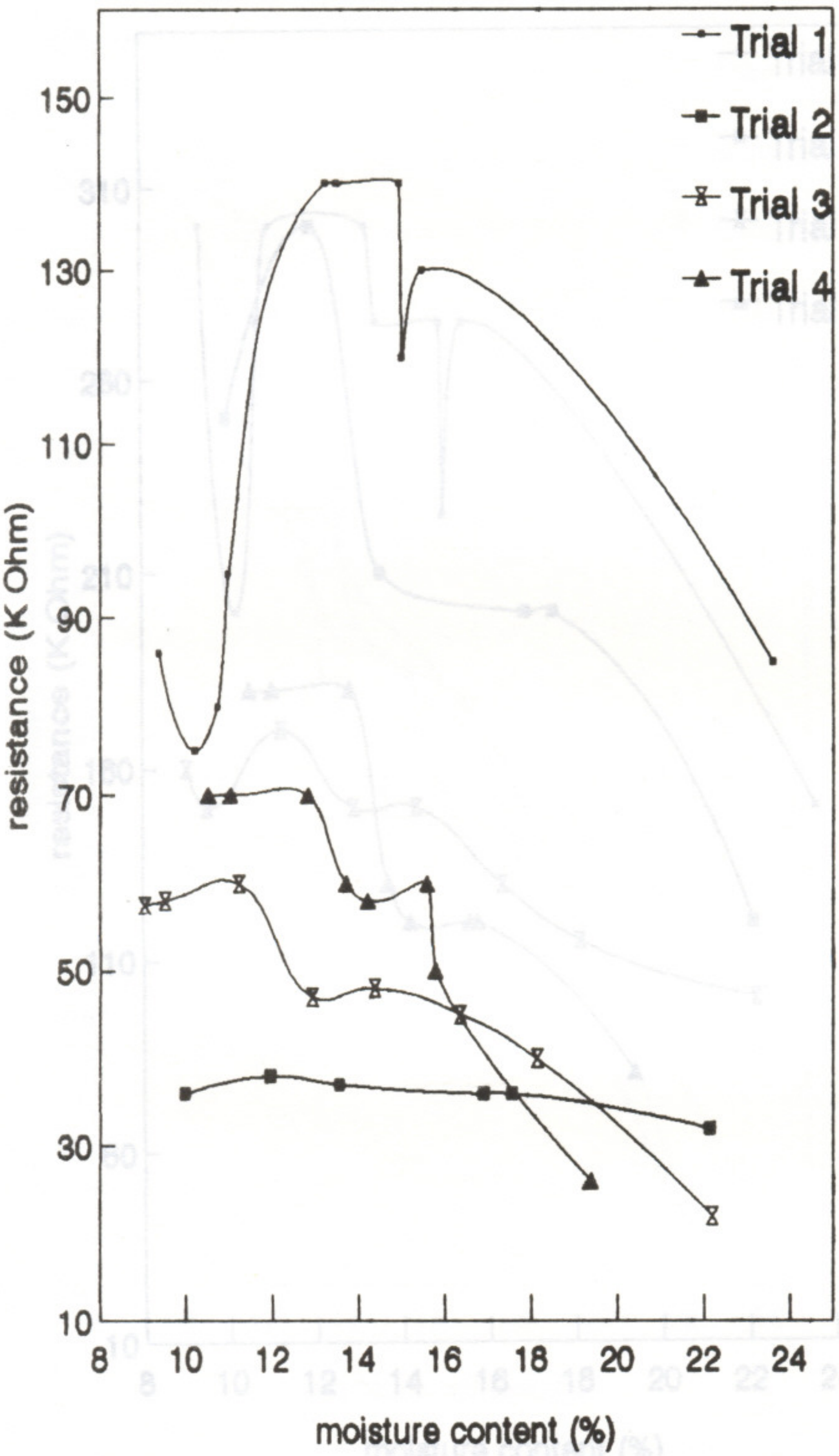


Fig. 4.6. Performance curve of sponge as porous medium.

