DEVELOPMENT AND EVALUATION OF AUTOMATED DATA ACQUISITION NFT HYDROPONICS SYSTEM

By

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(2020-18-002)

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TAVANUR - 679573, MALAPPURAM

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THESIS

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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KERALA, INDIA

2023

DECLARATION

I, hereby declare that this thesis entitled "**DEVELOPMENT AND EVALUATION OF AUTOMATED DATA ACQUISITION NFT HYDROPONICS SYSTEM**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place: Tavanur

Date: 20/10/2023

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Certified that this thesis entitled **"DEVELOPMENT AND EVALUATION OF AUTOMATED DATA ACQUISITION NFT HYDROPONICS SYSTEM"** is a record of research work done independently by Er. Shahala M under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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We, the undersigned members of the advisory committee of Er. Shahala M (2020-18-002), a candidate for the degree of Master of Technology in Agricultural Engineering with major in Soil and Water Conservation Engineering, agree that the thesis entitled **"DEVELOPMENT AND EVALUATION OF AUTOMATED DATA ACQUISITION NFT HYDROPONICS SYSTEM"** may be submitted by Er. Shahala M (2020-18-002), in partial fulfilment of the requirement for the degree.

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Dedicated to

My loving Family,

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Engineers

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SYMBOLS AND ABBREVIATIONS

'	:	Minute
%	:	Percentage
/	:	Per
=	:	Equal to
±	:	Plus-Minus
°	:	Degree
A	:	Ampere
ABS	:	Acrylonitrile Butadiene Styrene
AI	:	Artificial Intelligence
am	:	Ante Meridiem (before midday)
API	:	Application Programming Interface
ARM	:	Advanced RISC Machine
ARS	:	Agronomic Research Station
AS	:	Aeroponic Systems
AT	:	Atmel
Av.	:	Average
BC	:	Benefit Cost
BN	:	Bayesian network
BNC	:	Bayonet Nut Coupling
°C	:	Degree Celsius
C.S	:	Cross section
Ca	:	Calcium
Ca^{2+}	:	Calcium ion
CALIB	:	Calibration
CD	:	Critical Difference
Chla	:	Chlorophyll a
Chlb	:	Chlorophyll b
cm	:	Centimeter

cNFT	:	Conventional NFT system
CO_2	:	Carbon-dioxide
CPSS	:	Cyber Physical Social System
CRD	:	Completely Randomized Design
DC	:	Direct Current
DFT	:	Deep Film Technique System
DN button	:	Down button
DO	:	Dissolved Oxygen
DS	:	Depth Sensor
$dS\ m^{-1}$	:	Deci Siemens per meter
DSW	:	Desalinated Sea Water
E	:	East
EC	:	Electrical Conductivity
EEPROM	:	Electrically Erasable Programmable Read-only Memory
EFS	:	EBB and Flow Systems
Eq.	:	Equation
et al.	:	and others
EX	:	Exhaust fan
°F	:	Degree Fahrenheit
Fe^{2+}	:	Ferrous ion
Fig.	:	Figure
g	:	Gram
$g\ plant^{-1}$	:	Gram per plant
GI	:	Galvanized Iron
GPRS	:	General Packet Radio Service
GSM	:	Global System for Mobile communication
HFE	:	Hydroponics Farming Ecosystem
Hg	:	Hydragyrum (Mercury)
hp	:	Horsepower
hr	:	Hour

Hz	:	Hertz
i.e.	:	That is
I2C	:	Inter-Integrated Circuit
ICSP	:	In-Circuit Serial Programming
IDE	:	Integrated Development Environment
IoT	:	Internet of Things
IRR	:	Internal Rate of Return
K	:	Potassium
KAU	:	Kerala Agricultural University
KCAET	:	Kelappaji College of Agricultural Engineering and Technology
kg	:	Kilogram
kg/cm^{-2}	:	Kilogram per square centimeter
kW	:	Kilowatt
L	:	Litre
$L\ kg^{-1}$	:	Litre per kilogram
l/h	:	Litre per hour
l/min	:	Litre per minute
LCD	:	Liquid Crystal Display
LDR	:	Light Dependent Resistor
LED	:	Light Emitting Diode
LI	:	Light Intensity
lx	:	Lux
m	:	Meter
Max	:	Maximum
Mg^{2+}	:	Magnesium ion
MHz	:	Megahertz
mm	:	Millimeter
$mm\ day^{-1}$	:	Millimeter per day
mmhos/cm	:	Millimhos per centimeter
Mn^{2+}	:	Manganese ion

mNFT	:	Modified NFT
MoA and FW	:	Ministry of Agriculture and Farmers Welfare
mol m^{-2} s^{-1}	:	Mole per square meter per second
MQTT	:	Message Queuing Telemetry Transport
mS cm^{-1}	:	Milli Siemens per Centimeter
N	:	Nitrogen
N	:	North
NAR	:	Net Assimilation Rate
NFT	:	Nutrient Film Technique
NO	:	Normally Open
No.	:	Number
NO3- N	:	Nitrate nitrogen
Node MCU	:	Node MicroController Unit
NPV	:	Net Present Value
NS	:	Not Significant
P	:	Phosphorus
PBP	:	Payback period
PCB	:	Printed Circuit Board
pH	:	Potential of Hydrogen
PID	:	Proportional Integral Differential
pm	:	Post Meridiem (post midday)
PO_4^{3-}	:	Phosphate ion
PPF	:	Photosynthetic Photon Flux
ppm	:	Parts Per Million
prev	:	Previous
PVC	:	Poly Vinyl Chloride
R^2	:	R-Squared
RFS	:	Floating Raft System
RGR	:	Relative Growth Rate
RH	:	Relative Humidity
RMSE	:	Root Mean Square Error

RTC	:	Real Time Clock
RX	:	Receive
SC	:	Soil Cultivation
SCL	:	Serial Clock
SD	:	Secure Digital
SDA	:	Serial Data
SIM	:	Subscriber Identity Module
SMPS	:	Switched Mode Power Supply
SMS	:	Short Message Service
soln	:	Solution
SPAD	:	Soil Plant Analysis Development
TDS	:	Total Dissolved Solids
temp	:	Temperature
TRIG	:	Trigger
TS	:	Temperature Sensor
TX	:	Transmit
UART	:	Universal Asynchronous Receiver-Transmitter
UN	:	United Nations
US	:	Ultrasonic Sensor
USB	:	Universal Serial Bus
UV	:	Ultraviolet
V	:	Volt
VCC	:	Voltage Common Collector
viz.	:	Namely
W	:	Watt
WASP	:	Web Agri Stat Package
Wi-Fi	:	Wireless Fidelity
WSN	:	Wireless Sensor Networks
β	:	Beta
$\mu mol\ m^{-2}\ s^{-1}$	:	Micromole per square meter per second

Introduction

CHAPTER I

INTRODUCTION

India is one of the major players in the agricultural sector worldwide and 54.6% of its total workforce is engaged in agriculture and allied sectors (MoA and FW, 2022). Compared to other countries, India faces a greater challenge that with only a 2.3% share of the world's total land area; it has to ensure the food security to about 17.5% of the world population (MoA, 2011). It is expected that the world population will expand to approximately 9.7 billion people and India's population will rise to 166.8 crore by 2050 (UN, 2022). Overuse of land and water resources due to the increasing population leads to decrease in the availability of land and water resources for agricultural production. In addition, the decreased soil productivity in the cultivable areas and the inadequate soil fertility as a result of continuous cultivation round the year present serious obstacles for conventional soil-based agriculture. Along with these, unchecked pollution of water bodies, decline in groundwater levels, poor water resource management and over-irrigation leading to wastage of water are also challenges to conventional soil-based agriculture. Besides these, climate change poses threats in the form of temperature rise, frequent dry periods and changing weather patterns. These challenges pose a severe threat to traditional soil-based agricultural systems, making it increasingly difficult to produce food today. These challenges can be overcome by using the latest technologies with advanced methods of crop production. Modern agriculture should consider these challenges: decrease in per capita land availability, reduced productivity of soil, depletion in the nutrient content of the soil, water scarcity and climate change. Modification of growing medium is an alternative to sustainably feed the world's growing population.

Soilless or liquid culture techniques can be a solution to these problems by reducing the issues associated with soil-based crop production systems. The need for food security has paved the way for soilless agriculture, and is becoming more popular in the urban area and becoming a part of urban farming. Protected soilless cultivation facilitates control over the environment and avoids uncertainties in nutrient and water status. In today's agriculture industry, the soilless culture system is more effective in crop production. It provides good quality produce and high yield even in areas having adverse growing conditions (Putra and Yuliando, 2015).

There are several soilless cultivation systems such as Hydroponics, Aquaponics and Aeroponics. Among these, hydroponics is the mostly used soil-less cultivation system, because of its efficient management of resources and good quality produce. Hydroponics is a method of growing plants in solutions containing nutrients with or without the use of an inert medium to offer mechanical support, such as gravel, vermiculite, cocopeat, rockwool, peat moss, saw dust, coir dust, coconut fiber, clay pallets among other things. Hydroponics is derived from the Greek words hydros, which mean water, and ponos, which means work. Professor William Gericke invented the term hydroponics to describe the cultivation of plants with their roots suspended in water containing mineral nutrients in the early 1930s. Unlike other conventional agriculture, hydroponics has complete control over nutrition. It requires only the exact amount of nutrients which is needed for the crops and has better water management also. As irrigation and other types of sprays are not required with hydroponics, and water logging never happens, a significant amount of water is saved and prevents any loss of nutrients as precise amount is applied. Many conventional agricultural practices, like weeding, spraying, watering, and tilling can be eliminated and hence have less labour and also required less area for cultivation. Since there are more plants per unit area than in traditional agriculture and direct availability of the required amount of nutrients, better yields can be obtained. There is no risk of soil-borne diseases, bug, or pest infestation to the crops, the need for pesticides and other chemicals can be reduced or eliminated, hence producing improved quality of produces. Plants grow more quickly than field crops because their roots are not mechanically hampered and because all of the nutrients are readily available to them. Plants also require less time to mature than field crops do. Since hydroponics crops are not affected by climatic change, they can be grown year round and are not regarded to be seasonal. Due to the aforementioned reasons, hydroponics is usually considered a superior form of agriculture.

