DESIGN, DEVELOPMENT AND EVALUATION OF AN AUTOMATED LOWTUNNEL FOR HI-TECH AGRICULTURE

AISWARYA L (2013-02-002)

SHILPA S SELVAN (2013-02-038)

PROJECT REPORT

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Department of Land & Water Resources and Conservation Engineering

Kelappaji College of Agricultural Engineering & Technology, Tavanur,

Malappuram –679 573. Kerala, India

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DECLARATION

We hereby declare that, this project entitled **"DESIGN, DEVELOPMENT AND EVALUATION OF AN AUTOMATED LOW TUNNEL FOR HI-TECH AGRICULTURE**" is a bonafide record of project work done by us during the course of study, and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

AISWARYA L (2013-02-002)

SHILPA S SELVAN (2013-02-038)

Place: Tavanur

Date: 26-02-2017

CERTIFICATE

Certified that this project entitled **"DESIGN, DEVELOPMENT AND EVALUATION OF AN AUTOMATED LOW TUNNEL FOR HI-TECH AGRICULTURE"** is a record of project work done jointly by Aiswarya, L. and Shilpa S. Selvan under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of another University or Society.

Dr. Abdul Hakkim, V.M.
Professor & Head
Dept. of LWRCE
KCAET, Tavanur

Place: Tavanur
Date: 26-02-2017

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Aiswarya L

Shilpa S Selvan

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SYMBOLS AND ABBREVIATIONS

Agrl.Engg	Agricultural Engineering
A R S	Agricultural Research Station
ARM	Advanced RISC Machine
ATMA	Agricultural Technology Management Agency
° C	Degree Celsius
CO2	Carbon dioxide
Cm	Centimetres
Dept.	Department
e.g.	Example
et al.	And others
° F	Degree Fahrenheit
ft.	Feet
g	gram
ha	Hectare
ha-cm	Hectare Centimetres
hr	Hour
Hz	Hertz
KCAET	Kelppaji College of Agricultural Engineering and Technology

kg/ha	Kilogram per hectare
$kg/ha.m^3$	Kilogram per hectare cubic metre
kPa	Kilo Pascal
l/h	Litre per Hour
l/s	Litre per second
MCU	Micro Controller Unit
Min	Minute
mm	milli metre
pH	Potential of hydrogen
rpm	Revolutions per minute
SIS	scientific irrigation scheduling.
%	Percentage
WSN	Wireless Sensor Networks

CHAPTER 1

INTRODUCTION

Agriculture is the backbone of India's economic activity and our experience during the past 50 years has demonstrated the strong correlation between agricultural growth and economic prosperity. The present agricultural scenario is a mix of outstanding achievements and missed opportunities. If India has to emerge as an economic power in the world, our agricultural productivity should equal those countries, which are currently rated as economic power of the world. We need a new and effective technology which can improve continuously the productivity, profitability and sustainability of our major farming systems.

For a plant of given genetic make-up the factors that affect the plant growth are light, water, temperature, air composition and nature of the growing medium. Light reaching the surface of a plant is either as absorbed, reflected or transmitted. energy, in the form of sunlight is one of the driving forces in the chemical reaction known as photosynthesis. Photosynthesis is the process by which green plants manufacture food, mainly sugars, from carbon dioxide and water in the presence of chlorophyll (a green pigment), utilizing light energy and releasing oxygen and water. Together the quality, quantity and duration of light influence plant growth. Plants grown under direct sunlight are typically compact, whereas those grown under shade are taller and elongated. Seeds may start to grow (germinate) without light, but the plant growing from it must have light if it is to continue to grow

Water is essential for life, which is one of the most important requirements for plant growth. Water is the main component in the plant cells, that keeps the plant turgid (stiff) and is used in photosynthesis and transports nutrients throughout the plant. Plants also use water to lower leaf temperature, increase mineral absorption, and pull water from the roots to the top of the plants through a process known as transpiration.

Plants grow well only within a limited temperature range and a seed will only germinate at the right temperature. This is usually between 10-45°C, although some seeds need higher temperatures. The plant will only grow if the temperature is over 6°C and cold, frosty conditions can seriously damage plant growth. Extremely hot conditions of 40°C plus can cause stress to a plant particularly with a hot dry wind. Certain vegetable crops will only grow in cooler times of the year in some tropical countries.

The two primary reasons that plants need air are for photosynthesize (make food) and respiration. One of the raw materials used in photosynthesis is carbon dioxide. The content of carbon dioxide in the atmosphere is relatively stable at about 0.03 %. Carbon dioxide is continually being added to the air through respiration of plants and animals, decaying organic materials, combustion of fuels, and volcanic activity. Wind is air in motion and can be both beneficial and harmful to plants. Wind can benefit plants by accelerating the transfer of heat from leaf surfaces and increasing circulation in areas prone to fungal growth. Wind can be detrimental to plants by causing excessive drying, scattering of weed seeds, and sometimes destroying plants.

Soil serves as a medium for supporting plant growth and development. Its properties influence fertility, water relations, gas exchange, and physical support of plant roots.In addition to carbon dioxide and water, plants need 17 different nutrients to maintain growth. Although carbon, oxygen, and hydrogen are obtained from the air, most nutrients that a plant needs must be present in the soil or growing medium. These elements are divided into macro and micro elements. Macro nutrients needed in the largest amounts are nitrogen (N) for healthy foliage, phosphorus (P) for flower development, and potassium (K) for root growth.

Environmental factors affecting plant growth has to be suitably modified to maximize production leading to optimum productivity. To obtain maximum yield with minimum use of resources many modern agricultural techniques have been introduced, which gives better results than traditional methods. Protected cultivation is one such method to modify the natural environment to achieve optimum plant growth. Modifications can be made to both the aerial and root environments to increase crop yields, extend the growing season and permit plant growth during periods of the year not commonly used to grow open field crops.

Production of vegetables under protected condition is the best alternative to use the land and other resources more efficiently under changing climatic scenario. By adapting protected cultivation, year round availability of quality vegetables both for domestic use and export can be assured. Protected cultivation means some level of control over plant microclimate to alleviate one or more of abiotic stressfor optimum plant growth, which can be achieved ingreen houses, poly hoses, net house, poly-tunnels, cold frames, etc. Crop yields under these structurescan be several times higher than those of openfield conditions. Quality of produce is also superiorand input use efficiencies are usually higher undersuch structures.In many European Countries, USA, Japan, China, Israel, Morocco, Turkey etc., whereextreme climate reduces the choices for year round outdoor production, and vegetables are being produced in protected environments. India has entered into the area of greenhouse vegetablecultivation recently and the total area underprotected vegetable production is around 10,000 ha.

One method of protection is a low tunnel. Low tunnels are essentially miniature versions of high tunnels, usually two to four feet tall at their peak and four to six feet wide. Length varies, but less than 50 feet is recommended for windy areas. Unlike high tunnels, low tunnels are moved seasonally, lack much of the structural support offered by high tunnels, and have plastic weighted down to the ground or buried (rather than attached to the structure). They may be used within high tunnels (decreasing or negating the issue of wind), or on their own out in the field.

Low tunnels can provide a cost-effective investment option for those seeking an entry point to polytunnel production or for those wishing to enhance their current polytunnel production capacity. Low tunnels offer an alternative form of crop protection and season extension that may work even better than a high tunnel for some growers and in certain situations.

As with high tunnels, appropriate crops for winter production in low tunnels include: spinach, kale, collards, chard, leeks, scallions, carrots, parsnips, cabbage, Asian greens, parsley and arugula. Many other crops may not survive the entire winter in a low tunnel, but they can be pushed well beyond the first frost, often all the way to the New Year and their season can begin much earlier than traditional planting.

Unlike high tunnels, these low cost structures can be dissembled, moved throughout the farm, and work with the contours of the land. Similar to high tunnels, plastic covered low tunnels provide crops with several degrees of cold protection at night, but due to their smaller stature low tunnels heat up rapidly on sunny days, even if outdoor temperatures remain low.

Low tunnels have their own unique set of challenges. Because one can't stand-up in low tunnels, one must partially remove the covering to access crops which can make it difficult for harvesting or weeding in high wind, rain, snow or sub-zero temperatures. Low tunnel construction and dismantling must be done annually and is labour intensive.

Low tunnels modify microclimate by raising soil and air temperatures. In general, low tunnels allow shortwave solar radiation to pass through during the day and the plastic material slows long wave radiation from the surface at night. The heat that is absorbed could not easily be passed down into the soil because of the insulation of the air between the low tunnel, black plastic mulch, and the soils surface. The interior microclimate is further modified as the tunnel material slows convective mixing over the covered surface, reducing both sensible and latent energy losses from the surface (any condensation that does occur on the plastic will release latent heat and warm the plastic) and increasing the ground heat flux. Additional control over the interior microclimate is possible by changing the colour of the tunnel material (e.g. clear low tunnel plastic has a lower albedo than white plastic, and is moretransparent to incoming solar radiation resulting in a potentially warmer environment) or by perforating the top or sides of the tunnel to increase convective heat exchange with the surface.

Row covers or low tunnels can modify crop microclimate by raising temperature and promoting earlier plant growth. By using beds covered with black plastic mulch together with low tunnels, soil temperatures can be increased, weeds can be controlled, water can be conserved and fertilizer application is optimized. Plastic materials used for row covers are available in different colours, which impact the light quality and temperatures inside the tunnels. However, it is unknown which low tunnel colour, type, or configuration will provide the most protection and growth enhancement in temperate climates.