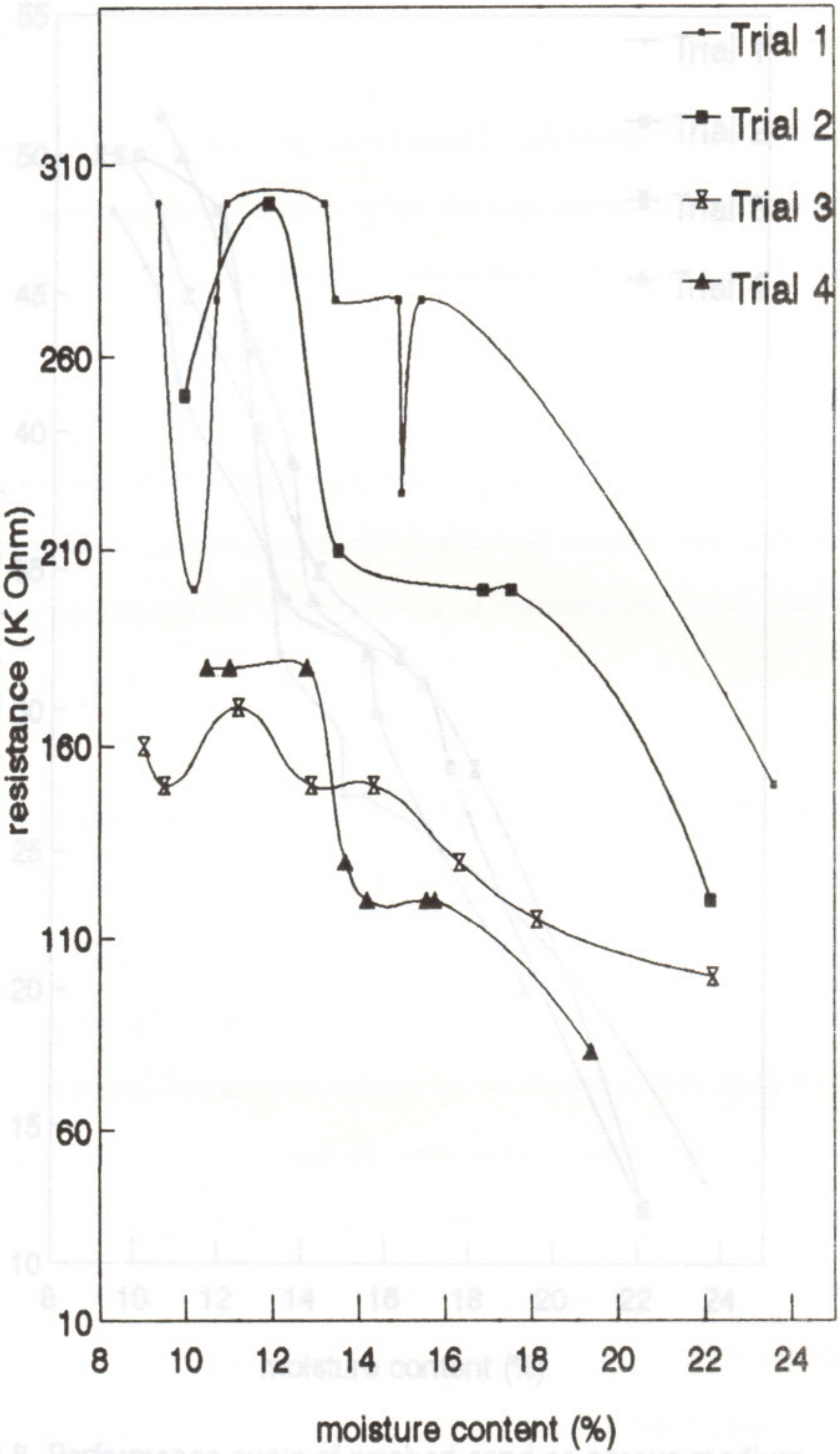


Fig. 4.7. Performance curve of nylon as porous medium.