There are different hydroponics systems, which include wick, ebb and flow, drip, deep water culture and Nutrient Film Technique (NFT) systems, etc. Among these, NFT is the most commonly used method for commercial crop production since the plant growth is better due to the adequate oxygen-rich nutrient solution supply (Helmy *et al*., 2016). In this system, the plant roots are suspended in gullies, which are channels through which a thin film of nutrient solution circulates, keeping the roots wet but not logged. The nutrients are mixed together in a primary reservoir, from which it continuously flows through the system and feeds the plants. Recirculation of nutrient solutions for crop production is the main principle of the NFT system. The system is widely used for a variety of crop production and is more suitable for short-term crops such as lettuce, leafy crops and herbs. In this system, the nutrient concentration, pH, flow rate, temperature of the nutrient solution and climatic parameters are the important parameters that affect crop yield. pH affects the availability of nutrients to plants. EC of the nutrient solution determines the growth, development and production of plants. The temperature of the nutrient solution influences the uptake of water and nutrients by the crop and also affects the availability of dissolved oxygen. Flow rate is an important parameter in the NFT hydroponics cultivation system; hence flow rate in NFT is essential to be ideal to allow the plant roots to absorb all elements needed from nutrient solution. Similarly, light intensity, air temperature and RH also affect crop growth. Since these parameters are important, they should be within the optimum level. Hence, it is necessary to continuously monitor and control these parameters every day for better crop production. Continuous monitoring and control is difficult manually. Here comes the importance of automation. Automation of the NFT hydroponics system makes management of the nutrient solution and microclimatic condition easier and more precise.

So, with this as a background, some amount of research has been carried out by employing automation in hydroponics agriculture. One among these, a data acquisition system for hydroponics cultivation was developed. As a microcontroller, a DFRobot Arduino Mega 2560 was employed. Vital indicators like ambient temperature, relative humidity, water temperature, water level, pH level, and light intensity are all monitored by the system and saved on an SD card (Tagle *et al*., 2018). Whereas Kuncoro *et al*. (2021) developed an automated nutrient film technique (NFT) Hydroponics system. The suggested system regulates and keeps track of the nutrient solution's pH level, electrical conductivity (EC), dissolved oxygen (DO), water temperature, water flow rate, and water level. The developed countries are utilizing these technologies more and more. Before being adopted in crop production, the technology must first undergo considerable research on various aspects because it is still in its infancy in developing countries. Particularly in India, population expansion has created a demand for hydroponically farmed cultivation practices. But due to a lack of research and proof on many aspects of the technology, the technique is still far from being put into practice.

It is a fact that the hydroponics method of cultivation has many advantages over conventional cultivation practices including water and nutrient conservation, less labour and area requirement, high yield and quality of produce, etc. But, the loss of yield is greater, if the parameters that affect the crop growth in the hydroponics system are not within the permissible limit when compared to soil-based cultivation. Hence, it is important to continuously monitor all the parameters as it is subject to continuous changes. It is difficult to continuously monitor the parameters manually. Hence, automation has significant importance in hydroponics cultivation. The challenges being faced by the conventional method of agriculture attract people towards hydroponics, but it is limited to a few hands due to the lack of development in many areas of the technology. In India, there is very less amount of research conducted on automated monitoring and control of hydroponics. Accurate data collection and presentation are essential as the automation in a hydroponics system is in the juvenile state. Information in general is a prerequisite to produce backed-up and evidential outcomes which could significantly improve yield and quality.

In view of all the above facts, the present study entitled **"Development and evaluation of automated data acquisition NFT hydroponics system."** was undertaken with the following specific objectives:

- To develop an automated data acquisition NFT hydroponics system
- To evaluate the performance of the developed NFT hydroponics system for different flow rates
- To study the microclimate and nutrient solution status

Review of Literature

CHAPTER II
REVIEW OF LITERATURE

This chapter reviews the research works conducted by different researchers on the topics related to NFT hydroponics cultivation, automation in hydroponics cultivation and effect of various parameters on crop growth in hydroponics including effect of flow rate of nutrient solution. It also discusses works related to effect of microclimate on crop growth.

2.1 NFT HYDROPONICS CULTIVATION

In this system the plant roots are suspended in gullies, which are channels through which a thin film of nutrient solution circulates, keeping the roots wet but not logged. Recirculation of nutrient solutions for crop production is the main principle of the NFT system. This system is widely used for a variety of crop production and is more suitable for short term crops such as lettuce, leafy crops and herbs.

Ahmed *et al*. (2003) evaluated nutrient film technique and sand culture for year round production of tomatoes in Tropical Asia. This study was carried out by using two cultivars of tomato include Egg tomato and Kinkong. They reported that sand culture was less costly and easy to establish and manage but higher production obtained in NFT hydroponics system.

Puerta *et al*. (2007) proposed a modified NFT (mNFT) for the uniform production of lettuce in long cultural bed. They provided 3 percent transversal slope. Along with that an irrigation hose at the upper lateral side of the secondary slope and a drainage channel at lower lateral side of the bed were placed. They also compared mNFT with the conventional NFT system (cNFT). The results revealed that as the distance from the nutrient inlet increased the fresh weight of plant was decreased in cNFT system, whereas it was uniform in mNFT system. Similarly, Leaf nitrate concentration, ascorbic acid concentration and oxygen content varied along the length of channel in cNFT system. Uniform growth and quality of plants can be achieved in long cultural beds of lengths up to 18 m with nutrient solution of low concentration.

Borges and Dal'Sotto (2016) analyzed the economic financial viability of hydroponics production based on NFT system of a family farm in the western region of Parana which produces lettuce and hydroponics arugula. Payback, internal rate of return (IRR), net present value (NPV) and point of equilibrium were used to verify the viability. The result revealed a rate of return of 20% per year and invested capital was returned in 2 years 5 months and 20 days.

Mohammed and Sookoo (2016) tested economic feasibility of a hydroponics system that was intended as a low-cost, simple method to measure the productivity of agriculture production. A semi-closed NFT hydroponics system was developed to grow lettuce and celery hydroponically in a somewhat regulated environment. The outcome showed that there was an ample output of celery and iceberg lettuce throughout a three-week period. The cost of operations for an 18 × 8 m commercial NFT hydroponics system was found to have increased due to expenses for packaging and vehicular transportation. They came to the conclusion that using the nutrient film approach might be very beneficial for a nation with little land resources and noted that one drawback of the NFT system is that it necessitates complete covering of all piping systems where the nutrient solution circulates. With even minimal exposure to a semi-open environment, algae development is predominant.

An assessment of soil cultivation (SC) and nutrient film technique (NFT) lettuce production systems with three supply scenarios of desalinated seawater (DSW) indicated that while compared to SC system, NFT system has 5.5 times higher yield, 3.5 times higher water productivity, 5.9 times higher total cost, 5.7 times higher revenue and 3.5 times higher profit. NFT system could be a better strategy than SC system as it shows 3.1 times higher net present value (NPV). However, SC investments have higher economic profitability, because it has four times higher internal rate of return than NFT system. Because of higher investment and operational costs in the NFT system it has a lower ratio of profit/total costs, hence SC system is placed above the NFT system under non-limiting conditions. Analysis considering price of DSW and lettuce yield NFT system was better than SC system (Maestre-Valero *et al*., 2018).

Rathod *et al*. (2020) conducted a field experiment to investigate the quality and growth of spinach in a controlled environment of hydroponics system. They studied three different structures including green, white and uv-polyethylene hydroponics structures. The experiment used a randomized block design. OPI STAT statistical software was used to examine the biometric traits and quality metrics. The length, width and height of the structure were 1400 mm, 970 mm, and 1800 mm respectively. According to the study, the green hydroponics structure's interior conditions including temperature, relative humidity, light intensity, and CO2 were ideal for spinach growth over the summer. Results of this study indicated that white and UV-polyethylene hydroponics structures came in second with superior results after the green hydroponics structure. White and UV-polyethylene hydroponics structures had higher inside temperature of 1-3 ℃ and maximum light intensity. They also compared these hydroponics systems with the open field and found that the biometric characteristics of spinach were higher in hydroponics structures compared to the open field. Two times less yield was obtained from open field compared to green, white and UV-polyethylene hydroponics structures.

Frasetya *et al*. (2021) provided recommendations for a more efficient hydroponics system to increase the growth of lettuce plants. Complete randomized design was the research method used and it consists of five treatments that were replicated five times. The treatment consists of five types of hydroponics installation systems, including Nutrient Film Technique System (NFT), Deep Film Technique System (DFT), EBB and Flow Systems (EFS), Aeroponics Systems (AS), and Floating Raft System (RFS). Plant height, leaf number, fresh weight, and shoot-root ratio were parameters observed to measure the effectiveness of each system. The observational data were then analyzed using analysis of variance at 5 percent significance level and Duncan's test at 5% level. The results showed that the NFT hydroponics system of lettuce plants was 6 percent to 10 percent more efficient and NFT and RFS systems were recommended for better lettuce production.

Thapa *et al*. (2021) carried out an analysis of economic viability of hydroponics cultivation in the hydroponics farm inside Trathmandu valley. An interview was also conducted among growers. A benefit cost ratio of 2.32 and an internal rate of return (IRR) of 27% with NPV after 10 years were pointed out in the economic analysis. The system also showed a quick recovery of invested capital and it was around 3.81 years.