The current system of protected cultivation in India needs overhaul in terms of technological improvements. To fully exploit the enhanced possibilities for crop and resource management in greenhouses, it is indispensable to perform the adjustment of the control variables in an automatic way. This is because it is almost impossible for human being to understand and manipulate system with more than two dependent processes without additional aid. Hence the introduction of automatic controllers and computer-controlled greenhouses in the second half of the twentieth century was a major step forward to economically attractive crop production.

Even the most basic automatic control will enhance the capacities of the greenhouse industry in emerging greenhouse areas all over the world. There is a need to find balance between the cost of investment that goes into process of cultivation and the returns obtained, at the same reducing the complexity and making the system easily accessible to farmers. One such approach is the practice of polyhouse farming, which encompasses the optimal control of greenhouse cultivation. This asset allows the grower to steer the cultivation in the desired direction.

Water is very crucial component for vegetable production. Vegetables require timely and adequate irrigation for proper growth which should be managed properly through microirrigation system so as to promote utilization of each drop and to check the wastage of such critical input. Further, micro irrigation methods are promising methods for applying fertilizers at root zone of the crops. Drip irrigation is the slow and precise delivery of water to the plants. It uses flexible polyethylene tubing with devices for dripping water (emitters) and low-volume sprays. The systems are easy to install, require no trenching and the only tools needed are pruning shears and a punch. Drip irrigation maintains near-perfect moisture levels in the root zone of plants, avoiding the too wet/too dry swings typical of overhead watering. Drip systems are controlled by hand or by an automatic timer and can also be used to apply fertilizers directly to the roots of plants.

During past two decades, many experiments have been conducted at various levels for the design 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 performance could be used to develop automated drip irrigation systems which can restrain 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, increases production, reduces 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 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.

Instead of soil, a mix of cow dung, coco peat, sand and soil can be used with external supply of nutrients. Cow dung manure is a nutrient-rich fertilizer, because of its satisfactory level of nutrients and fertile efficiency and contains high levels of ammonia which is potentially dangerous for pathogens. Composted cow manure fertilizer provides an excellent growing medium for low tunnel. Cow manure also contains beneficial bacteria, which convert nutrients into easily accessible forms so they can be slowly released without burning tender plant roots. Coco peat is eco –friendly, having high water retention capacity, improves aeration, reduces water consumption (save 70 % water) and produces a better yield. It retains water and feed the plant according to its need .It also helps better root development and enhances plant growth. It retains the fertilizer added to the plant instead of going waste. The water retention capacity of coco peat makes it more suitable for humid and dry conditions due to slow water releasing capacity. Sand is least expensive and cheaply available material. It does not hold much water so it helpful to drain, if excess water is present in the media.

An automated low tunnel with a soil moisture sensor, temperature controller and inlet and exhaust fans for controlling the environmental factors will be beneficial for growing plants under extreme weather conditions and to reduce man power requirement. With the help of automation, minimum and effective use of valuable resources can lead to achieve maximum benefit cost ratio.

The main objective of the present study is design, development and evaluation of an automated low tunnel for hi-tech agriculture. The specific objectives are:

- To design and develop an automated low tunnel suitable for hi-tech farming.
- To evaluate the performance of the structure developed without crop.
- To compare the performance of the automated low tunnel developed with a non- automated low tunnel by growing amaranths crop.

CHAPTER 2

REVIEW OF LITERATURE

High demand of fresh vegetables is generated in the domestic and export market throughout the year. But due to unfavourable climatic conditions, there is a flood of vegetables during its season and very high priced vegetables during off-season. Vegetables can be cultivated during off-season, with the induction of artificial techniques like greenhouses, low and high poly tunnels technology, in which temperature and moisture are controlled for specific growth of vegetables. Presently, river bed cultivation is in practice for production of cucurbitaceous vegetables during off-season in northern parts of our country, although area under river bed cultivation is very limited, which cannot be extended further, but with the use of protective structures such as row covers or low tunnels vegetable crops like muskmelon, watermelon, long melon, round melon, bitter gourd, bottle gourd, summer squash etc. can be grown very early in the spring or summer season. Low tunnels are essentially miniature versions of high tunnels, usually two to four feet tall at their peak and four to six feet wide. Length varies, but less than 50 feet is recommended for windy areas. Unlike high tunnels, low tunnels can be moved seasonally; lack much of the structural support offered by high tunnels and have plastic weighted down to the ground or buried (rather than attached to the structure). They may be used within high tunnels (decreasing or negating the issue of wind), or on their own out in the field.

Some studies have shown inconsistencies in growth and yield results for Solanaceous crop (tomato, cucumber etc.) species under row covers (Reiners et al. 1997, Peterson and Taber, 1991, Sotani et al. 1995). Seasonal variations in yield may be caused by later planting dates correspond to high temperature fluctuations that negatively affect growth and development (Reiners et al. 1997). High temperatures above 40°C for 3 consecutive hours or more increased flower abortion, which decreased tomato early and total yields under row covers (Peterson and Taber, 1991). Cucurbits species have responded more favourably to row covers than Solanaceous species (Sotani et al. 1995).

Ladakh, the cold arid region of Jammu and Kashmir State experiences prolonged severe winters and has a short cropping season starting from last week of March to last week of September in double cropped areas and from first week of May to Last week of August in mono=cropped areas. Due to high altitude the intensity of solar radiation and long photoperiod (12 to 14 h) is good enough to support crop growth but the aridity and speedy wind dips temperature which limits growing of vegetable crops for large part of the year (Sharma, 2000). Plasticulture involves using plastic soil mulches and crop covers to improve microclimate conditions surrounding the crop, thereby enhancing earliness, improving yields and increasing profitability (Waterer, 2000). A low cost and low maintenance technique, low tunnel technology was tried that ensures supply of vegetable during scarcity and help the grower to obtain reasonable and profitable return of their produce. Summer and winter vegetables both can be grown under tunnel out of their growing season (Pradhan, 2003). The production of winter vegetables in summer by creating artificial environment involves large capital but the production of summer vegetables in winter by developing optimum temperature in tunnels by using plastic sheets is very economical (Werner, 1991; Dorg, 2003). By increasing air temperature, reducing wind damage and providing a degree of frost protection, the low tunnels accelerate crop production and extend the growing season (Waterer, 2003). Row covers plus black plastic mulch increased cucumber dry weight of plants, yield earliness, and total yields in cucumbers (Ibarra-Jimenez et al. 2004). However, row covers must be taken off when plants flower so bees can successfully pollinate the flowers. Plastic sheet provides warmth temperature by saving the energy of the sun through the absorption of sunlight and not allowing it to go back into the atmosphere (Kumar and Srivastava1997; Gao et al., 2005; Singh et al., 2012). This technology suits to the farmers having small land holding (Singh and Sirohi 2006). Producing vegetables on small land under tunnels can meet dietary requirements of the country and it will become able to export these vegetables (Rafique, 2011).

In Punjab, threat of the cold wave affecting vegetable production, the low tunnel technique is coming up as a savior for the farmers as it not only protects their crop but also helps them get better prices for the produce. Launched in 1999 in the district, Patiala, as a pilot project by the Agricultural Technology Management Agency (ATMA), the low tunnel technique is catching up among the farmers. The technique, also known as poly-house cultivation, has proved a boon for vegetable growers, especially those with small landholdings. Besides saving their vegetables from chilling weather, it also helps them grow off-season vegetables as well. As per available information, around 5000 hectares of area is under vegetable cultivation in Patiala, with maximum vegetable growers from Ghanaur, Sanaur and Nabha blocks. Around, 1200 hectares of vegetable cultivation is done through low tunnel technique. One of the farmers in Ghanaur, Bachitar Singh said using the technique is a profitable option as vegetable growers can grow both summer and winters vegetables at any time of the year. "Farmers can grow summer vegetables in winters as perfect and appropriate temperature conditions of summers are available through low cultivation technique", he said. Another farmer Harmeet Singh from village Gadayia said it helps them earn good money at the end of every season by selling off-season crops in markets not only in Punjab but across the country. To motivate farmers, the horticulture department is giving subsidy on the purchase of ultraviolet 50-micron plastic sheets in order to increase quality and yield of the crop, which they get by using normal plastic sheet.Fruit and Vegetable Development Project (F&VDP) was launched by the Government of Punjab in 12 districts of Punjab to facilitate vegetables and fruit growers for enhancing their production. The 12 districts were Shiekhupura, Okara, Kasur, Sialkot, Attock, Rawalpindi, HafizAbad, Pakpattan, Sahiwal, Gujranwala, Faisalabad and Lahore for off season vegetable production (Government of Punjab, 2012).

Low tunnels covered with poly-spun row cover allow air and water to penetrate while providing several degrees of frost protection. Though row cover does not offer the daytime temperature increase that plastic covered low tunnels can provide, on sunny days it can be beneficial that no ventilation is required. Using thick row cover (1.5 oz.) and/or a double layer of row cover on low tunnels can help give warm season crops a jump start in the spring and can help extend the growing season past the first frost, perhaps as late as winter solstice (but not for overwintering most crops). Thick row cover also protects crops from the wind, though additional measures must be taken in high wind areas to keep the row cover attached. Note: The thicker the row cover or the more layers of row cover, the less light penetration. To offset this effect, growers can remove row cover on warm, sunny days to allow maximum light penetration.