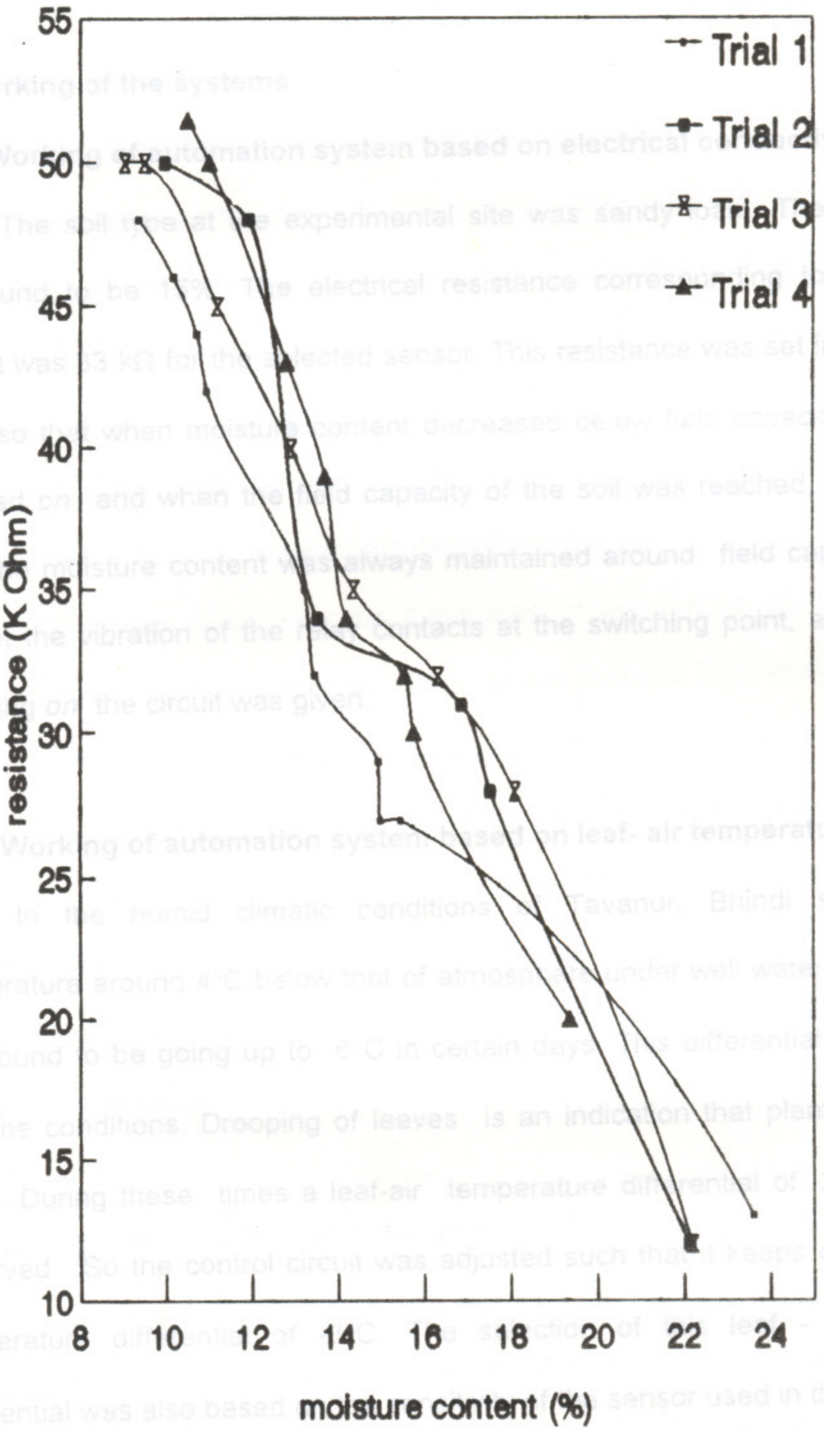


Fig. 4.8. Performance curve of washed sand as porous medium.

4.3. Working of the systems

4.3.1. Working of automation system based on electrical conductivity of soil

The soil type at the experimental site was sandy loam. The field capacity was found to be 15%. The electrical resistance corresponding to this moisture content was 33 kΩ for the selected sensor. This resistance was set in the switching circuit so that when moisture content decreased below field capacity, the system switched *on* and when the field capacity of the soil was reached, it switched *off*. Thus the moisture content was always maintained around field capacity level. To prevent the vibration of the relay contacts at the switching point, a time delay for switching *on* the circuit was given.

4.3.2. Working of automation system based on leaf- air temperature differential

In the humid climatic conditions of Tavanur, Bhindi showed a leaf temperature around 4°C below that of atmosphere under well watered conditions. It was found to be going up to 6°C in certain days. This differential became 0°C at extreme conditions. Drooping of leaves is an indication that plant is stressed for water. During these times a leaf-air temperature differential of -2°C or less was observed. So the control circuit was adjusted such that it keeps *on* at a leaf - air temperature differential of -3°C. The selection of this leaf - air temperature differential was also based on the sensitivity of the sensor used in this study.

This system was also installed during the same testing period. It was found that the system worked efficiently without frequent supervision and moisture content in the soil was maintained nearly a constant.

4.4. Testing of the automation systems

4.4.1 Automation system based on electrical conductivity of soil

The system was tested during the month of February to April, 1998 and was found to be efficiently working without frequent supervision. The testing was done by monitoring the moisture content three times a day. i.e. at 8.30 am, 12.30 pm and 3.30 pm. The variation of soil moisture content with time during the testing period is shown in Fig. 4.9. It can be seen that the moisture content remained nearly constant throughout the day. i.e. around field capacity of the soil.

About one week after the installation of the sensor, some deposits were found to form on the electrode plates which reduced the electrical conductivity between the electrode plates. This deposits may be due to the polarisation of certain ions present in the soil. The same trend was found immediately after the addition of fertilizers to the soil. Addition of fertilizers increases the ion content of the soil and thus causing more deposits on the electrode plates. The system was not working during the hours of power failure. No parallel arrangements were done during power failure.

4.4.2. Leaf - air temperature differential based automation system

To evaluate the system, soil moisture content and temperature of leaf and atmosphere were monitored three times a day. The moisture content- time relationship was plotted and is shown in Fig. 4.10. The system was found to keep the soil moisture content at a constant level but less than field capacity of the soil. The system always kept the temperature of the leaves below nearly 3°C from