2.2 AUTOMATION IN NFT HYDROPONICS CULTIVATION

Domingues *et al.* (2012) developed a system for 24 hour monitoring of conductivity and pH during the entire cycle of production of lettuce which is completely managed by lab-made software. The software used here is called ControlHidro, pH meter and EC meter were used to monitor the pH and EC of nutrient solution. By using solenoid valves that deliver acid/base or nutrient solutions, automatically corrected any fluctuation in conductivity and pH. This method is employed to cultivate lettuce (*Lactuca sativa* L.). The efficiency of the developed system was evaluated by comparing it with conventional soil based cultivation of lettuce. The result indicated that the developed hydroponics system requires 64 days to harvest against 71 days in the conventional system and had reduced labour, better control and higher productivity with fresh and dry matter of aerial parts of 267.56 and 13.33 g plant^{-1} respectively.

Velazquez *et al*. (2013) explained the first advances in the development of a hydroponics system for the cherry tomato culture using NFT. Electrical conductivity and pH were the parameters monitored in this study. Sensors and conditioning circuits were designed and implemented to monitor such parameters. The result indicated that pH measurement has a high accuracy with a correlation coefficient of 0.994 for expected values and a standard deviation of 0.01 after repeated measurements.

Helmy *et al*. (2016) discussed the necessity of monitoring of different parameters such as EC, pH and nutrient solution temperature which have important roles in hydroponics production and developed a NFT hydroponics monitoring system. Arduino UNO was used as the microcontroller and collected data such as pH, TDS, and temperature through respective sensors. GSM/GPRS shield is used to send all acquisition sensor data to the server, so that farmers were able to monitor TDS, pH and temperature online. This system had a delay between sending data from GPRS modem and data receiving at the server. It was more in daylight and afternoon and less during night and morning.

Eridani *et al*. (2017) constructed a prototype scaled Nutrient Film Technique (NFT) hydroponics having an automated nutrient supply system with Arduino UNO R3 as controller. This system uses GP2Y0A21 proximity sensor to detect water level, TDS sensor for indication of electrical conductivity of the nutrient solution and flow of nutrients from the container is controlled by a servo motor. The results showed that system can deliver water automatically when the water level is below the minimum level and add nutrients automatically when the nutrient solution concentration is below 800 ppm.

Gosavi (2017) created an automated system to monitor pH, luminosity and conductivity of solution in water culture. The proposed system also controls the luminosity as light is the parameter that changes continuously. The microcontroller used for this system was ARM7 and the software used was KEIL µVISION® IDE. Cucumber was used as the crop for this study.

Ruengittinun *et al*. (2017) proposed a Hydroponics Farming Ecosystem (HFE) to assist amateur farmers, city residents with little experience in farming, and those who are interested in growing vertically in limited urban places such as building tops, balconies, in tall buildings, and small office spaces. The system monitors humidity, nutrient solution temperature, air temperature, pH and

Electrical Conductivity (EC) using IoT devices. An Android application makes the system easy to control and easy to use and the system alarm users when their farm is in an abnormal situation. The architecture consists of multiple sensors, an Arduino UNO board, a Wi-Fi Shield, a Relay, an MQTT Broker, a Server, a Database and mobile user. Sensors send data to Arduino UNO which is used as the microcontroller and then data is transferred to other parts.

Siregar *et al.* (2017) proposed a monitoring system for hydroponics cultivation. The system consists of pH sensor, electrical conductivity sensor, water temperature sensor, air temperature sensor and light sensor to monitor the parameters. Arduino UNO was used as the main board. They tested the working of the developed system for two weeks with cultivation of spinach, lettuce, mustard and pakchoy. The end result showed that the system and sensors were working properly.

The Cyber Physical Social System (CPSS) has made it possible for hydroponics farmers to work together. A hydroponics smart farming system that can be monitored online via Telegram Messenger is created using this novel idea. Important hydroponics system factors can be monitored by the created design, including light intensity, room temperature, humidity, pH, nutrient temperature, and electrical conductivity (EC). The Raspberry Pi 3 is used to create the prototype, which is directly connected to sensors such as DHT11 module, LDR, pH sensor module and EC sensor. Additionally produced is a Telegram BOT that enables online sensor monitoring over Telegram. The flexibility of hydroponics system monitoring increases with the combination of the Physical System (Raspberry Pi, sensor) and Social System (Telegram Messenger), both of which are connected online via the internet (Sisyanto *et al.*, 2017).

Changmai *et al.* (2018) developed a smart hydroponics farm using Internet of Things technology and investigated its benefits by comparing it with regular hydroponics farm. The crop used for the experiment was Lettuce. Arduino MEGA 2560 Rev. 3 is used as the control module. The system consists of three IoT subsystems. The first subsystem monitors the growing environment and sends data to the server. The second one adjusts nutrient solution based on the data obtained from the environmental monitoring system and the last adjusts air temperature and humidity according to the situation automatically. Results of this study indicated that a smart hydroponics farm has 36.59% more weight, 13.9% larger stem diameter and 17.2% more leaf compared to a regular farm.

Sihombing *et al*. (2018) discussed the importance of automatic watering of hydroponics plants and developed an automated nutrient solution flow control tool for hydroponics prototype system using Arduino microcontroller that can be controlled by Smartphone. Arduino UNO was used as the microcontroller and the system also used ultrasonic sensor HC-SR04 to detect height of the nutrient solution and temperature sensor LM35 to detect temperature around plants. Data send by sensors to Arduino UNO was displayed in the liquid crystal display (LCD) and transmitted to an android Smartphone through wireless fidelity (WIFI) ESP8266 module. A relay linked to the microcontroller port will connect the sensor detection data. The water pump was operated to irrigate the hydroponics plant when the relay port pin is lower than the required height. The water pump will turn off when the relay for port pin is high, indicating that the water level has risen above the desired level. The nutrient pumps are also used to add nutrients in addition to increasing water levels.

The success or failure of the yield in hydroponics system depends on a number of elements and external factors. According to Tagle *et al*. (2018), conventional methods of observation and manual measurements, which are used to identify the components that contributed to yield quality, were ineffectual and insufficient. Readily available data help in the accurate collection and presentation of data. These data are facts and statistics collected together for reference or analysis. They developed a data acquisition system for hydroponics cultivation. As a microcontroller, a DFRobot Arduino MEGA 2560 was employed. Vital indicators like ambient temperature, relative humidity, water temperature, water level, pH level, and light intensity are all monitored by the system. An Arduino data logger was designed to gather data from the sensors after every 5 minutes and then saved them in an SD card. In order to provide real-time access to the system's performance, a 4X20 LCD module was incorporated. The data collected by all of the sensors and saved on an SD card revealed changes in the environment that were happening in the system in real-time, making it simple to monitor and identify problem areas. The hydroponics tower's performance in relation to the growth factors was displayed by the data collecting system. After validation, it was discovered that the average percentage error for each growing condition based on the corresponding standard instrument was close to 5%, demonstrating the viability of using sensors that are currently on the market to accurately monitor a hydroponics system.

Automation with IoT is not only for internet support and self updating readings from sensors and also should have to make useful data by using data analytics to have a sustainable production. Alipio *et al*. (2019) designed and implemented a smart NFT hydroponics system that automates the growing process of crops using Bayesian network (BN) model. The parameters including light intensity, pH, electrical conductivity, water temperature, and relative humidity are monitored and controlled by sensors and actuators. The sensor data were utilized to construct a Bayesian network, which categorizes and predicts the appropriate value for each actuator, allowing the hydroponics farm to be autonomously controlled. They also compared automated system with manually controlled system and observed that automated system with BN had less fluctuation in sensor values. The result indicated that after model validation, the prediction model had an accuracy of 84.53%, and the automatic control produced 66.67% more crops than the manual control.

Gomez-Chabla *et al.* (2019) mentioned that there were no reports of automated hydroponics monitoring systems that allow for reducing losses of plants in Ecuador. They described a case study of monitoring system implementation for the cultivation of lettuce in NFT hydroponics system. This system monitored humidity, temperature, pH, dissolved oxygen and EC of nutrient solution. Arduino MEGA was used as the microcontroller and the user will get the information through the mobile application.

Lakshmiprabha and Govindaraju (2019) suggested a smart irrigation system for hydroponics systems that makes use of the Internet of Things (IoT). The experimental prototype is created with the aid of the IoT platform ThingSpeak. Real-time physical data like temperature, humidity, and water flow are tracked, managed, and recorded. The proposed system can monitor and adjust the hydroponics environment, and the results showed that it can increase crop productivity.

Ullah *et al*. (2019) discussed the advantages of hydroponics systems and pointed out the convenience of farmers in cultivation by automating all the processes using IoT. They designed and developed a vertical hydroponics system using the IoT concept. The proposed system monitors and controls water level, temperature, humidity and pH through mobile application. ESP32 was used as the microcontroller. Farmers get data through the mobile application and are able to control the hardware components of the system using mobile phones.

Dudwadkar *et al*. (2020) designed a hydroponics system with controlled environment for ensuring maximum crop production. The system was composed of sensors like temperature and humidity sensor, pH sensor, conductivity plate sensors, light sensor and ultrasonic sensor to monitor corresponding parameters and actuators including water pump, air pump and Peltier cooling system to control the system. They developed an Android application for remote monitoring using IoT. They also predicted the required quantity of nutrient fluid to be added to the water based on pH and conductivity detected by sensors.

Iswanto *et al*. (2020) explained the methodology for the development of an automated system with Arduino UNO as microcontroller to control nutrient circulation in NFT hydroponics system. Ultrasonic sensor, peristaltic pump and solenoid valves were used. The filling of water and nutrients in the tank is controlled based on readings from ultrasonic sensor. They also pointed out that solenoid valve is not suitable for low water pressure.

Lakshmanan *et al*. (2020) presented a design and implemented an automated hydroponics system using the internet of things. The design consists of NodeMcu, Node Red, MQTT and sensors that detect different parameters and send these to the cloud. They developed a prototype first and tested it. Sensors collected data from two different environments and monitored using cloud based web page with a mobile application. This system also used bot to control the supply chain and for providing notifications.