Thinner row covers (0.5 oz.) offer little cold protection, but instead serve as physical barriers to insects - preventing pests like squash bugs and cucumber beetles from reaching the crop. However, many tunnel crops require pollination. In these cases, the row cover is removed for pollination once the plants start flowering, at which time the plants are established enough to deal with some pest pressure. Perforated plastic provides about as much frost protection as row cover, but also provides much higher daytime temperatures - similar to those of greenhouse plastic. However, unlike greenhouse plastic, perforated plastic self-ventilates when temperatures reach a certain point and the slits in the plastic walls contract, allowing heat to escape.

2.1 Effect of microclimate inside low tunnel

Low tunnels are being used for producing high quality high valued nurseries and crops such as tomatoes, cucumber, radish, beans and capsicum The production of vegetables all around the year enables the growers to fully utilize their resources and supplement income from vegetable growing as compared to other normal agricultural crops. Libik and Siwek (1994) studied the changes in soil temperature affected by the application of plastic covers in field production of lettuce and watermelon. It was reported that at 8.00 h soil temperature was 3°C higher than in the open ground and by 14.00 h the air temperature under the cover was 10-15°C higher than the ambient temperature. Lamarrel*et al* (1996) was found that the use of low tunnel has been beneficial during winter when the crop has to be protected from frost and low temperature for higher productivity.

By using beds covered with black plastic mulch together with low tunnels, soil temperatures can be increased, weeds can be controlled, water can be conserved, and fertilizer application is optimized (Schrader, 2000). Plastic materials used for row covers are available in different colors, which impact the light quality and temperatures inside the tunnels. However, it is unknown which low tunnel color, type, or configuration will provide the most protection and growth enhancement in temperate climates. Field experiment was conducted at the Research Farm of the Department of Soil and Water Engineering, PAU, Ludhiana from October, 2008 to June, 2009. They conclude that the mean air temperature was higher in low tunnel than open field by 3.25°C to 3.71°C and 6.38°C to 9.30°C at 7:30 am and 2:30 pm respectively. The mean soil temperature was higher in low tunnel than open field by 1.29°C to 4.76°C and 3.52°C to 6.30°C at 7:30 am and 2:30 pm respectively. The highest relative humidity observed at 7:30 am and lowest at 2:30 pm. At 7:30 am, in the low tunnels mean relative humidity lowered by 4.58% to 6.55% than open field but at 2:30 it was higher by 11.52% to 17.57%.The mean solar radiation under low tunnels lowered by 16.65% to 37.45% as compared to open field at 2:30 pm. Row covers or low tunnels can modify crop microclimate by raising temperature and promoting earlier plant growth (Hochmuth, et al. 2009).

Low tunnels can also be used in combination with a high tunnel, a greenhouse-like structure covered with UV-stable plastic and large enough to walk in. When low tunnels are used with a high tunnel, night time air temperature under the low tunnel can be 3 to 5°F higher than the high tunnel air temperature and 5 to 7°F higher than the outside air temperature (Wien et al., 2006; Maughan, 2013).

2.2 Automatic microclimate control

Wang*et al*. (2008) developed a multi-channel system for simultaneous monitoring of multiple environmental factors and electrical signals in cucumber plants in the greenhouse. The system includes a special sensor, which is both sensitive and reliable for long-term use for collecting electrical signals. Using this system, they proved that the electrical signals in plants respond to environmental changes under natural conditions in the greenhouse. The system could provide a long-term stable tool to measure and analyze the electrical signals in plants in greenhouses. Junxiang and Haiqing (2011) designed a greenhouse surveillance system based on embedded web server technology. Based on ARM-Linux development environment, they constructed embedded web server and use it in acquisition and transmission of greenhouse information. Experiment results show that the working performance of the system is quite stable and can reach the design requirements in real-time data acquisition and remote control.

Dondapati and Rajulu (2012) designed a sensor based automation system for greenhouse. This is capable of managing the greenhouse without any human interference. Based on real time data collection from different sensors, it is capable of controlling the greenhouse microclimate by operating foggers, fans, irrigation system and lighting system. Real time display of microclimatic data on liquid crystal display screen helps the greenhouse technicians to know the exact environmental parameters in it. The system consists of different sensors for collecting data, analogue to digital converter, microcontroller and actuators. Threshold values of microclimatic parameters can be set according to the crops to be cultivated and when any of the parameters exceeds the threshold value, the microcontroller actuates the required equipment to maintain favourable environment for crop growth. Experimental results show that the system performance is good for managing greenhouses.

Khandelwal (2012) developed GSM modem based automation system to control greenhouse microclimate. The system consists of various sensors to collect information about greenhouse temperature, relative humidity, light intensity, rain sensors and transistor switches and relay nodes for automation control. There is a data server to store the information about the environmental conditions inside the greenhouse. Based on the requirement of crop, automation system will maintain required environmental conditions for crop growth.

In conventional Agronomical practices, the crops are being cultivated in the open field under natural conditions where the crops are more susceptible to sudden changes in climate i.e. temperature, humidity, light intensity, photo period and other conditions due to which the quality, yield of a particular crop can get affected and may be decreased. Here the concept of protected farming comes into picture. But the current system of greenhouse farming in India needs overhaul in terms of technological improvements. To fully exploit the enhanced possibilities for crop and resource management, it is indispensable to perform the adjustment of the control variables in an automatic way. This is because it is almost impossible for human being to understand and manipulate system with more than two dependent processes without additional aid. Hence the introduction of automatic controllers and computer-controlled greenhouses in the second half of the twentieth century was a major step forward to economically attractive crop production.Development of an automated greenhouse system that is low cost, operates with minimum human intervention, accurately able to maintain its set points, able to learn and adjust itself have been some of the very obvious interests in which investigators are working to fulfill economic, environmental, market, industrial and human preference needs (Salokhe and Sharma, 2012).

Matrinovic and Simon (2014) developed a mobile measuring station for greenhouse microclimate control. They used wireless sensor networks (WSN) for gathering and monitoring microclimate parameters both inside and outside the greenhouse.

2.3 Growing medium

The term growing medium is amongst others used to describe the material used in a container to grow a plant. Growth and development of vegetables are enhanced, when plants are grown in inorganic media compared to organic ones

(Böhme et al., 2001; Ikeda et al., 2001). In contrast, Tzortzakis and Economakis (2008) found that plants grew faster in organic media compared to inorganic media. For yield enhancement several authors have recommended to grow vegetables in inorganic media (rockwool, sand) rather than organic media (Lee et al., 1999; Böhme et al., 2001; 2008; Ikeda et al., 2001; Kobryń, 2002). Furthermore, there is a growing body of studies indicating the benefit of mixing organic and inorganic components for vegetable growing media with improved performance in greenhouse production (Tzortzakis, Economakis, 2005; Gao et al., 2010). Addition of inorganic substances to organic substances produces higher yield probably owing to increasing water-holding capacity and aeration by organic substances, which demonstrates that inorganic substances could partially replace organic substances (Gao et al., 2010).

2.4 Soil moisture content

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.

2.5 Drip irrigation system

Ahluwalia *et al.* (1993) observed that when compared with conventional irrigation systems, drip system yielded on an average 6 and 56 per cent higher and saved up to 57 and 37 per cent irrigation water in tomato and cauliflower crops respectively resulting in tremendous increase in water use efficiency. They also revealed that at optimum irrigation levels, the drip method resulted in saving of water by 38 per cent with consequent increase of 60.9 per cent in water use efficiency over surface irrigation method. The irrigation requirement of hybrid tomato crop was studied by Bafna*et al*. (1993). Irrigation requirement was found to be 67 ha.cm in surface method and 32 ha.cm in drip method, there by effecting a saving of 53 per cent of irrigation water by using drip system. Banker and Pampattiwar, (1995) recorded considerable increase in chilli yield with drip over surface irrigation. Drip irrigation offered maximum water use efficiency, increase in yield, better quality fruits, and highest net profit in watermelon (Benke, 1995).As reported by chandio and yaseen, (1995) higher water use efficiency was obtained under drip irrigation (1.21 kg/ha.m3) than under furrow irrigation (0.44 kg /ha.m3) in chillies.

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 centre 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.

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).

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).

2.5.1 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).

2.5.1.1 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 400°C 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). 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.

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 values 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.

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.

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.

2.6 Amaranthus

The main vegetable type of amaranth, *Amaranthus tricolor* L., seems to have originated in South or Southeast Asia (Grubben et.al,1981) and then spread through the tropics and the temperate zone (Martin et.al, 1979). The two main types of amaranth grown as leafy vegetables are loosely termed red amaranth and green amaranth. Red amaranth grows well in hot and humid weather. However, during winter, red amaranth growth and development is slow, compared with summer and rainy season (Bose et.al, 1993). The fresh tender leaves and stem of red amaranth are delicious when are cooked by boiling and mixing with condiments. The leaves and tender stems of red amaranth are rich in protein,minerals,vitamin A and C (Wadud et.al, 2002). The most important agronomic considerations for red Amaranthus growers to optimize yield and quality are to select optimum air temperature and sunlight intensity. The correlation between plant height and mean growing period air temperature and sunlight intensity was highly significant, which confirms air temperature and sunlight variability is a major factor influencing plant growth. Amount and effects of air temperature and sunlight intensity during plant growing period, significantly affected biomass yield, leaf color and betacyanin accumulations, (Khandaker et.al, 2010).

CHAPTER 3

MATERIALS AND METHODS

The present study mainly focused on the design and development of an automated low tunnel with automated drip irrigation system using soil moisture sensor and temperature controller for controlling the temperature inside the structure. Materials used and methodology adopted for the study are briefly described in this chapter.