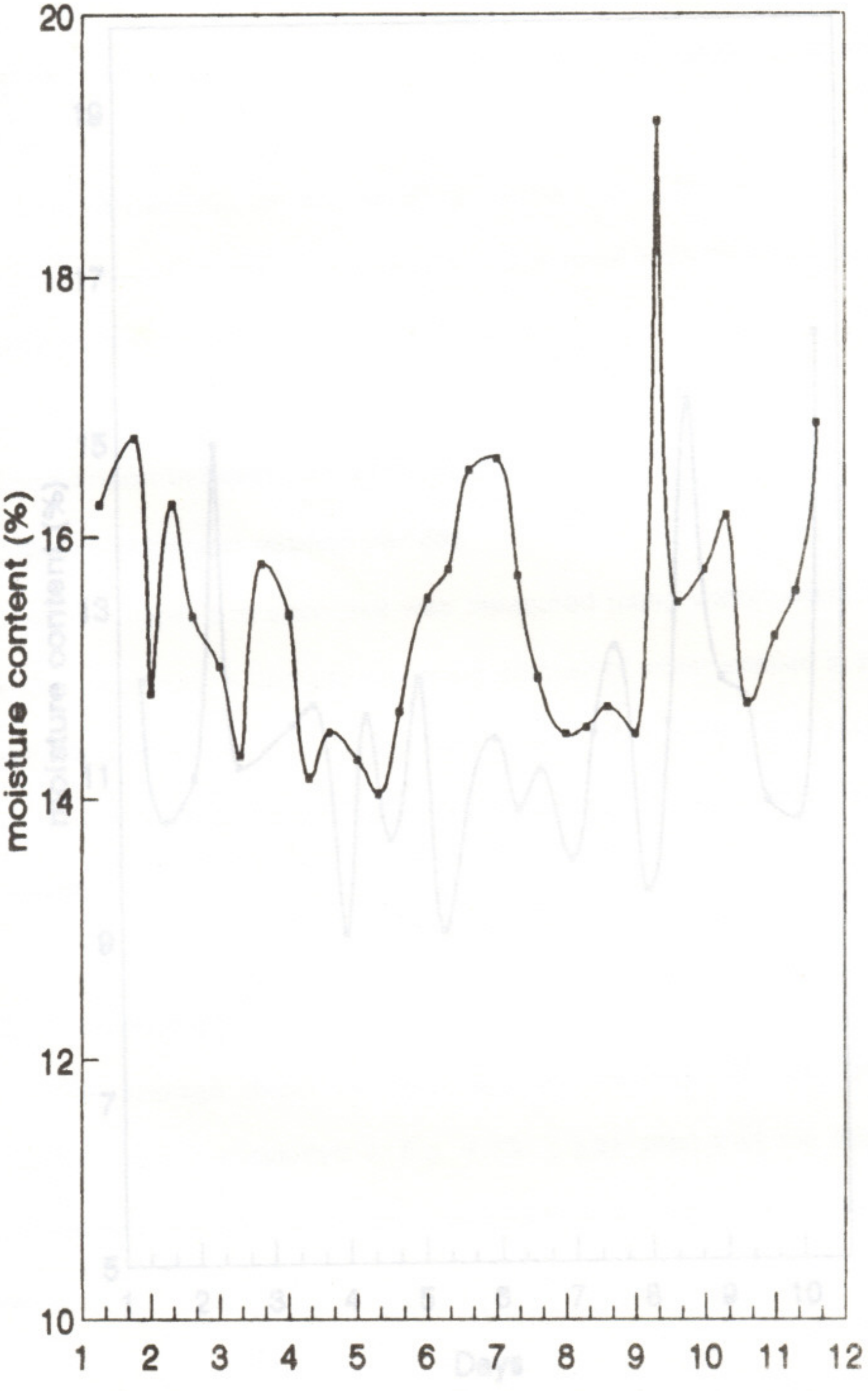


Fig. 4.9. Soil moisture status with time in plot 1.
(Automation based on soil electrical conductivity.)