Modu *et al*. (2020) investigated smart hydroponics systems and discussed the challenges that remain in this field. They classified smart hydroponics systems into four categories. Based on the automation level hydroponics was classified into semi- automated and fully automated systems. Next category was task automated, according to that smart hydroponics can be designed to offer assistance to the hydroponics system by maintaining the system's hardware, providing consumables or securing (cyber or physical) the system. Another type is that systems help in crop cultivation and the final subcategory includes those systems which monitor the various aspects of the hydroponics system and reports to farmer. Depending on the type of automation there are Embedded Systems, Wireless Sensor Networks (WSN) and Internet of Things (IoT) based systems. Based on mode of control also smart systems were classified as Proportional Integral Differential (PID) Controller and Artificial Intelligence (AI) based systems. Number of researchers have contributed to developing different smart hydroponics systems, but there are some challenges still in this field including system security, unexplored areas like automation of harvesting, study of impact of the sensors used in the development of plants, investigation of tolerance plants to high EC and/or pH and lack of data sets to develop efficient AI- based hydroponics system. AI- based research was less due to the requirement of huge computation and expense, but they were efficient in controlling hydroponics systems.

Saaid *et al*. (2020) demonstrated a system for automatically monitoring and adjusting pH levels for hydroponics cultivation. Hardware, programming, and functionality testing are the three basic approaches used in system development. Users must first establish the pH values for the plant's maximum and lowest requirements. The pH sensor will thereafter keep track of the water's pH level in real time. If the water pH level exceeds the user-specified parameters, a syringe pump with pH up (alkaline) and pH down (acid) solutions will drip the solutions to maintain the pH level. Results demonstrated that automated pH level monitoring and control had been created effectively, and that functionality had been examined and found to be satisfactory. Based on the validation performed, which demonstrated 100% accuracy of the syringe pump replies, the syringe pumps precisely replied upon variations in the water pH value.

Ezzahoui *et al*. (2021) conducted a comparative study of hydroponics and aquaponics farming. They compared and tabulated different studies of hydroponics and aquaponics based on IoT technologies, architectures and protocols. They also discussed the advantages and limitations of the studies. From the organized data they found that aquaponics system is perfect for their project based on the availability of information and as the hydroponics system is included in the aquaponics system.

Hartanto *et al*. (2021) created an automated hydroponics nutrient mixing system for both circulating NFT hydroponics system and non-circulating drip system. ESP32 was used as the microcontroller and IoT cloud Blynk was used for monitoring and control. This system used water temperature sensor (DS18B20), humidity and temperature sensor (DHT22) and luminosity sensor (TSL2561) along with pH and EC sensor. Lighting was also controlled in this system. Results of this study revealed that water temperature sensor DS18B20 has higher accuracy of 96.9%, while DHT22 has an accuracy of 93.3% in room (for temperature about 26 ℃) and 87.8% only in colder temperature about 19 ℃. The accuracy of humidity reading of DHT22 was less (82%) compared to temperature reading. The accuracy of EC sensor was 96.3%.

Kuncoro *et al*. (2021) developed an automated nutrient film technique (NFT) hydroponics system. The suggested system regulated and keeps track of the nutrient solution's pH level, electrical conductivity (EC), dissolved oxygen (DO), water temperature, water flow rate, and water level. Sensors, microprocessor, actuators, and data logger make up the system. By turning on the nutrient pumps, the pH sensor and EC sensor regulated the pH and quantity of nutrients the plant needs. Based on information gathered by the water temperature sensor and DO sensor on the mixing tank, the water temperature and dissolved oxygen level of the nutritional solution were also adjusted. The level of the nutrient solution in the mixing tank was controlled by data collected by a water level sensor on the mixing tank, and a water flow sensor is installed on the growing tray to determine the water flow speed. The data logger module recorded all of the nutritional environment variables that were being tracked on a micro SD card. A laboratory test showed that the system's ability to monitor and regulate the hydroponics system's environment's nutrient solution parameters was sound. A field test with Chinese cabbages as the target plant showed that the created method generated fresh, healthy, and high-yielding plants in a harvest period of only about 3.5 weeks.

Wibisono and Kristyawan (2021) addressed one of the drawbacks of NFT hydroponics systems the electricity dependence of water pump for twenty four hours and also proposed a solution for this. They created a more efficient automated NFT hydroponics system using Arduino. In this system, nutrient solution is pumped from reservoir to a storage tank, which is kept at a higher elevation than the plant. Nutrients are supplied to each plant by gravitational force. This automation system has two parts, pH level and nutrient distribution control based on the pH sensor and ultrasonic sensor. It is found from the result that the designed system saved 70% of electricity consumption.

Nguyen *et al*. (2022) discussed the currently facing problems in hydroponics systems including climate change and reduction of arable land area. They reported the design and development of an internet of Things-based automatic monitoring system for hydroponics farming. Real-time data collection from sensors is made possible by this system. To send and store this collected data in the cloud, an IoT gateway and virtual server were constructed. The user can view all sensor data from the hydroponics solution and surroundings, as well as manage the farming machinery, via the web interface.

2.3 EFFECT OF FLOW RATE ON CROP GROWTH

Among various parameters on crop growth, the effect of the flow rate of the nutrient solution has gained increasing attention in recent years. Genuncio *et al.* (2012) conducted a study to evaluate the accumulation of fresh weight of hydroponics lettuce in terms of ionic concentrations and flow rates of nutrient solution. Lettuce cultivars Lucy Brown, Izabela and Veneza were grown in different ionic concentrations of 100, 75 and 50% and flow rates of 1.50, 1.00 and 0.75 l/min. Analysis concluded that fresh mass production of lettuce cultivars in hydroponics was more at a flow rate of 1.5 l/min and 100% of ionic concentration.

Khater and Ali (2015) did a study on the effect of source of nutrients (effluent fish water and nutrient solution), flow rate (1.0, 1.5 and 2.0 l/min) and length of gully (2, 3 and 4 m) on lettuce production. Results indicated that fresh and dry weight of shoots, dry weight of root and NO3- N content increased in nutrient solution over those of effluent fish farming. Fresh and dry weight of shoots, dry weight of root and NO3-N content decreased with increasing the flow rate and length of gully.

Nuwansi *et al*. (2016) suggested an optimum water flow rate of 0.8 l/min for an aquaponics system having koi carp goldfish with water spinach. They conducted experiments with different flow rates 0.8, 2.4 and 4 l/min as treatments T_1, T_2 and T_3. Higher growth of water spinach was observed in T_1 in terms of yield, percentage height gain and plant height. Maximum fish growth was also found in the same flow rate. Plant growth and nutrient removal were increased with a decrease in flow rate.

Al-Tawaha *et al.* (2018) conducted an experiment to find out the ideal water flow rate in nutrient film technique system in order to optimize the uptake of nutrients with growth of lettuce. Ideal water flow in the nutrient film technique is essential for allowing absorption of all needed elements from nutrient solution through plant roots. To ensure good contact time between roots and nutrient solution water movement in the system should be designed. The nutrient balance through uptake and accumulation of essential elements in nutrient solution increases the yield of biomass under NFT and it changes at different water flow rates in hydroponics.

Dalastra *et al*. (2020) evaluated the production of head lettuce and nutrition based on different flow rates in NFT hydroponics system. Flow rates of 0.5, 1, 2 and 4 l/min were applied in each cultivation channel and treatment consists of five replications having 15 plants each. The highest shoot production was observed at the flow rate of 1 l/min followed by 2 and 4 l/min. Less amount of production was obtained with a flow rate of 0.5 l/min. In the case of root system fresh mass, the highest production was at 4 l/min and followed by 2 and 1 l/min which were similar to 0.5 l/min, whereas the higher nutrient content was provided by the flow rate of 1 l/min. The highest production of head lettuce was obtained at the flow rate of 1 l/min due to greater nutrient accumulation and its use efficiency.

Soares *et al*. (2020) conducted two experiments to evaluate the effect of brackish water in the preparation of nutrient solution and different flow rates for the cultivation of cauliflower in NFT hydroponics system. Flow rates used in the experiment were 1.5 and 2.5 l/min. The flow rate of 1.5 l/min provided higher fresh and dry masses, leaf area, number of leaves, shoot diameter and plant height.

Baiyin *et al*. (2021a) conducted a study on hydroponically cultivated Swiss chard (Beta vulgaris L. ssp. cicla) under different flow rates to analyze changes in growth, nutrient uptake, and nutrient use efficiency. This study reveals that leaf area, fresh weight, dry weight, and root length are increased by increasing the flow rate from 2 to 4 l/min and further increase in flow rate from 4 to 8 l/min, values of these growth parameters decreased. This indicates plant growth which is influenced by the nutrient uptake is affected by the flow rate. The optimum flow rate also improves nutrient use efficiency. Yield is increased by an increase in flow rate, at the same time intensive flow rate may cause excessive physical stimulation to plants and inhibit their growth. Therefore, it is important to choose an appropriate substrate flow rate for optimal hydroponics production. Baiyin *et al*. (2021b) mentioned that regulation of the optimal flow rate is also related to the types of plants and the shape of cultivation containers.

Baiyin *et al*. (2021c) found that proper flow rates, functioning as eustress, provided the roots with the proper mechanical stimulation to encourage root growth, boost nutrient absorption, and increase plant growth in general. On the other hand, excessive flow rates operated as distress that reduced root surface area and prevented root growth by causing the roots to become compact. So, compared to plants cultivated under a proper flow rate, excess flow rate led to a decreased root surface area, this in turn resulted in less nutrient ion absorption and inferior plant growth. These conclusions were based on a hydroponics cultivation study carried out using different flow rates under light-emitting diode lighting. Nutrient uptake, root morphology and plant growth were investigated. Swiss chard plants were cultivated hydroponically. Different flow rates of 2 l/min, 4 l/min, 6 l/min, and 8 l/min. plants were harvested after 21 days and root morphology, root and shoot fresh weight, root and shoot dry weight and root cellulose and hemicellulose content were analyzed. The result revealed that flow rates ranging from 2 l/min to 4 l/min has more plant growth and a flow rate of 4 l/min has a maximum yield. When the flow rate increased from 2l/min to 4l/min, the fresh weight of plant is increased by 26.0%. Plant fresh weight decreased by 43.6%, when the flow rate increased from 4 l/min to 6 l/min and by 58.3% when the flow rate increased from 4 l/min to 8 l/min. A similar trend was observed in all other parameters.