3.1 Location of the study

The experiment was conducted in experimental plot of Precision Farming Development Centre (PFDC), KCAET, Tavanur in Malapuram District, Kerala. The place is situated at 10°52′30"North Latitude and 75°58′34" East Longitude. The total area of KCAET campus is 40.99 ha, out of which total cropped are 29.65ha. Agro-climatically, the area falls within the border line of Northern zone and Central zone of Kerala. Major part of the rainfall in this region is obtained from South West monsoon. The area is having a relative humidity of about 62%.the mean maximum temperature of the area is about 42.1°C and mean minimum temperature of the area is about 22°C. An area of about 5×4 m is used for installing the automated and non-automated low tunnel structures in the experimental plot.

3.2 Experimental set up

3.2.1 Low tunnel structure

Two low tunnel structures were used in the present study, one with automated drip irrigation using soil moisture sensor and a temperature controller sensor and another without automation. Low tunnel is generally a structure featuring a series of four hoops fabricated with MS rod having 1 inch diameter and MS flat of 5mm thick and 9 m in length. The hoop shape means that semi-circular shape, with length more than the width. Low tunnels deliberately built on a skid which allows them to be dragged or carried from one location to another without being torn down and rebuilt. The structures used for the study are shown in Plates 3.1.

Plate 3.1 Low tunnel structures without covering materials

UV polythene sheet of 205 micron thick, having 6.7 m length and 1.35 m width was used as the covering material for the whole structure as shown in Plate 3.2.

Plate 3.2 Low tunnels with covering materials

The materials required for the fabrication of both automated and non-automated low tunnels are given in the Table 3.1.

Table 3.1 Materials used for construction of low tunnels

Materials	Quantity
1” MS rod and MS flat	26.800 kg
Nut & bolt	535 g
Metal primer	1000 ml
Enamel paint	500 ml
UV sheets (200 micron)	41.25 m^2

3.2.2 Irrigation system

Irrigation was given using drip method. On line laterals of 12mm size and online drippers of 4 l/h capacity were used. Plants were irrigated daily in non-automated low tunnel, where as in the other automated drip irrigation was provided. The irrigation system is shown in Plate 3.3.

Plate 3.3 Drip irrigation system in low tunnel

The materials required for providing drip irrigation system are given in Table 3.2.

Table 3.2 Materials required for drip irrigation system

Materials	Quantity
PVC pipes(1.5 inch)	7.5 m
Laterals	18 m
Emitters (4lph)	28 nos
Take off(16mm)	4 nos
Washers	4 nos
T connector(16mm)	3 nos
End cap	4 nos
¾" ball valve	2 nos
¾" bend	2 nos
T cap(1.5 inch)	3 nos

3.2.3 Drip automation system

The system is developed using electronic equipment so that it can regulate 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 is less in weight, portable and water resistant. All measurements can be done rapidly because the calibration of system is dependent upon response time and soil types.

3.2.3.1 Soil moisture sensor

The term moisture content is used in a wide range of practical and scientific areas and is expressed as a ratio. Water contained in 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 soil, 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. The sensors are calibrated and tested to use as automated irrigation system. Fig. 1 shows the block diagram of the soil moisture sensor control system.

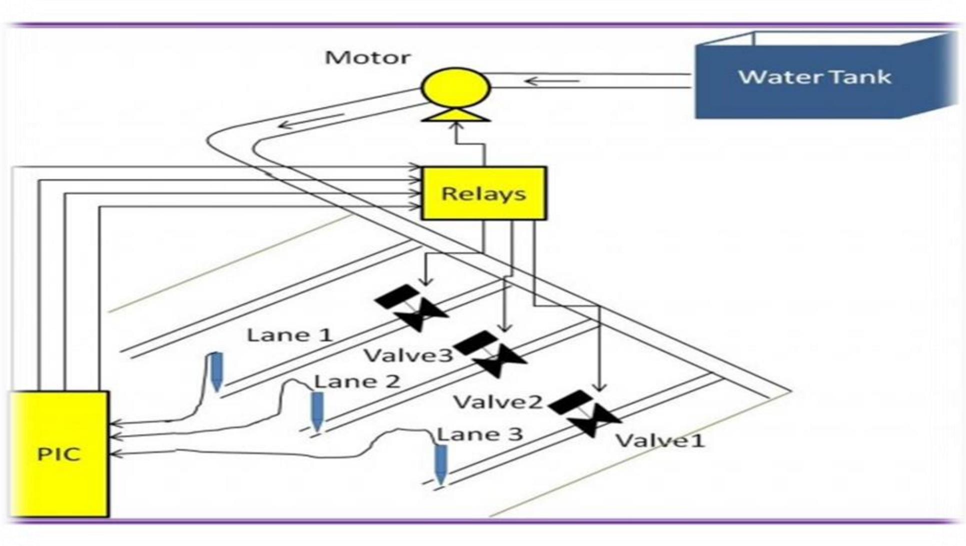


Fig.3.1 Block diagram of soil moisture control system

3.2.3.2 Electronic control board (microcontroller unit)

Microcontroller unit receives data from soil moisture sensors and these data are transferred to the solenoid valve. MCU can read data from soil moisture sensor. If the measured parameters differ from the pre-set levels, the microcontroller unit will switch ON/OFF the solenoid valve. In this study one solenoid valve is connected with the relay circuit. Whenever moisture level reaches above or below the limit, then MCU will switch OFF the operation of solenoid. Otherwise if switch ON the solenoid valve. The microcontroller arrangement is shown in Plate 3.4

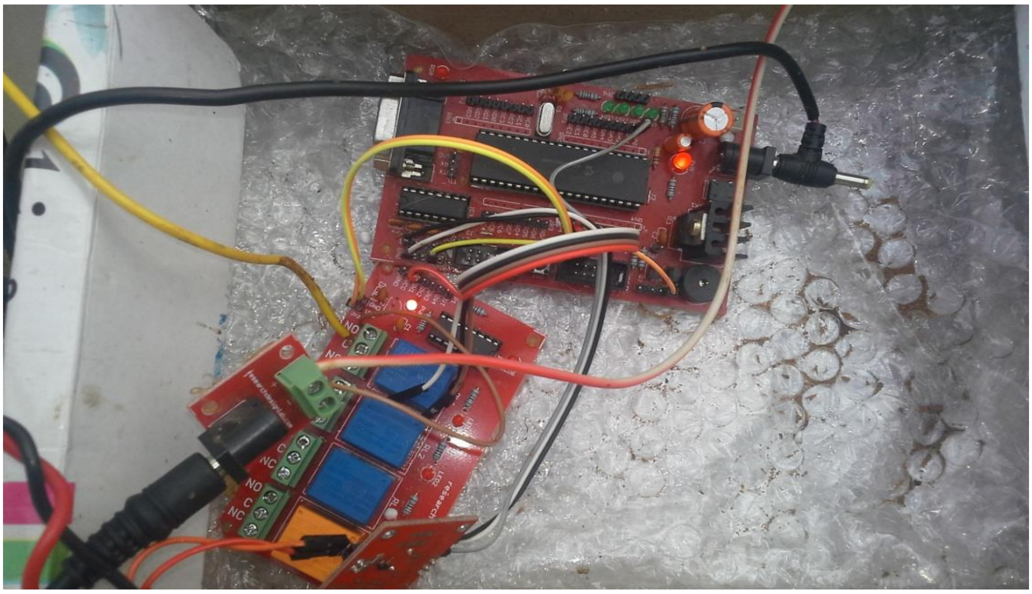


Plate 3.4 Board with micro controller

3.2.3.3 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.

3.2.3.4 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 3.5 shows the electrical relay of the motor.

3.2.3.5 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. One valve is placed for irrigation of 2 beds, which will work in accordance with the message received from the operator. Plate 3.6 shows the solenoid valves installed in the field.

Plate 3.5 Electrical relay

Plate 3.6 Arrangement of solenoid valve

3.2.4 Temperature controller

Temperature controller is a device, used to hold a desired temperature at a specified value. In a typical application sensors measure the actual temperature. This sensed temperature is constantly compared to a user set point. When the actual temperature deviates from the set point, the controller generates an output signal to activate the temperature regulating devices like micro fans to bring the temperature back to the set point. The temperature controller used is shown in Fig 3.2

Fig. 3.2 Temperature sensor controller

Item Details:	
Temperature Measuring Range:	-50°C~+110°C
Temperature Controlling Range:	-50°C~+110°C
Temperature Measuring Error:	±0.5°C
Sensor:	NTC (10K / 3435)
Control Accuracy:	1°C
Working Voltage:	AC 220V
Max Power Consumption:	＜2W
Relay Contact Current:	AC 5A / 220V
Operating Temperature:	0°C~50°C
Storage Temperature:	-10°C~+60°C

3.2.4.1 Thermostats

Thermostat is a device for sensing temperature and for activating/deactivating the attached equipment with reference to a set of temperature thermostat is made by either a bimetallic strip or thin metal tube filled with fluid as sensor and it will produce some physical displacement corresponding to the temperature. These sensors activate a mechanical switch by differential expansion of bimetallic strip or by movement of tube due to change in the volume of fluid. Plate 3.7 shows the thermostat.

Plate 3.7 Thermostat

3.2.4.2 Micro fan

Ventilation was given to the completely closed structure by means of two fan s having a speed of 1300 rpm, working under 230V – 50 Hz. In the automated low tunnel there is provision for placing the exhaust and inlet fans as part of temperature control as shown in Fig. 3.2. The micro fan used in the system is shown in Plate 3.8.