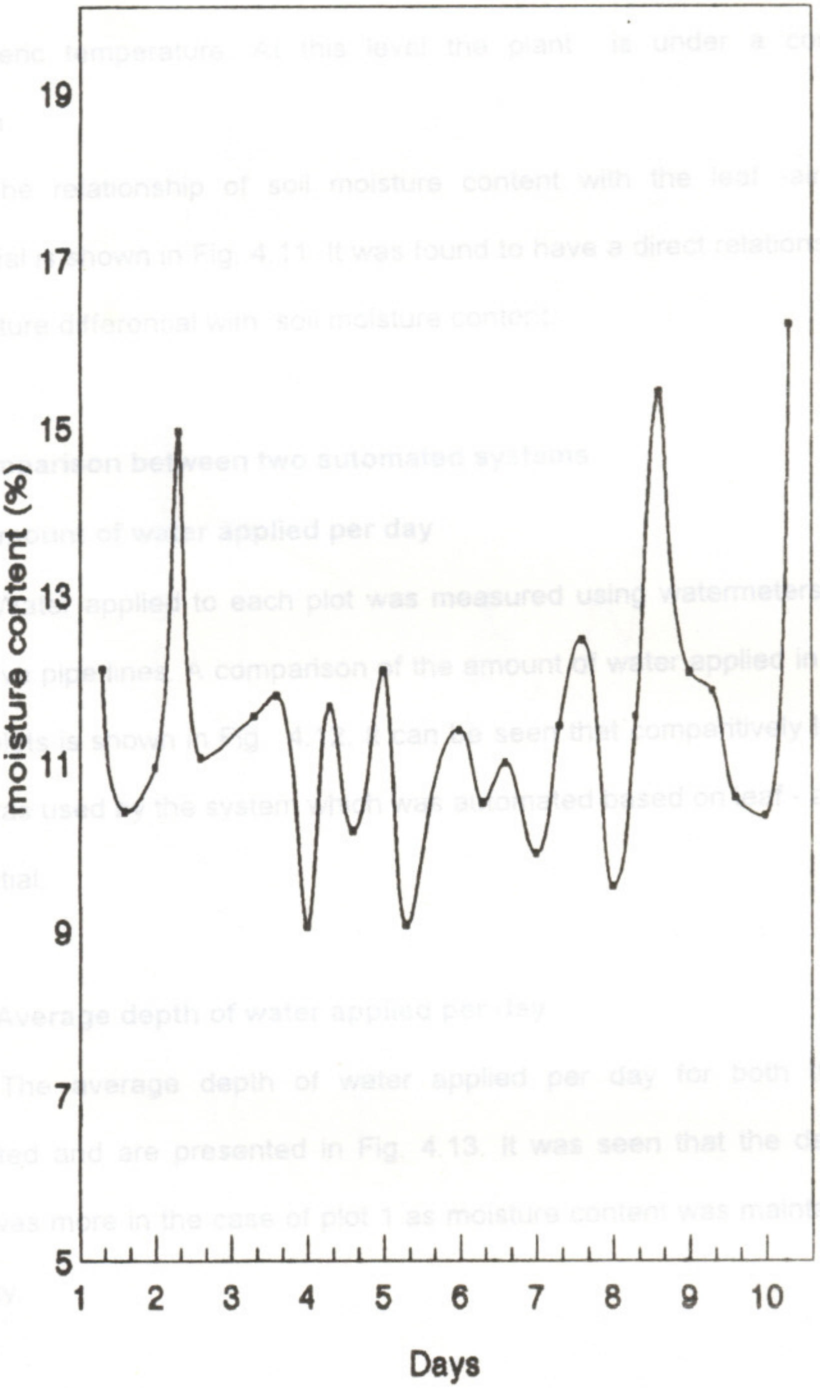


Fig. 4.10. Soil moisture status with time in plot 2.
(Automation based on leaf-air temperature differential)

atmospheric temperature. At this level the plant is under a constant stress condition.

The relationship of soil moisture content with the leaf -air temperature differential is shown in Fig. 4.11. It was found to have a direct relationship of leaf-air temperature differential with soil moisture content.

4.5. Comparison between two automated systems

4.5.1. Amount of water applied per day

Water applied to each plot was measured using watermeters connected in respective pipe lines. A comparison of the amount of water applied in different days in two plots is shown in Fig. 4.12. It can be seen that comparitively less amount of water was used by the system which was automated based on leaf - air temperature differential.

4.5.2 Average depth of water applied per day

The average depth of water applied per day for both the plots were calculated and are presented in Fig. 4.13. It was seen that the depth of applied water was more in the case of plot 1 as moisture content was maintained near field capacity.

4.5.3. Average yield obtained per week

The harvesting was done for the two automated plots in an interval of one week. The average yield per week for the plot 1 was 1.25 kg and that of the plot 2

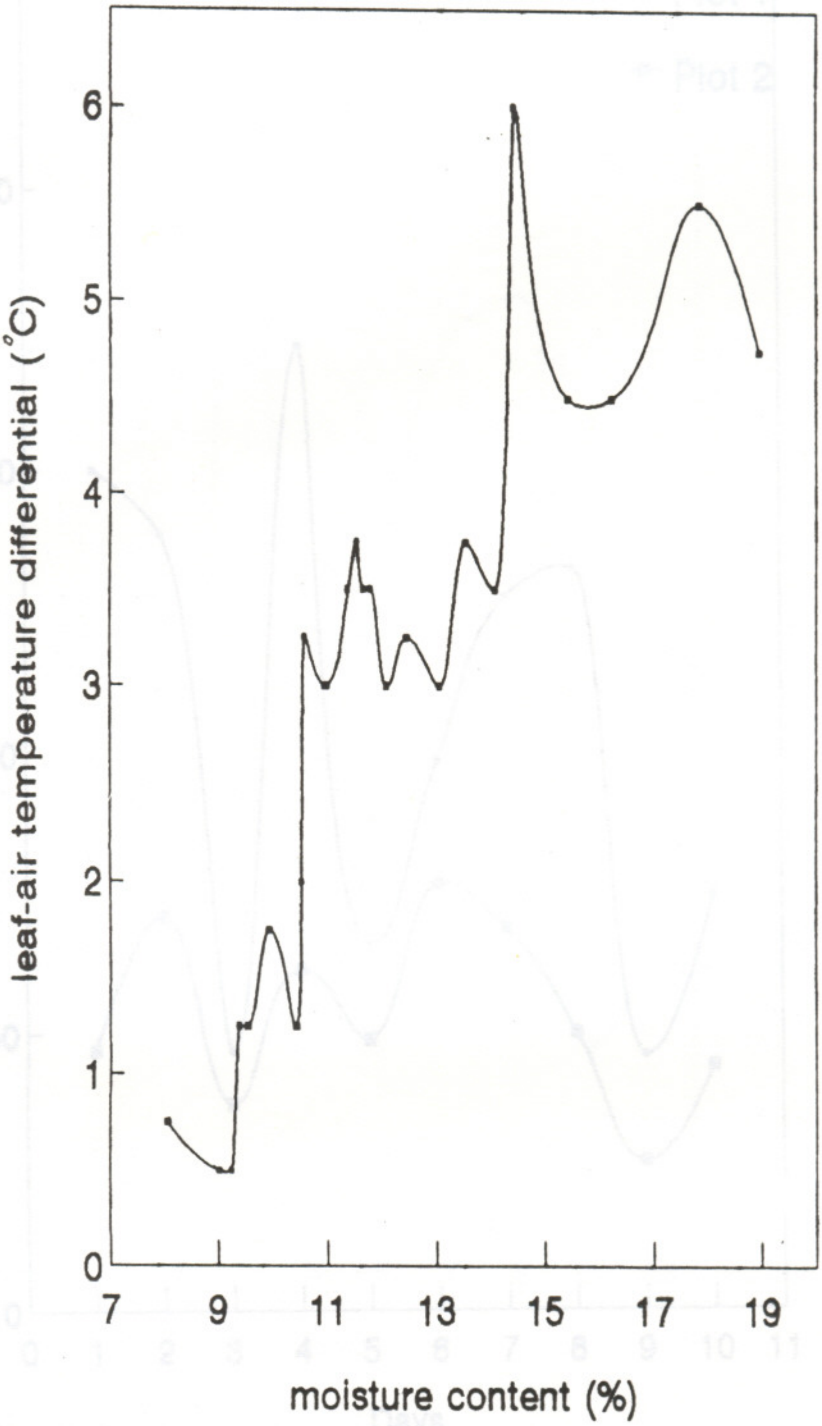


Fig. 4.11 Variation of leaf-air temperature differential with soil moisture status.