2.4 EFFECTS OF NUTRIENT SOLUTION PARAMETERS ON CROP GROWTH IN NFT HYDROPONICS

Crop growth in a hydroponics system depends on the physical and chemical properties of nutrient solutions, which include pH, temperature, dissolved oxygen concentration, composition, and nutrient concentrations. pH has an effect on the availability of nutrients to plants. Resh (2004) cited by Trejo-Tellez and Gomez (2012) states that nutrient availability for plant uptake at pH above 7 may be restricted due to precipitation of Fe2+, Mn2+, PO3−4, Ca2+ and Mg2+ to insoluble and unavailable salts. The proper pH values of nutrient solutions for the development of crops lie between 5.5 and 6.5.The temperature of the nutrient solution also affects the uptake of water and nutrients by the crop. The development and growth of plants are determined by the total ionic concentration of the nutrient solution, which is indirectly indicated by the electrical conductivity (EC) of the nutrient solution. The value of EC in a hydroponics system ranges between 1.5 to 2.5 dS m^{-1}. Both higher and lower EC affects plant health and reduces yield (Samarakoon *et al*., 2006). In alkaline and highly acidic solutions the concentration of P decreases in a significant way (Dysko *et al*., 2008).

2.4.1 pH of nutrient solution

Samarakoon *et al*. (2020) studied the effect of different pH levels on the yield and tipburn of lettuce. Four pH levels of 5.8, 6.0, 6.2 and 6.4 were used and maintained a constant EC of 1.8 mS cm^{-1}. Results indicated that pH 6.0 and 6.2 were ideal for all varieties and different pH levels had no effect on the tipburn symptoms.

2.4.2 Electrical conductivity of nutrient solution

Abou-Hadid *et al*. (1996) conducted a study to determine the effect of electrical conductivity on the growth and mineral composition of lettuce in hydroponics system. Three varieties of lettuce plants were cultivated in this study. Three different electrical conductivities were studied, which include 1.0, 1.5 and 1.8 mmhos/ cm. The result of the study indicated that the increment in EC of nutrient solution reduce the fresh weight in all three varieties of lettuce. The mineral composition of lettuce was less affected by the different EC levels and varieties for some nutrients like N, P and K. whereas micronutrients were affected. This study revealed that 1.0-1.5 m mhos was the optimum EC level of nutrient solution for lettuce production.

Investigation on the impact of different EC levels of nutrient solution on the degree of tipburn and yield of lettuce found that proper management of pH and EC is necessary for control of tipburn and to get the maximum yield. Four different levels of EC were used in this study, which include 1.4, 1.6, 1.8 and 2.0 mS cm^{-1} and a constant pH of 5.8 were used. Among these systems having EC more than 1.8 mS cm^{-1} provided maximum yield for both 'Green Butter' and 'Red Butter' varieties and more than 1.6 mS cm^{-1}produced maximum for the variety 'Red Oakleaf'. It was found that symptoms of tipburn were minimal at 1.4 mS cm^{-1} for 'Green Butter' (Samarakoon *et al*., 2020).

2.4.3 Temperature of nutrient solution

The growth of plants in hydroponics media may be impacted by temperature variations. Most plants are unable to grow at less than ideal conditions. Numerous physiological processes, including photosynthesis, chlorophyll production and pigmentation, nutrient intake, accumulation, and the synthesis of secondary metabolites in plants, are impacted when temperatures are not at an ideal level. Thermo regulation of the hydroponics solution in the glasshouse is a method that can be utilized to maximize the production of flowers or flowering plants throughout the winter (Nxawe *et al*., 2010).

Thakulla *et al*. (2021) suggested to maintain the water temperature within an optimum range as °Brix and yield were affected by hydroponics nutrient solution temperature. They cultivated lettuce plants in NFT hydroponics system and applied three different temperatures of 18.3 ℃, 21.1 ℃ and ambient temperature. Results showed that plant width, root and shoot fresh and dry weight, and °Brix for lettuce were all influenced by water temperature. The shoot fresh weight of lettuce produced at 21.1 °C was 15% higher than that of plants cultivated at ambient temperatures. According to these findings, lettuce grown at 21.1 °C had 26% lower Brix than lettuce cultivated at 18.3 °C but showed stronger growth and biomass.

Hendrickson *et al*. (2022) determined the ideal water temperature for hydroponically cultivating various varieties of basil. In this treatment, three water temperatures of 23, 27.5, and 31 °C were used. Height, width, average leaf area, leaf number, chlorophyll concentration, shoot fresh weight, shoot dry weight, and root dry weight were all examined. In general, basil grown in nutrient solutions heated to 27.5 and 31 °C grew better than basil cultivated in solutions heated to 23 °C. The treatment at 31 °C had the maximum height, while the 27.5 °C treatment did not differ from it in terms of width, average leaf area, shoot fresh weight, or shoot dry weight. The highest chlorophyll concentration (SPAD) value was found in the 23 °C treatment. These findings imply that raising nutrient solutions to a temperature of 27.5 °C will enhance basil quality and growth in the majority of basil varieties cultivated in NFT hydroponics systems.

2.5 EFFECT OF MICROCLIMATIC PARAMETERS ON CROP GROWTH

A framed structure called a greenhouse creates a barrier between the plant microclimate and the outside climate. A greenhouse can be used to generate a microclimate that is better suited for crop development than the outside environment, resulting in increased crop growth and uniformly high-quality products. The maintenance of the optimum level of the variables for success and improved productivity in protected cultivation is typically stressed since the microclimate components inside the structures influence the functional aspects of plants. Crop photosynthesis accounts for 90% of the dry matter accumulation and plant production, therefore maintaining it is crucial under the protective structure (Umesha *et al*., 2011).

Light intensity and air temperature have a positive correlation with the electrical conductivity of hydroponics nutrient solution, whereas relative humidity has a negative correlation. Water uptake by plants increases as the air temperature and light intensity increase, which results in the rise of nutrient concentration of the solution and hence an increment in the EC of the solution. No significant correlation between the pH and climatic factors (Pokluda and Kobza, 2001).

2.5.1 Temperature

One of the main elements influencing plant development is temperature. Plant productivity will be impacted by the anticipated warming of the environment and the potential for more extreme temperature events.

Gent (2016) discussed the effect of temperature on hydroponics lettuce production under both cold temperature and higher temperature. The dry matter content of leaf blades increased at cool temperatures more than that for petioles or roots. In contrast to other plant parts, it also reduced nitrate and raised malic acid in the leaves. All these processes were reversed at higher temperatures. Under cool conditions, the ratio of leaf blades to shoots was similarly higher. It was found that 20 percent more dry matter content in the plants grown under cool temperatures. Compared to the warm temperature treatment cool temperature condition had 40 per cent less nitrate concentration and 50% higher concentration of sugars. It would be advantageous to harvest lettuce for human consumption after a little period of growth at a cool temperature for all the aforementioned reasons.

Arunadevi *et al*. (2020) evaluated the inside and outside microclimatic parameters of a shade net house and the nutrient solution properties of the hydroponics system inside the shade net house. A slightly lesser temperature was found inside the shade net house compared to the outside. The reduction was in the range of 1.6 ºC to 2.7 ºC. Even though the change was extremely little, it had a big impact on crop development. It decreased the transpiration loss from plants. As a result, the crop's need for water was slightly reduced, and water use efficiency went up.

Spinach cultivation is very difficult in hot seasons, even with cultivars relatively resistant to high temperature. Tai *et al*. (2020) investigated a strategy for minimizing heat stress in spinach cultivation in greenhouses. The growth of spinach with and without a micro-mist system was compared. Through the evaporation of mist, this system successfully lowered the temperature in the greenhouse by as much as 4.3 °C. The micro-mist operation scheme was set up so that when the greenhouse's ambient temperature rose above 32 °C, the micro-mist began spraying a mist at a rate of 60 mL per minute for 6 minutes then stopping for 1.5 minutes. When the temperature fell to 30 °C or below, the micro-mist was then turned off. The results demonstrate a 30% increase in crop output and a 1.4-fold increase in lutein content in spinach produced with a micro-mist system than conventional system during the hot season.

2.5.2 Relative humidity

Relative humidity (RH) has a direct impact on a plant's water relations and a secondary impact on leaf development, photosynthesis, pollination, the development of diseases, and ultimately economic production. Leaf growth is influenced by both the physical process of cell enlargement and synthetic activities that come from biochemical processes. Turgor pressure that has built up inside the cells causes cell enlargement. Due to lower transpiration at RH, turgor pressure is higher. Thus, leaf enlargement is more common in humid climates. RH has an indirect effect on photosynthesis. When RH is low, transpiration occurs and the plant experiences water deficiencies. Water shortages cause stomata to partially or completely close and increase mesophyll resistance blocking the entry of carbon dioxide.

Codarin *et al*. (2006) studied the effect of relative humidity on Hydrangea macrophylla cv. Leuchfeuer growth. They reported that relative humidity affects the size of the plant and the total leaf area. It is observed that while reducing relative humidity from 80 percent to 50 percent it shows a 38 percent decrease in height growth and a 30 percent decrease in leaf growth. Fifty percent treatment of relative humidity has an average plant height of 12.03 ± 0.77 cm and 80 percent treatment has 16.19 ± 1.76 cm.