Plate 3.8 Micro fan

3.2.5 Growing medium

The production of low tunnel crops involves a number of cultural inputs. Among these, perhaps the most important is the type of growing medium used. Due to the relatively shallow depth and limited volume of a grow bag, growing media must be amended to provide the appropriate physical and chemical properties necessary for plant growth. Field soils are generally unsatisfactory for the productions of plants in grow bags. This is primarily because soils do not provide the aeration, drainage and water holding capacity required. To improve this situation instead of soil, a mix of cow dung, sand and coco peat mix is used. Following media were used for the production of crops in low tunnel structures.

3.2.5.1 Cow dung

Composted cow manure fertilizer provides an excellent growing medium for low tunnel plants. It can be mixed into the soil or used as top dressing. By mixing this cow dung into the soil, we can improve its moisture-holding capacity. Also it will improve aeration, helping to break up compacted soils. Cow manure also contains beneficial bacteria, which convert nutrients into easily accessible forms so they can be slowly released without burning tender plant roots.

3.2.5.2 Coco peat

Coco peat is produced as coir dust, a by-product during coconut husk processing, while making coir and other products (Plate 3.9). The processed coir dust becomes coco peat and is a very good growing medium for plants. It has high resistance to bacterial and fungal growth and also has the ability to release nutrients to plants for extended periods of time. Coco peat has great oxygenation property which helps for root development and a pH level of 5.2 to 6.8 which is neutral to slightly acidic in nature. Coir has a high cation exchange, meaning it can store unused minerals to be released to the plant as and when it requires it. Coir is available in many forms but most commonly as coco peat.

3.2.5.3 Sand

Sand, a basic component of soil, ranges in particle size from 0.05 mm to 2.0 mm in diameter. Although sand is generally the least expensive of all inorganic amendments it is also the heaviest. This may result in prohibitive transportation costs. Sand is a valuable amendment for both potting and propagation media.

Plate 3.9 Coco peat

3.2.6 Selection of crop

Two varieties of Amaranthus crop were selected for the study inside the automated and non- automated low tunnel structures viz. CO_1 and Arun. Amaranthus belongs to the family Amaranthaceous. It is extensively grown as a green, leafy vegetable in many temperate and tropical regions and can grow to a height of 2 to 8 feet, depending on the species. Amaranth is highly tolerant of an arid environment and needs soil temperatures of between 18 °C and 25 °C to germinate and an air temperature above25 °C for optimum growth. It belongs to C- 4 plants and has efficient photosynthetic activity. Amaranthus requires good seed-soil contact for rapid germination and emergence and adequate soil moisture must be maintained at the seeding depth throughout initial stages. The growth of amaranth is adversely affected by a soil pH of between 4, 7 and 5, 3. A soil with a pH of 6, 4 could produce high yields. The crop cannot withstand water logging as it has a relatively low capacity for water consumption. Selection of crop for the experiment is based on some factors such as plant height, resistance to pest and diseases, root growth, tolerance to light intensity etc. Moreover Amaranthus is more suitable for this kind of studies.

3.3 Methodology

A low tunnel is generally a structure featuring a series of four hoops fabricated with MS rod having 1 inch diameter, MS flat of 5 mm thick and 9 m long. The structures were installed on 23rd September 2016 in the PFDC plot for experimental verification. Two low tunnels having similar size and shape, one automated and other non- automated were used for the study. Both tunnels were covered with UV polythene sheets for protecting the crop from extreme wind, rain and sunlight. Both tunnels were provided with plastic mulching sheets to avoid weed growth inside the tunnels. Automated low tunnel structure is fitted with a soil moisture sensor based drip irrigation system and a temperature controller with 2 fans of 1300 rpm for regulating and controlling the temperature inside the structure. Non-automated low tunnel structure is simple in construction and drip irrigation was done by manually. Two trials were carried out to study the system performance of both the structures without crop and to study and evaluate the crop performance inside the structures.

3.3.1 System performance

The two structures were installed in the experimental plot after covering the whole structure with UV sheets. Temperature variations and performance of drip system inside both structures were checked. In the case of automated low tunnel structure artificial ventilation is given using micro fans. Micro fans are controlled by the temperature sensor controller, which is maintained at 2 set points: 30°C and 35°C in order to maintain the desired temperature inside the tunnel. Drip irrigation is automated using soil moisture sensor which is limited to work in the range of 350 -800millimho/cm.

3.3.2 Crop performance

In each structure, seven CO_1 and seven Arun varieties of Amaranthus crop were grown. Seedlings were raised in pro-trays and transplanted to the growing containers after 3 weeks. Total 28 plants were transplanted to both the structures. Drip emitters of 4 lps were used to provide irrigation to the root zone of the plant. In non-automated tunnel, irrigation was given for about 5 minutes, every day. Growth of plants was observed at every 5 days interval after planting till the harvest. Biometric observations were also taken.

3.4 Biometric observations

For analysing the growth of the plants under the two structures, two plants of each variety were selected randomly from each structure. Biometric observations such as plant height, girth and number of leaves were made at every 5 days interval after planting for each selected plants. The collected data were tabulated and compared separately. The heights of the randomly selected plants were measured from the surface of the rooting media to the tip of the plant. Harvesting of Amaranthus from both the low tunnel was done after 45 days after transplanting and was weighed for analysing the total yield.

Chapter 4

RESULT AND DISCUSSION

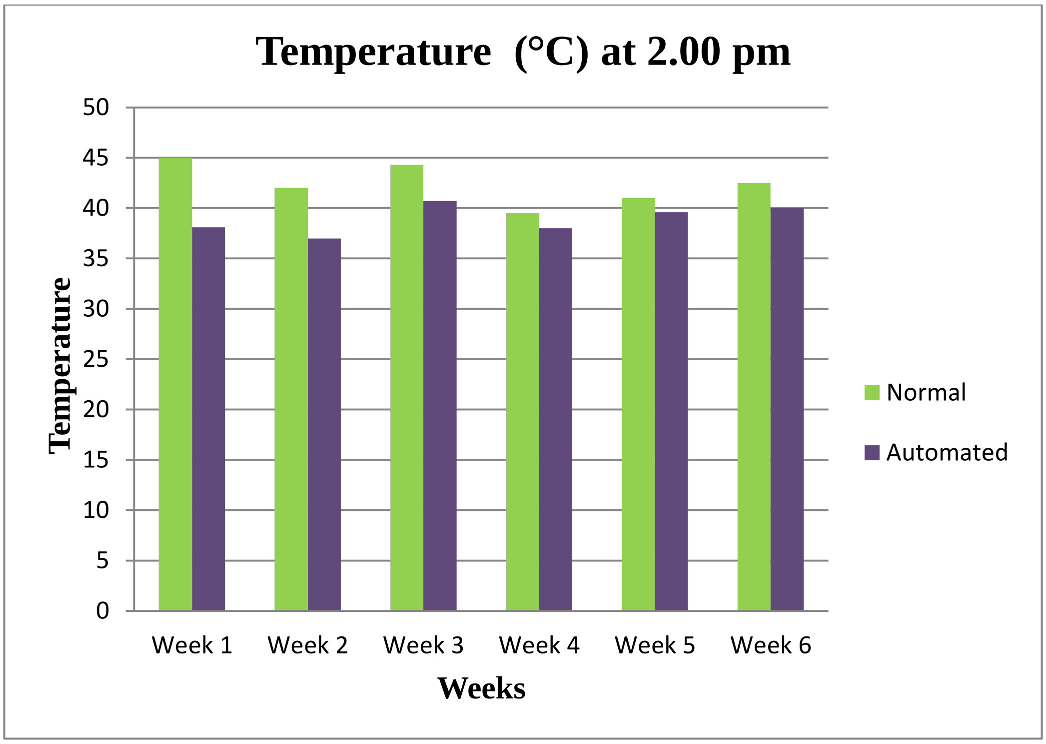
The study was undertaken with the objectives to evaluate the performance of the low tunnel structures developed without crop and also to compare the performance of the automated low tunnel developed with a non- automated low tunnel by growing amaranths crop. Two studies were carried out, first study to evaluate the performance of the structure without crops and second study to compare the performance of two varieties of Amaranthus crop grown inside the automated and non-automated low tunnel structures. In both experiments field observations were taken and the results are discussed in this chapter.

4.1 System performance without crops

In non-automated low tunnel it was found that temperature inside the tunnel was too high around 38°C - 42°C in a normal sunny day. In this structure drip irrigation is given manually on daily basis. It was found that when the temperature inside the automated structure changes beyond the set points, it will switch ON and OFF respectively the micro fans to maintain the temperature in between the set points. Since the drip system is automated using soil moisture sensor, when the electrical conductivity of the soil media reaches less than 350, sensor activates the solenoid valve thereby providing irrigation, whereas it closes the valve when electrical conductivity reaches beyond 850.

4.1.1 Temperature

Air temperature was measured inside both the structures at 2:00 PM and 5:00 PM every day after transplanting for a period of 6 weeks. It was observed that temperature inside the automated low tunnel is maintained between the set points, providing optimum condition for the plant growth. The temperature inside the non- automated structure, in peak hours of the day rises up to 44.3°C, leads to heat stress. Discoloration, blistering, or a water-soaked and sunken appearance is the symptoms of heat stress. Variation of temperature at2:00 PM and 5:00 PM of both the structures were shown in the Fig 4.1.