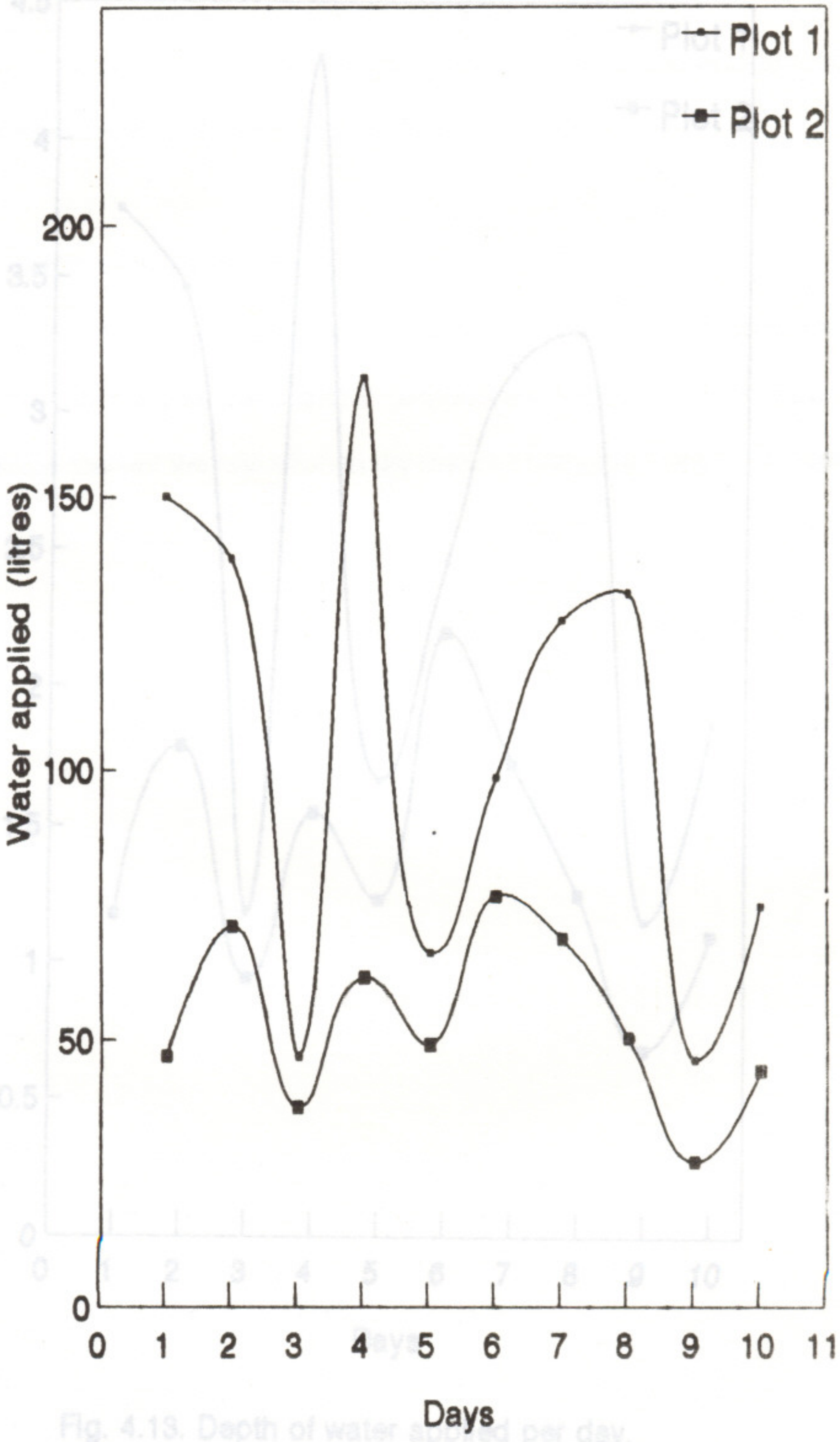


Fig. 4.12 Amount of water applied per day.