Suzuki *et al*. (2015) investigated the effects of higher humidity levels on plant growth and nutrient uptake of tomatoes under elevated CO_2 conditions. Tomatoes are grown hydroponically in two greenhouses; one is equipped with a humidification system and the other one is taken as control. The study reported that humidification does not affect the leaf area per plant whereas high EC treatment increased the leaf area. Results suggested that higher humidity increases water use efficiency, whereas the nutrient content of leaves was suppressed by mist in the low EC.

Vanhassel *et al*. (2015) observed in experiments of hydroponics lettuce in the NFT system that high relative humidity decreases the occurrence of tipburn in lettuce. The result revealed that 60 to 100 percent control plants show tip burn disorder, whereas by maintaining RH above 95 percent tipburn is reduced to 3 to 50 percent. This is due to the increased Ca transport to the young leaf margins of lettuce.

2.5.3 Light intensity

Another factor that influences the physiological and morphological process is light. Plant growth is correlated with light intensity. It is an important limiting factor in the growth and development of plants. Low light intensity exposure resulted in an increase in the surface area of the leaf (Guo *et al*., 2013). Starch and carbohydrate production is induced by higher light intensity, which resulted in the increment of biomass production (Ncise *et al*., 2020).

Li *et al*. (2011) conducted a study on spinach biomass production and carotenoid pigments based on light quality and photosynthetic photon flux (PPF). The study reported that white and/or red fluorescent lamps of 300 μmol m^{-2} s^{-1} PPF increase dry mass accumulation in spinach than in blue fluorescent lamp. Light quality and PPF are important parameters that affect β-carotene and lutein concentrations of spinach on a fresh and dry mass basis. It concluded that β-carotene and lutein concentrations and biomass production of spinach are depends on PPF.

Esa *et al*. (2018) compared the effect of natural light and light Emitting Diode (LED) light on plant growth in hydroponics systems. The result indicated that the number of leaves, average height and average dry matter content was about twofold with LED lighting as compared to natural lighting.

Effects on the growth, biochemical and physiological properties of Aralia elata seedlings by different shading treatments were conducted. Different treatments of 50 percent, 65 percent, and 80 percent shadings were studied. It resulted that maximum plant growth is attained at 65 percent shading and chlorophyll contents were higher in 50 percent and 65 percent shaded plants compared to 80 percent shaded and control on the 45th day. The leaf protective enzyme activities and resistance indexes increased in 80 percent shading treatment and 65 percent shading treatment has more soluble protein content. The study concluded that a favorable condition for the normal growth and development of A. elata is 65 percent shading (Gao *et al*., 2019).

Under a mix of red and blue LEDs (R660/B450 = 80/20) in a home environment, the impact of four different light intensities (90, 140, 190, and 240 µmol $m^{-2}s^{-1}$) on the growth, photosynthesis, and leaf microstructure of hydroponically grown spinach was examined. With increasing intensity, the plant's height, leaf area, RGR, NAR, Chla, Chl(a + b), and photosynthetic capacity all increased. Between the four treatments, there were statistically significant differences in leaf thickness, palisade tissue length, and spongy tissue length. Even yet, 1.4 times increase in leaf thickness was seen in the 190 µmol $m^{-2}s^{-1}$ treatment compared to the 90 µmol $m^{-2}s^{-1}$ treatment. Epidermal cell area, stomatal length, and stomatal width all increased with increasing light intensity. The results showed that the 190 µmol $m^{-2}s^{-1}$ treatment had the highest fresh weight and dry weight of stem and leaf, theoretical yield, and final harvest yield. The finding of this research indicated that a light intensity of 190 µmol $m^{-2}s^{-1}$ would be suitable for spinach development (Nguyen *et al*., 2019).

Mohamed *et al*. (2021) conducted a study on the effects of three different LED light treatments for supplemental light intensity on the properties of the Thymus vulgaris L. plant. The obtained findings and the control were compared (with no supplemental LED light). In addition to natural sunlight, LED light sources had light intensities of 30, 25, and 20 µmol $m^{-2}s^{-1}$. Plant length (cm), fresh weight (g) and dry weight (g) were measured. Additionally, the number of photosynthetic pigments and essential oil accumulation in leaves was measured. The findings revealed that the highest fresh weight, dry weight, and height measurements for thyme plant growth were 28.7g, 8.4g, and 36 cm, respectively, at the highest light intensity of 30 µmol m^{-2} s^{-1} (L_1). The highest concentration of photosynthetic pigments was found in leaves at a light intensity of 25 µmol m^{-2} s^{-1} (L_2.) It is evident that at the greatest light intensity of 30 µmol m^{-2} s^{-1}, the highest essential oil accumulation was 4.66%. (L_1).

The above mentioned studies revealed that agricultural industry is experiencing a profound transformation in hydroponics with the integration of automation technologies. The world is utilizing these technologies more and more, but very few researches were conducted in India with the adoption of automation technologies in hydroponics cultivation. The studies referred also shows that some of the researches conducted only on the monitoring of various parameters whereas some of them conducted on both monitoring and control, but of few parameters. Due to a lack of research and proof on many aspects of the technology, the technique is still far from being put into practice. Hence the technology must first undergo considerable research on various aspects because it is still in its infancy in countries like India. Flow rate is an important parameter which affects the growth of crop in NFT hydroponics. Among the two studies reviewed on optimum flow rates, with the cultivation of lettuce, result is contradictory.

All these motivated to develop an automated data acquisition NFT hydroponics system. This system aims to monitor the nutrient solution parameters like pH, electrical conductivity, nutrient solution temperature and depth of nutrient solution in the tank and in the channel and climatic parameters including air temperature, relative humidity and light intensity in real time and also to control the operation of fans and foggers to optimize the climatic condition inside the polyhouse. The study also aims to evaluate the performance of the developed NFT hydroponics system for different flow rates and to study the microclimate and nutrient solution status.

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the materials used and methodologies adopted for the study under the title "Development and Evaluation of Automated Data Acquisition NFT Hydroponics System" conducted at Agronomic Research Station, Chalakudy, Thrissur, Kerala.

3.1 STUDY AREA

The experiment was conducted in the naturally ventilated polyhouse of the Agronomic Research Station (ARS), Chalakudy in Thrissur, Kerala. The site is situated at 10° 20' N latitude and 76° 26' E longitude with an altitude of 3.25 m above mean sea level.

3.1.1 Climate

The area receives both South West monsoon and North East monsoon and a few summer showers. South West monsoon contributes the major part of total rainfall. The average annual rainfall of the area is 3289 mm. The maximum temperature ranges from 26.17℃ to 36.75℃ and the minimum temperature range from17.98℃ to 28.1℃. The maximum relative humidity of the area is 92.97 % and the minimum relative humidity is 68.18 %. The mean evaporation rate of the study area is 3.71 mm day^{-1}.

3.2 DESIGN AND INSTALLATION OF NFT HYDROPONICS SYSTEM

Three benches (Bench I, Bench II and Bench III) of NFT hydroponics system were designed and installed in the polyhouse to grow crops in the study.

3.2.1 Components of NFT hydroponics system

Each bench of the NFT hydroponics system consists of NFT channels, rack, net cup, pump, nutrient solution tank, aerator and timer (Plate 3.1).

3.2.1.1 NFT channels

Four NFT channels, each of (Plate 3.1(a)) 3 m in length made of food-grade PVC material were used in each bench of the hydroponics system. The width of the channel was decided based on the crop to be grown. The width and depth of the channel were 10 cm and 5.5 cm respectively. It is white in colour which ensures thermal insulation protecting the roots from warm or cold temperature and has a removable lid that can be easily assembled and dismantled. Each channel consists of 19 holes of 5 cm diameter for placing net cups. Holes are spaced 15 cm centre to center distance.

3.2.1.2 Rack

A rectangular rack (280 x 80 x 75 cm) made of 25 mm GI square pipe (Plate 3.1(b)) was used to support the channels in each bench of NFT hydroponics system. A slope of one percent was provided to allow the continuous flow of nutrient solution through the channels.

3.2.1.3 Net cup

Net cups of size 5.5 cm upper diameter were used for growing plants in the NFT hydroponics system. Plate 3.1(c) shows the net cup used in the NFT hydroponics system.

3.2.1.4 Pump

A submersible pump (Plate 3.1(d)) was used to pump nutrient solution from the tank to the channels. The size of the pump is decided based flow rate the pump would need to supply to the system and the total head against which the pump is to be worked. It's crucial to account for the pump's 15–30% efficiency reduction in the calculations. Loss in efficiency was taken as 30%. The total flow rate was calculated using equation 3.1 and is given in Table 3.1.

Total flow rate (l/hr) = (number of channels * flow rate (l/hr)) + loss in efficiency … (3.1)

Table 3.1 Total flow rates of each hydroponics bench

Sl. No	Bench	Flow rate per channel (l/h)	Total flow rate (l/h)
1	Bench I	60	312
2	Bench II	120	624
3	Bench III	180	936

The head against which the pump is to be worked is the distance from the water level in the nutrient solution tank to the highest level to which the water is to be lifted. To the head, add 20 percent for friction inside the pipes and 30 percent to make up for back pressure loss in velocity. Hence the total head is obtained. It is recommended to choose a pump that can pump at least two times more water than the minimum required. Three HQB- 2500 water pumps of 55 watts, having 2.5 m head and 2000 (l/h) capacity were used in the study.

3.2.1.5 Nutrient solution tank

Tanks of capacities 150 l, 200 l and 500 l were used to hold the nutrient solution for Bench I, Bench II and Bench III respectively. Plate 3.1(e) shows the nutrient solution tank of capacity 150 l used.

3.2.1.6 Aerator

The availability of dissolved oxygen in the nutrient solution can be increased by aerating the nutrient solution using an aerator. AP-208 aquarium air pump (Plate 3.1(f)) of 2.5 W was used for aerating the nutrient solution.