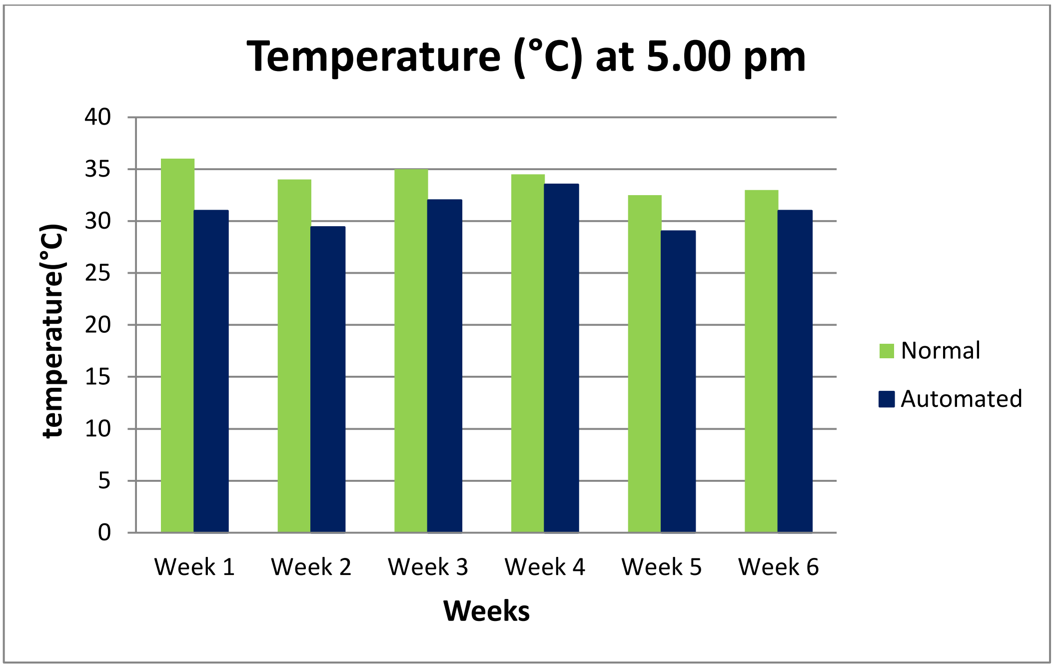


Fig 4.1 Variation in the temperature at 2:00 pm and 5:00 pm inside the structures

Table 4.1 Temperature variation inside the structures at 2:00 PM and 5:00PM

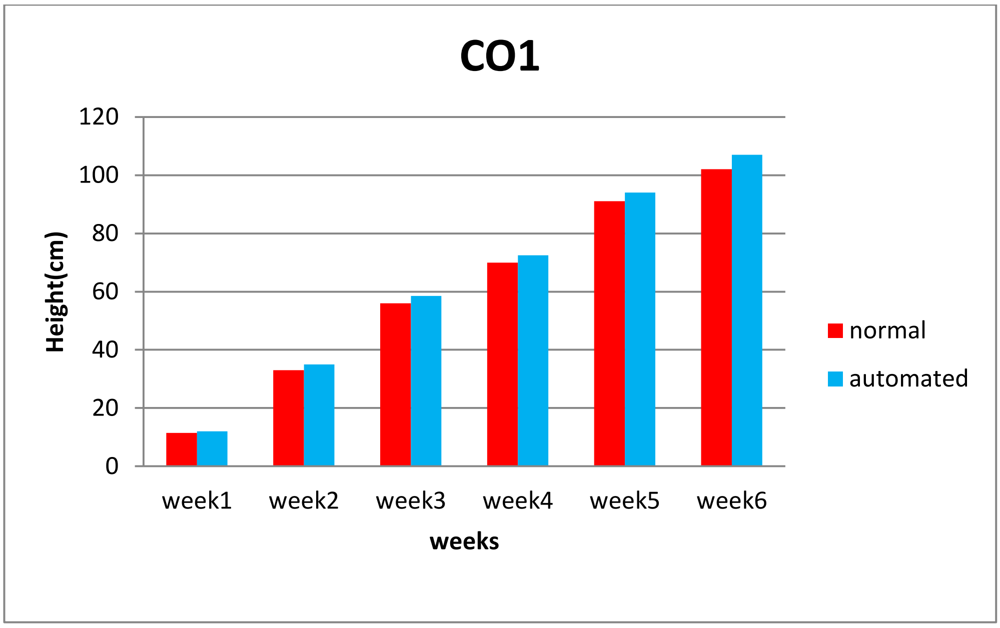
TEMPERATURE(°C)				
	NORMAL		AUTOMATED	
WEEKS	2:00PM	5:00PM	2:00PM	5:00PM
WEEK 1	45	36	38.1	31
WEEK 2	42	34	37	29.4
WEEK 3	44.3	35	40.7	32
WEEK 4	39.5	34.5	38	33.5
WEEK 5	41	32.5	39.6	29
WEEK 6	42.5	33	40	31

4.2 Crop performance

4.2.1 Growth parameters

4.2.1.1 Plant height

Heights of the plants are influenced by the temperature and soil moisture. Observations were taken in weekly interval after planting. The variation of plant heights of CO_1 and Arun grown inside the two structures are shown in Fig. 4.2. It is found that maximum height is in the automated low tunnel than non-automated one.



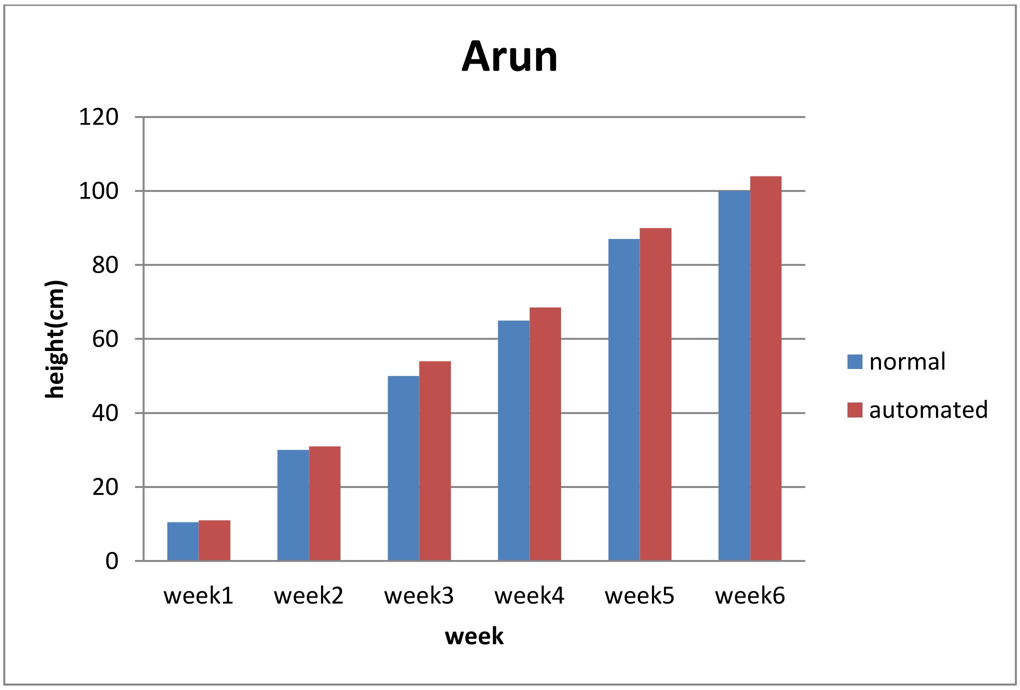
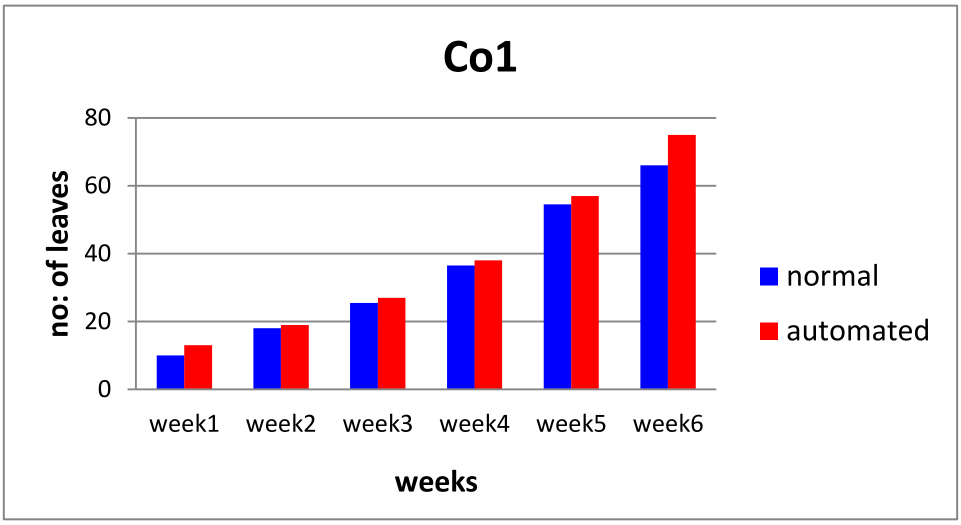


Fig. 4.2 Variation in plant height (cm) of CO_1 and Arun inside the structures

4.2.1.2 Number of leaves

The data on number of leaves were recorded at weekly interval after planting, which reveals that leaf production has been much influenced by the conditions prevailed inside both the structures. The variations in the number of leaves of CO1 and Arun inside the two structures are shown in Fig 4.3.