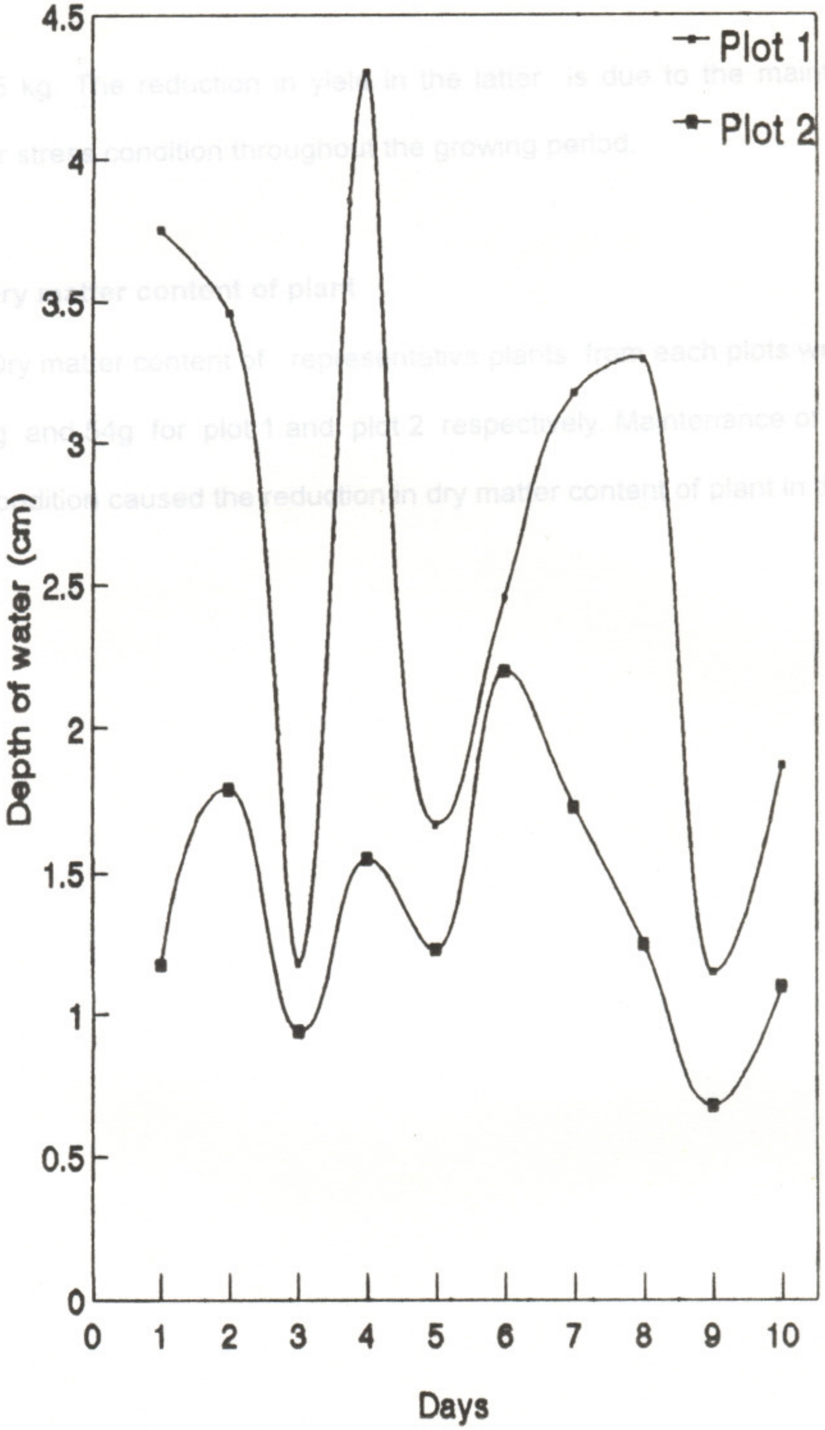


Fig. 4.13. Depth of water applied per day.

was 0.75 kg. The reduction in yield in the latter is due to the maintenance of a particular stress condition throughout the growing period.

4. 5.4. Dry matter content of plant

Dry matter content of representative plants from each plots were found to be 61.7g and 54g for plot 1 and plot 2 respectively. Maintenance of a particular stress condition caused the reduction in dry matter content of plant in the latter case.

Chapter V

SUMMARY AND CONCLUSIONS

A study was conducted to evaluate the electrical conductivity of the soil and leaf-air temperature differential as indicators for irrigation automation. Relationships between soil moisture content and electrical conductivity of soil; and soil moisture content and leaf - air temperature differential were evaluated. The study was conducted at Kelappaji College of Agricultural Engineering and Technology, Tavanur, Malappuram district, Kerala. The crop selected for this study was Bhindi *(Abelmoschus esculentus)*. The crop was planted in two plots, each of size 2m × 2m. An automated irrigation system based on electrical conductivity of soil and another system based on leaf - air temperature differential were installed in these two plots.

Soil moisture sensor is the important component of the automation system based on electrical conductivity of soil. To find the suitability of the electrode material of the sensor, three sensors with different electrode materials . i.e. copper, stainless steel and brass were tested. Also, to find the suitability of the porous medium between electrode plates of a sensor, five sensors. i.e. gypsum block and four others having brass plates as electrode material and soil in the field itself, sponge, nylon and washed sand as porous medium were tested.

The automation system based on electrical conductivity of soil consisted of a soil moisture sensor, switching circuit and an electrically operated solenoid valve. The sensor was placed in the root zone and based on the signal from the sensor the switching circuit in the control board was activated. The relay of switching circuit actuated the functioning of the solenoid valve which supplied water to the plot. As soon as the desired moisture content was reached, the switching circuit switched off the solenoid valve and terminated the water supply.

Button type thermistor served as the leaf as well as air temperature sensor in the automation system based on leaf - air temperature differential. The control system consisted of thermistors, switching circuit and solenoid valve. When the leaf - air temperature differential reached -3°C(the temperature at which the leaves started drooping) the circuit was activated ,which caused the opening of solenoid valve through the relay in the circuit.