3.2.1.7 Timer

A programmable timer (Plate 3.1(g)) was used to control the operating time of the pump. ON and OFF time periods of the pump were set in the timer using program button. During the day, from 6 am to 6 pm, the circulation of the nutrient solution was done for 15 minutes every 15 minutes (48 cycles). During the night, the circulation was for 15 minutes every 3 hours (4 cycles). The pumps were operated for 13 hours a day.

Plate 3.1 Components of NFT hydroponics system: (a) NFT channels, (b) Rack, (c) Net cup, (d) Pump, (e) Nutrient solution tank, (f) Aerator, (g) Timer

3.2.2 Installation of NFT hydroponics system

Three benches of NFT systems were installed in the polyhouse with one meter spacing between each bench (Fig 3.1). Polyhouse of size 12 m in length, 5 m in width and 6 m in height is oriented in the North-South direction. NFT systems were oriented in the East-West direction in the polyhouse. Each system consists of four channels and one nutrient solution tank, a submersible pump, aerator and a timer. Four channels were placed on a rack with a spacing of 20 cm. Each channel consists of 19 holes of 5 cm diameter for placing net pots. Plants were planted in the net pots. Holes are spaced with 15 cm centre to centre distance. Valves of 32 mm were used to control flow into each channel. Plate 3.2 shows Bench I of the NFT hydroponics system and the materials used for the construction of one bench of the NFT hydroponics system is given in Table 3.2. The installed NFT system is shown in Plate 3.3.

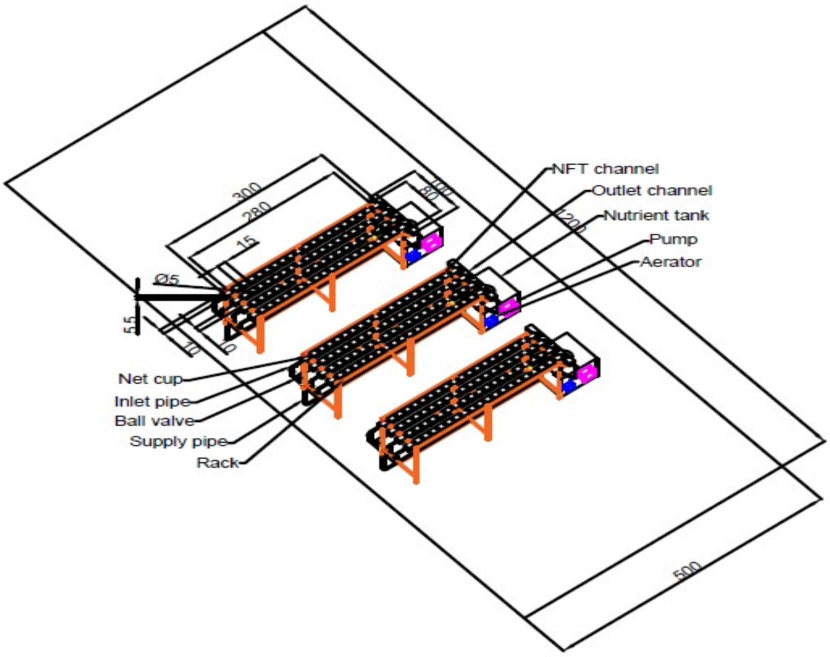


Fig. 3.1 Schematic diagram of NFT hydroponics systems installed in the polyhouse

Plate 3.2 Bench I NFT hydroponics system

Table 3.2 Materials used for the construction of one Bench of NFT hydroponics system

Sl. No	Material	Quantity
1	25 mm square pipe	20m
2	Bush	6
3	3 m NFT channel	4
4	1 m outlet channel	1
5	32 mm elbow	15
6	25 mm PVC pipe	10 m
7	32 mm valve	4
8	32 mm tee	3
9	flexible hose	2 m
10	submersible pump	1
11	Tank	1
12	25 mm FTA	1
13	25 mm hose collar	2
14	Aerator	1

Plate 3.3 Three benches of NFT hydroponics system installed in the polyhouse

3.3 DEVELOPMENT AND INSTALLATION OF IoT BASED AUTOMATED DATA ACQUISITION SYSTEM

An automated data acquisition system was developed for three benches of NFT hydroponics system to detect and monitor various parameters of microclimate such as air temperature, relative humidity and light intensity, nutrient solution parameters which includes electrical conductivity, pH, temperature and depth of nutrient solution in tank and channel using different sensors. The system also controlled the operation of fans and foggers in the polyhouse and gathered data that was accessed and displayed in mobile phones and computers using an IoT platform called ThingSpeak. This system consists of two subsystems, the first one was an automated monitoring system and the other one was the automated control system for fans and foggers.

The steps involved in the development of automated data acquisition system consist of;

i. Selection of hardware and software components
ii. Calibration of sensors
iii. Hardware designing
iv. Software designing

3.3.1 Hardware components

Hardware components of automated data acquisition system includes Arduino MEGA, Arduino UNO, various sensors and actuators, GPRS module, SIM 800 L GSM module, RTC module, liquid crystal displays, relay unit, I2C module, power supply, buck converter, PCB, metal box and push button switches. Sensors used in the study consist of pH sensors, EC sensors, temperature sensors, ultrasonic sensors, depth sensors, air temperature & RH sensor and light intensity sensor. Air circulating and exhaust fans, foggers and DC pumps were the actuators used in the study.

3.3.1.1 Arduino MEGA

The Arduino MEGA 2560 (Plate 3.4) was the microcontroller board used which is based on the ATMEGA 2560. It has 54 digital input/output pins, 16 analog inputs, USB connection, 16 MHz crystal oscillator, 4 UARTs, ICSP header, power jack and reset button. Its operating voltage is 5V. All sensors and actuators used were connected to the Arduino board. Program coding for automation was uploaded to this board. It interacts with digital, analog or electromechanical components and reads inputs and produces outputs. It controls actuators and sends collected data to ThingSpeak through GPRS module.

Plate 3.4 Arduino MEGA microcontroller board

3.3.1.2 Arduino UNO

Arduino UNO is a microcontroller board based on the ATMEGA328P (Plate 3.5). It has 14 digital input/output pins, 6 analog inputs, 16 MHz ceramic resonator, USB connection, power jack, ICSP header and reset button. It was the microcontroller board used for the automated unit of pH sensors.

Plate 3.5 Arduino UNO microcontroller board

3.3.1.3 Sensors

Sensors were used to measure the various parameters of nutrient solution and different environmental parameters inside the polyhouse. Based on these measured values of sensors and pre-set threshold values microcontroller controls actuators connected with that.

a. pH sensor

It measures pH of the nutrient solution in the range of 0-14 with an accuracy of ± 0.01 within the temperature range of 0-50°C. It has a 5V DC module power supply. The pH sensor used is shown in Plate 3.6 (a).

b. Electrical Conductivity (EC) sensor

EC sensor measures the electrical conductivity of nutrient solution, which is an indirect measure of nutrient concentration of the solution. DFRobot analog electrical conductivity meters were used in the study (Plate 3.6 (b)). It has two parts: **signal conversion board and electrical conductivity probe.** Supply voltage to the signal conversion board is 3 to 5 V and output voltage is 0 to 3.4 V. Probe connector is BNC (Bayonet Nut Coupling) type. It has a cable of length 100 cm. Recommended detection range of this EC sensor is 0 to 20 dSm^{-1}.

c. Temperature sensor

DS18B20 (Plate 3.6 (c)) temperature sensor was used to measure the nutrient solution temperature. It can be used in a temperature range of -55 to 125°C (-67°F to +257°F) and measure temperature of solution with an accuracy of ± 0.5°C. The required power supply is 3.0-5.5V. Sensor has digital output and one- wire interface for communication.

d. Ultrasonic sensor

HC-SR04 ultrasonic distance sensor (Plate 3.6 (d)) was used to measure the depth of nutrient solution in the tank. It is a digital sensor and it has a detection range of 2 to 400 cm. Resolution of the sensor is 0.3 cm.

e. Depth sensor

Depth of nutrient solution in the channel was measured by using depth sensor (Plate 3.6 (e)). It measures the depth in the range of 0- 32 mm.

f. Air temperature and relative humidity sensor

Both air temperature and relative humidity were measured by using DHT22 digital temperature and humidity sensor (Plate 3.6 (f)). It has an operating voltage of 3.5to 5.5V. It measures temperature in the range of -40 to 80°C and relative humidity in the range of 0 to 100%.

g. Light intensity sensor

Light intensity inside the polyhouse was measured by using BH1750 light intensity sensor (Plate 3.6 (g)). It measures light intensity in the range of 0- 65535 lx.