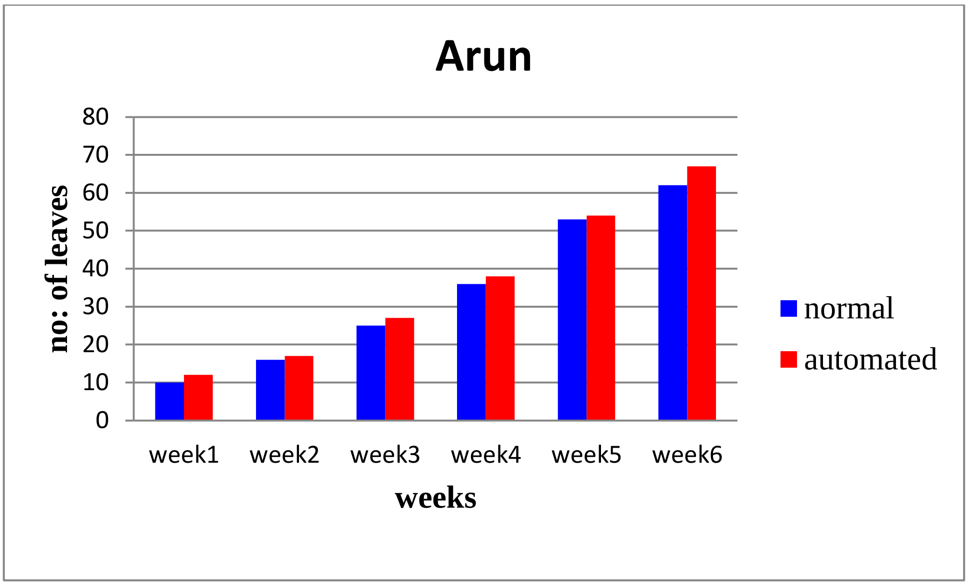
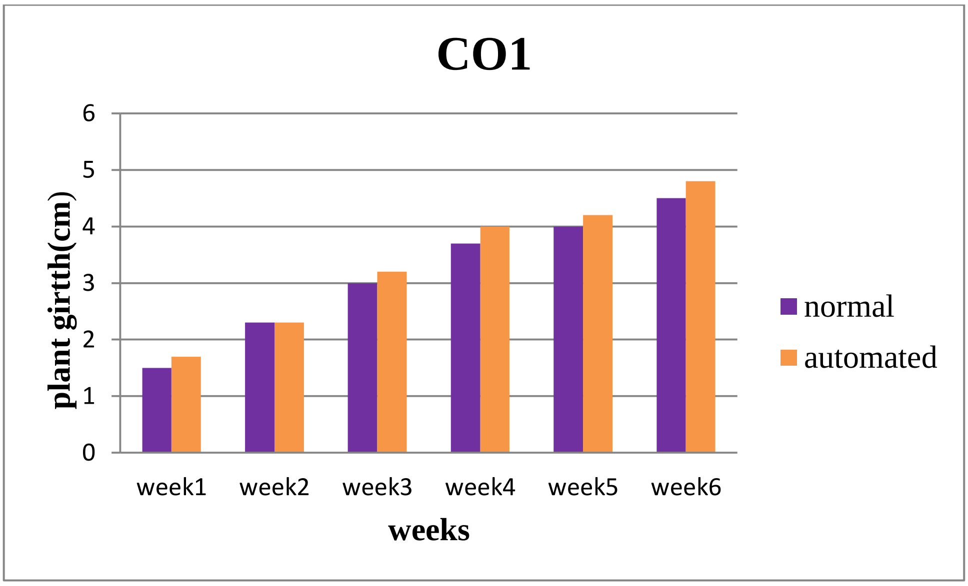


Fig. 4.3 Variation in number of leaves of CO_1 and Arun inside the structures

4.2.1.3 Plant girth

At the end of 6^{th} week the maximum plant girth was observed in case of CO_1 variety inside the automated low tunnel and minimum was in the case of Arun variety inside the non- automated low tunnel and the values were 5 cm and

4.2 cm respectively. Variation of plant girth of CO_1 and Arun inside the structure is shown in Fig. 4.4.



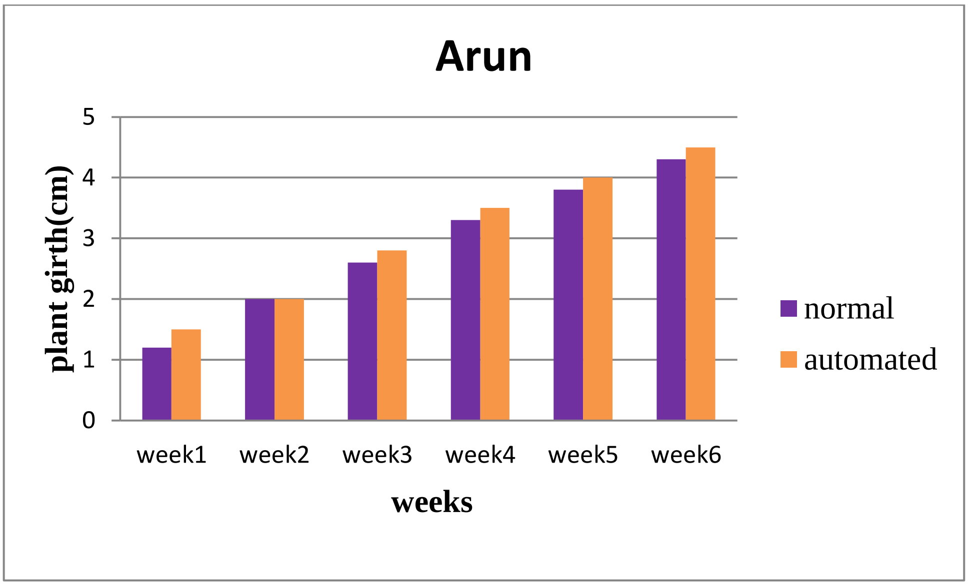


Fig. 4.4 Variation in plant girth of CO_1 and Arun inside the structures

Table 4.2 Crop parameters inside the non-automated low tunnel

NORMAL						
	CO1			ARUN		
WEEKS	PLANT HEIGHT	NO:OF LEAVES	PLANT GIRTH	PLANT HEIGHT	NO:OF LEAVES	PLANT GIRTH
Week 1	11.5	10	1.5	10.5	10	1.2
Week 2	33	18	2.3	30	16	2
Week 3	56	26	3	50	25	2.6
Week 4	70	38	3.7	65	36	3.3
Week 5	91	54	4	87	53	3.8
Week 6	102	66	4.5	100	62	4.3

Table 4.3 Crop parameters inside the automated low tunnel

AUTOMATED						
	CO1			ARUN		
WEEKS	PLANT HEIGHT	NO:OF LEAVES	PLANT GIRTH	PLANT HEIGHT	NO:OF LEAVES	PLANT GIRTH
WEEK 1	12	13	1.7	11	12	1.5
WEEK 2	35	19	2.3	31	17	2
WEEK 3	58.5	27	3.2	54	27	2.8
WEEK 4	72.5	38	4	68.5	38	3.5
WEEK 5	94	57	4.2	90	54	4
WEEK 6	107	75	4.8	104	67	4.5

4.2.2 Pest and disease infestation

4.2.2.1 Powdery mildew

Powdery mildew starts on young leaves as raised blister-like areas that cause leaves to curl, exposing the lower leaf surface. Infected leaves become covered with a white to grey powdery growth, usually on the upper surface; unopened flower buds may be white with mildew and may never open. Leaves of severely infected plants turns to brown colour and fall down. The disease attacks young, succulent leaves and matured leaves are usually not affected. It is caused by a variety of closely related fungal species, each with a limited host range. Low soil moisture combined with high humidity levels at the plant surface favours this disease.

4.2.2.2 Mealy bug

Mealybugs are insects in the family Pseudococcidae, unarmored scale insects found in moist, warm climates. They are considered pests as they feed on plant juices of greenhouse plants, house plants and subtropical trees and also act as a vector for several plant diseases found in warmer growing climates, mealy bugs are soft-bodied, wingless insects that often appear as white cottony masses on the leaves, stems and fruit of plants.

4.2.2.3 Root rot

Pythium crown and root rot is a troubling disease for many growers and at times may seem unavoidable and tough to control. *Pythium* is a water mold and “nibbles” the feeding roots of plants, resulting in stunted growth and death. Root rot disease is favored by growing conditions that are “too wet,” such as when media does not drain quickly or when weather doesn’t allow rapid drying.

ROOT ROT **POWDERY MILDREW**

MEALY BUG

Plate 4.1 Various plant diseases observed

4.2.3 Yield data

The observation on yield of CO1 and Arun inside the structures was taken 45 days after planting. The plants in the automated low tunnel showed better performance than the non-automated low tunnel. The total yield obtained from the automated low tunnel in case of CO1 was 310 g and in case of of Arun was 280 g. The total yield obtained from the non-automated low tunnel in case of CO1 was 290 g and in case of Arun was 270 g. Plates 4.2 and 4.3 shows the yield of CO1 and Arun indide the structures. Fig 4.5 shows the variation in yield data obtained from both the structures.