The working of the two automated system were evaluated during the period from February to April 1998. From the two plots , soil moisture content was monitored three times a day. i.e. at 8.30 am,12.30 pm and 3.30 pm. Leaf as well as air temperature was also measured from the plot which is automated based on leaf - air temperature differential. The water delivered to each plots also monitored by water metres. Inorder to compare the performance of two automated systems, amount of water applied per day, average depth of water applied per day, yield per week and dry matter content of plant were calculated. The results are summarized as follows:

(1) The sensor having brass plate as electrode material showed a reliable relationship between soil moisture content and electrical resistance of the soil. the sensor with brass plate as electrode and washed sand as porous medium showed nearly a constant trend in the relationship between resistance and soil moisture content..

(2) The automated systems were found to be working efficiently for the testing period without frequent supervision. The moisture content of the fields maintained nearly a constant value. i.e. around field capacity value for the automated system based on the soil electrical conductivity and maintaining a particular stress condition in the automated system based on leaf - air temperature differential.

(3) The amount of water applied per day and average depth of water per day were found to be less in the automated system based on leaf - air temperature differential. Yield per week and dry matter content of plant were also reduced in this system. The reduction was due to the maintenance of a particular stress condition throughout the growing period.

Suggestions for future work

The installation of a single sensor in the root zone of the plant may not be representing the soil moisture status of the entire field. A number of sensors can be installed spreading at different locations in the field and at different depths in the root zone of the same plant. All these sensors are to be connected either in series or in parallel to a single point in the control circuit.The effective resistance of the network at field capacity has to be found out and the same should be set at the control circuit. The system will switch *on* at this resistance.

The 9V dc used for driving the control circuit was found to be inducing polarisation of ions at the electrode plates of the sensor. So the use of either alternating current or a device to alternate the direction of current flow intermittently *across the sensor plates is recommen*ded in further studies.

A number of temperature sensors can be used as a network, either in series or in parallel located on different plants. All the leaf temperature sensors are to be connected to one point and all the air temperature sensors to another point in the circuit. This will give a true representation of plant water status of entire field. Thermistors used as temperature sensors in this study had less sensitivity. For the accurate maintainence of the automation system, temperature sensors having high sensitivity are recommended.

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APPENDIX I

Cost of switching circuit for the automation system
based on soil electrical conductivity

Circuit Components	Notation	Quantity (No.)	Rate (Rs)	Price (Rs)
Variable resistance	VR (100 K)	2	1.50	3.00
Variable resistance	VR(470 K)	1	3.00	3.00
Diode	D IN4148	2	1.00	2.00
Resistance	R (8.2 K)	1	1.00	1.00
Resistance	R (27 K)	2	1.00	2.00
Integrated circuit	IC CD4011	1	16.00	16.00
Integrated circuit	IC NE555	2	8.00	16.00
Capacitor	C (220μ,16V)	1	6.00	6.00
Capacitor	C (0.01μ)	2	1.00	2.00
Capacitor	C (100μ,16V)	1	4.00	4.00
Capacitor	C (10μ,16V)	1	2.00	2.00
Transistor	T SK100	1	16.00	16.00
Relay	RL (6V,150Ω)	1	35.00	35.00

Total = 108/-

APPENDIX II

Cost of switching circuit for the automation system based on leaf temperature

Circuit Components	Notation	Quantity (No.)	Rate (Rs)	Price (Rs.)
Variable resistance	VR (2.2 K)	2	1.00	2.00
Variable resistance	VR (470 K)	1	3.00	3.00
Thermistor	RTH (1 K)	1	8.00	8.00
Thermistor	RTH (2 K)	1	10.00	10.00
Integrated circuit	IC 741	1	12.00	12.00
Integrated circuit	IC CD4011	1	16.00	16.00
Integrated circuit	IC NE555	1	8.00	8.00
Capacitor	C (220µ 16V)	1	6.00	6.00
Capacitor	C (0.01µ)	1	1.00	1.00
Diode	D IN4148	1	1.00	1.00
Resistance	R (15 K)	1	1.00	1.00
Transistor	T CL100	1	16.00	16.00
Relay	RL (6V 150Ω)	1	35.00	35.00

Total = 119/-

IRRIGATION AUTOMATION BASED ON SOIL ELECTRICAL CONDUCTIVITY AND LEAF TEMPERATURE

by

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ABSTRACT OF THE PROJECT REPORT

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ABSTRACT

Two automated drip irrigation systems - one based on soil electrical conductivity and the other based on leaf temperature were developed and tested for Bhindi (*Abelmoschus esculentus).* The most important component of both systems is the sensor. The soil moisture sensor consists of two electrode plates kept at a particular distance with a porous medium filled in between them to measure the soil electrical resistance. The sensor is selected based on the studies on the performance of different electrode materials and porous medium. The sensor with brass electrode material and washed sand as porous medium was selected for the present study. A low cost commercially available thermistor was used as the leaf and air temperature sensor.

The automated irrigation system based on soil electrical conductivity was adjusted to keep the soil moisture at field capacity level and system based on leaf temperature was adjusted to keep the plants at a constant stress condition. During the testing period, both the systems were found to be working satisfactorily without frequent supervision. The amount of water applied per day, depth of water applied per day, yield per week and dry matter content of plant were found to be less in the plot in which irrigation is automated based on leaf temperature. This is due to the maintenance of a constant stress condition in this plot.