Table 4.4 Yield variation inside the structures

	YIELD (gm)	
VARIETY	**Normal**	**Automated**
CO_1	**290**	**310**
ARUN	**270**	**280**

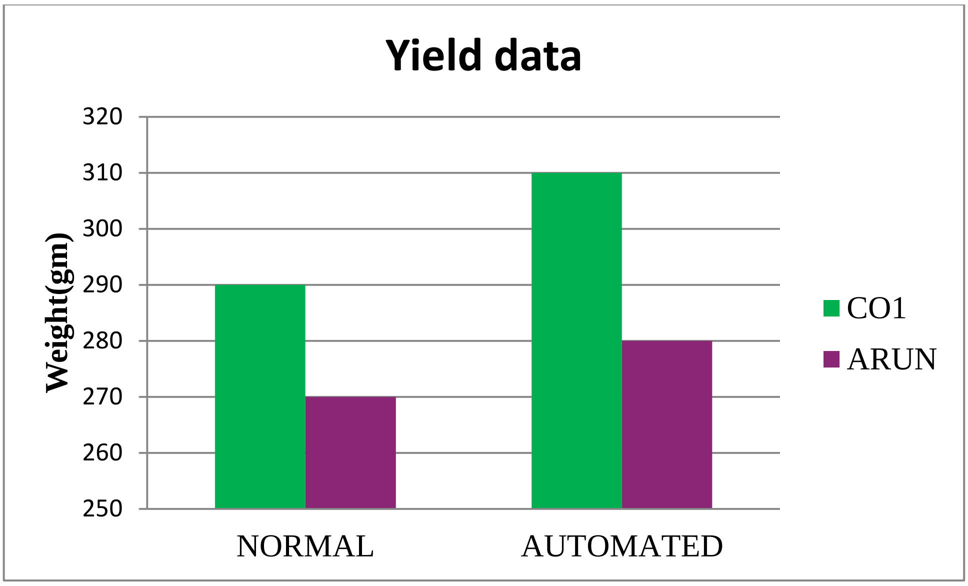


Fig 4.5 Variation in yield data inside the structures

Plate 4.2 Crop stand inside the non-automated low tunnel

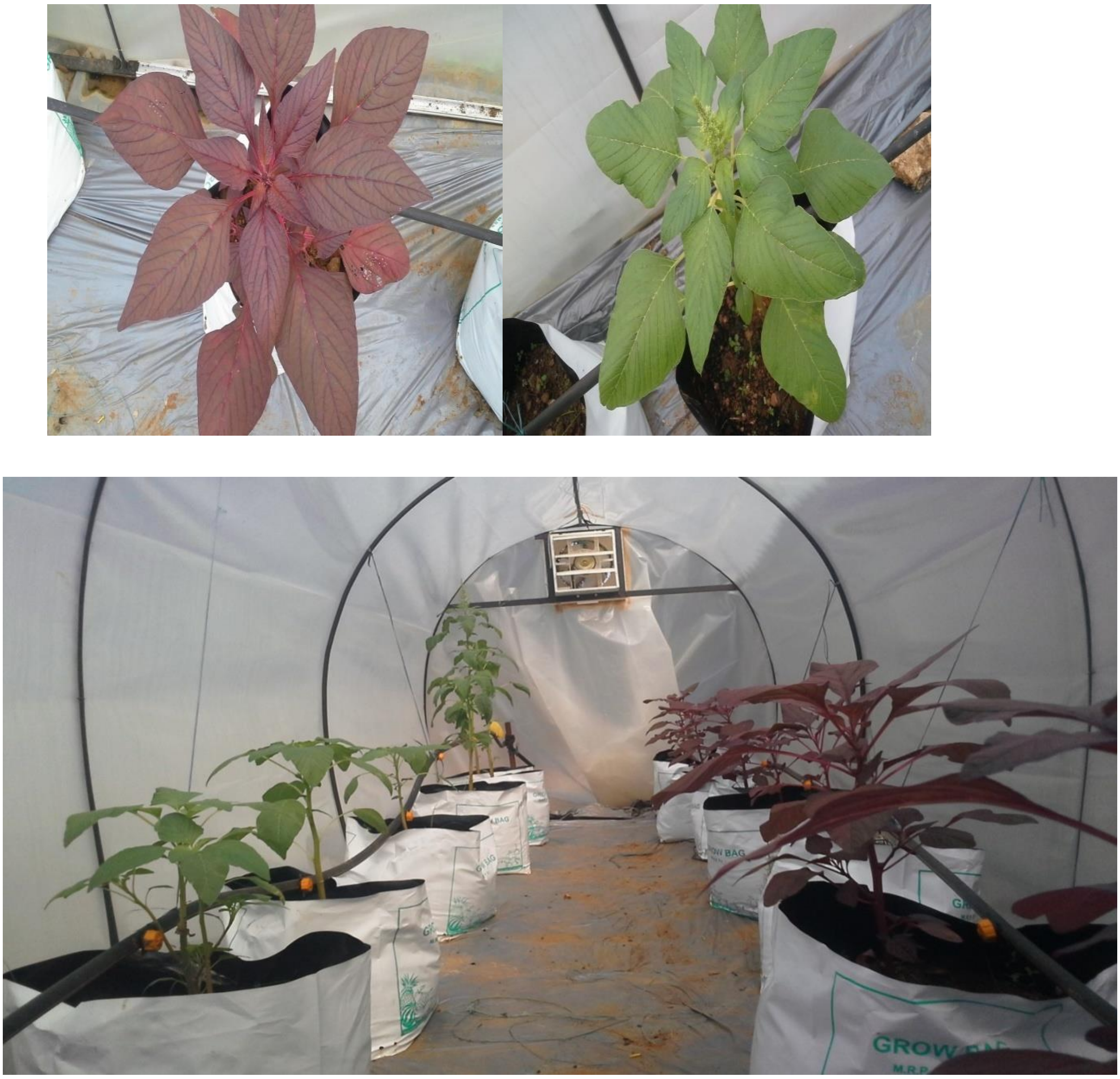


Plate 4.3 Crop stand inside the automated low tunnel

4.2.4 General observations

Comparing the performance of automated and non-automated low tunnels by growing Amaranthus crops, following advantages were noted in the case of automated low tunnel.

- Considerable saving of inputs and energy and lesser chance of pest and disease .
- Better yield and crop performance.

Plate 4.4 Yield of the crops from automated low tunnel

Plate 4.5 Yield of the crops from non-automated low tunnel

CHAPTER 5

SUMMARY AND CONCLUSION

The study entitled “Design, Development and Evaluation of an Automated Low Tunnel for Hi-tech Agriculture” was carried out to develop a low tunnel structure with an automation unit. Two low tunnel structures (one with automation unit and other one non-automated) were installed in the experimental plot of Precision Farming Development Centre (PFDC), KCAET and studies were conducted under automated and non- automated conditions. For studying the performance of automation unit in controlling the temperature sensor and soil moisture sensor, the unit was installed inside one low tunnel. Two studies were conducted, one for analysing the system performance without crops and other, to evaluate the crop performance under automation by growing Amaranthus crop ($C0_1$ and Arun varieties) inside the automated and non- automated low tunnel structures. Seedlings were raised in pro-trays and were transplanted at four leaves stage. Total 28 plants were planted inside each structure. Rooting media used was a mix of cow dung, sand and coco peat as it can provide proper aeration and drainage. Drip irrigation inside the non- automated structure was provided manually and inside the automated structure irrigation was automated using soil moisture sensor. Temperature measurements and biometric observations were made inside both structures for a period of 6 weeks. In non-automated structure, the temperature inside the tunnel was too high around 38°C - 44°C in a normal sunny day and daily drip irrigation was provided manually. Temperature inside the automated low tunnel could be maintained between the set points (30°C and 35°C) with the help of micro fans and drip irrigation was automatically regulated using soil moisture sensor. Biometric observations such as plant height, girth and number of leaves were made in selected tagged plants at 5 days interval. The collected data were tabulated and analysed separately. The heights of the randomly selected plants were measured from the surface of the rooting media to the tip of the plant. Harvesting of Amaranthus from both structures was done 45 days after transplanting and was weighed for analysing the total yield.

Analysis of the result revealed that crops grown inside automated structure shows better growth performance than inside non-automated one. Among the two varieties of Amaranthus, CO_1 showed better result compared to Arun. Maximum plant height of 107 cm was obtained in automated tunnel for CO1 and in non-automated tunnel it was only 102cm.Similarly the number of leaves and plant girth in automated tunnel was 75and 4.8 cm respectively for CO1 and 67 and 4.5cm respectively for Arun. The total yield obtained from the automated low tunnel was 310 g and 280 g for CO1 and Arun respectively, whereas it was 290 g and 270 g respectively, from the non-automated low tunnel. Maximum plant height was observed in the automated low tunnel. Analysis of the growth parameters like plant height, plant girth, number of leaves and total yield showed that, the crop performance inside the automated low tunnel was better than that inside the non-automated low tunnel. Also, it was noticed that crop inside the automated low tunnel was more disease resistant than non-automated low tunnel, which may be due to the reason that they were not exposed to heat stress and received proper irrigation at the right time in right quantity. The use of rooting media enhanced the plant growth in both cases, as it provides better environment and aeration. From the study it can be concluded that, an automated low tunnel can ensure better crop performance when compared to a non-automated low tunnel.

From the result of the study it can be conclude that, there is considerable saving of inputs and energy with less chance of pest and disease attack in automated structure. It also ensures better yield and crop performance. Automation can reduce the human intervention and can accurately maintain its set points at desired levels.

Scope for further study includes the following:

- Studies on the micro climatic parameters inside the structure like relative humidity, CO_2 concentration etc.
- Studies incorporating the nutrient film technology.
- Studies using different growing media with different composition of the mixtures.

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