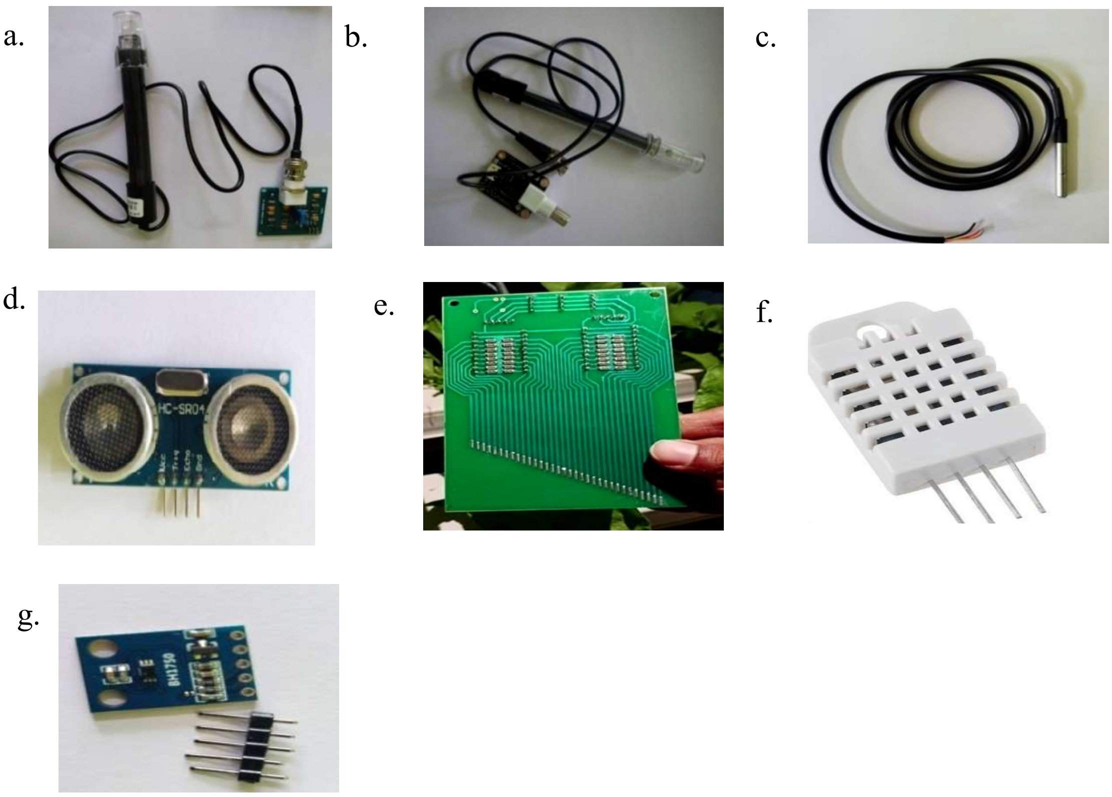


Plate 3.6 Various sensors used: (a) pH sensor, (b) EC sensor,(c) Temperature sensor, (d)Ultrasonic sensor, (e) Depth sensor, (f) Air temperature and relative humidity sensor, (g) Light intensity sensor

3.3.1.4 Actuators

The various measured values of parameters received from the sensors are compared with the preset values and based on that, the actuators are automatically controlled by the microcontroller. Actuators used in this study consist of air circulating fan, exhaust fans, booster pump for foggers, DC pumps. The actuators are shown in Plate 3.7.

a. Air circulating and exhaust fans

Air circulating and exhaust fans (Plate 3.7 (a) and 3.7 (b)) were used to increase the air circulation between the polyhouse and outside environment. Air circulating fan was fitted at center of the polyhouse and exhaust fans were fitted on two opposite walls of polyhouse. The specifications of air circulating fan and exhaust fans are given in Table 3.3.

b. Fogger

Eight four-way foggers of 2-4 kg cm^{-2} operating pressure were employed for evaporative cooling inside the polyhouse. Foggers were installed in 1.5 m × 2 m spacing, and a booster pump of 0.5 hp was used to operate them. Water for the fogger was supplied from a tank placed on the ground surface; hence a booster pump was required. Tank was fitted with a float valve, it automatically fills the tank.

c. DC pump

Two R385 6-12 V DC diaphragm mini aquarium water pumps were used for each NFT system, DC pump I is for pumping nutrient solution from the tank to a jar kept at a height of 0.5 m above the tank level. The pH and EC sensors were kept in a plastic jar for measuring pH and EC of nutrient solution. The DC pump II is used for pumping back the nutrient solution from the plastic jar to the nutrient solution tank once the pH and EC values were measured by the sensors. The specification of the DC pump is given in Table 3.4.

a. b. c. d.

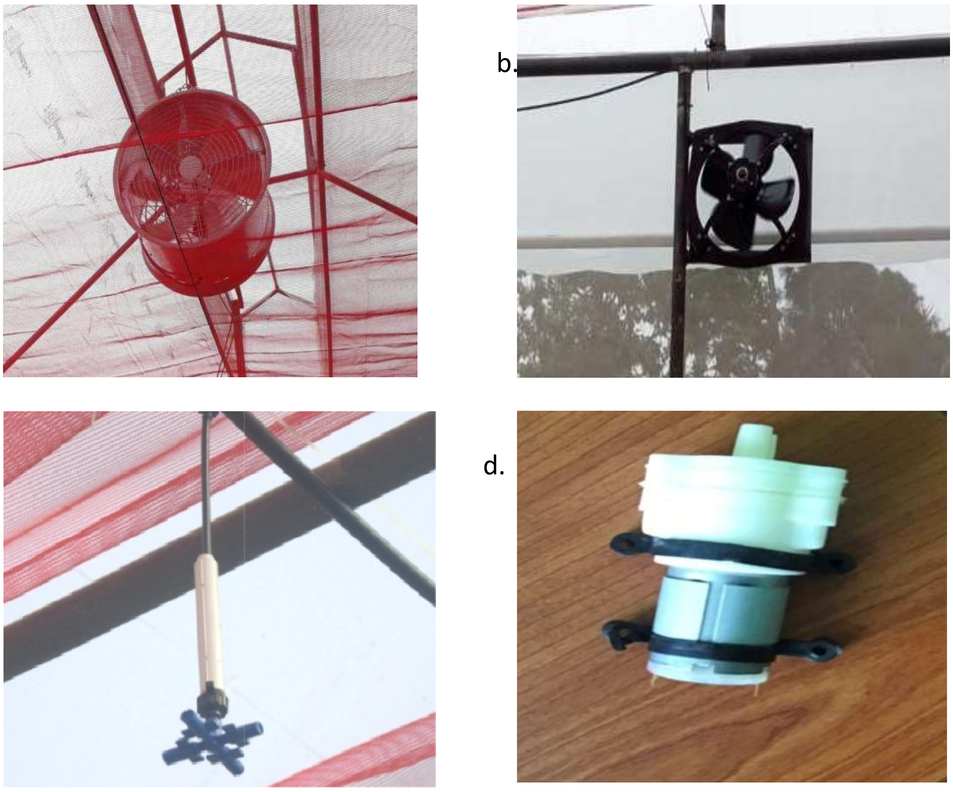


Plate 3.7 Various actuators used: (a) Air circulating fan, (b) Exhaust fan, (c) Fogger, (d) DC pump

Table 3.3 The specifications of air circulating fan and exhaust fans

Sl. No	Specification	Air circulating fan	Exhaust fan
1	Size	500 mm	300 mm
2	Voltage	230 V	230 V
3	Frequency	50 Hz	50 Hz
4	Power ratings	250 W	90 W
5	No. of blade leaf	7	4

Table 3.4 Specifications and features of R385 6-12V DC diaphragm mini aquarium water pump

Model	**R385**
Rated Voltage	**DC 6V to 12V (1 amps)**
Working current	**0.5A to 0.7A (Max)**
Power	**4W-7W**
Max Lift	**3m**
Max Suction	**2m**
Pump Size	**90mm * 40mm * 35mm**
Maximum flow rate	**up to 1 – 3 l/min**

3.3.1.5 GPRS module

SIM900A GSM/ GPRS module (Plate 3.8) was used in the study to provide network connection for data transfer between Arduino MEGA and the IoT platform. It requires a power supply of 12V and 1 to 2 A.

Plate 3.8 GPRS module

3.3.1.6 SIM800L GSM module

It is a miniature GSM modem (Plate 3.9), used for GPRS transmission, sending and receiving SMS and making and receiving voice calls. It was used to get connected to network for automation of pH monitoring system.

Plate 3.9 SIM800L GSM module

3.3.1.7 RTC module

The DS3231 RTC (Plate 3.10) module is a precise real time clock module which maintains accurate timekeeping when the main power to the device is interrupted. The DS3231 can keep track of seconds, minutes, hours, days, dates, months, and years. The RTC module was connected to Arduino MEGA board and fitted on the PCB inside the metal box.

Plate 3.10 RTC module

3.3.1.8 Liquid Crystal display (LCD module)

Three 20x4 LCDs (Plate 3.11) were used to display microclimatic parameters and nutrient solution status of each NFT system. It also displayed the status of internet connection and indicates whether fans and foggers were working or not. First it displays date and time, then EC of each system displayed in each LCD, then it shows humidity, air temperature and light intensity in all three LCDs and finally it displays water temperature, depth of solution in the channel and depth of solution in the tank.

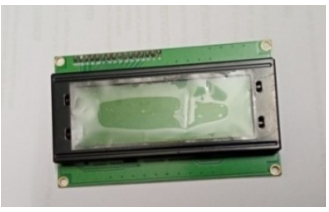


Plate 3.11 LCD module

3.3.1.9 Relay unit

Three heavy duty power relays of 12 V and 30 A were used in this system (Plate 3.12). One is to control the working of the air circulating fan and second one controls the working of two exhaust fans. Booster pump was controlled by the third relay.

Plate 3.12 Relay

3.3.1.10 I2C module

I2C module (Plate 3.13) has an inbuilt PCF8574 chip that converts I2C serial data to parallel data for the LCD. It helps to reduce the number of pins of Arduino required for the connection of LCD.

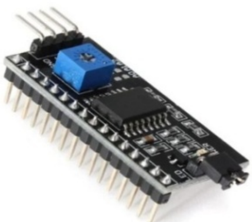


Plate 3.13 I2C module

3.3.1.11 Power supply

AD-11 ERD four channel Switched Mode Power Supply (SMPS) was used (Plate 3.14) to provide power supply to Arduino. It has an output voltage 12V DC and indicator for each channel. This 12V output was stepped down to 5V before supply to Arduino using a buck converter.

Plate 3.14 SMPS

3.3.1.12 Buck converter

LM2596S DC-DC Buck Converter (Plate 3.15) steps down voltage from 12V to 5V. It has an input voltage range of 3-40V and output voltage range of 1.5-35V.

Plate 3.15 Buck converter

3.3.1.13 Printed circuit board (PCB)

PCB is a sheet of insulating material with metallic circuit or tracks printed or etched on it for electrical conductivity. All sensors, actuators and other components were connected to Arduino using PCB (Plate 3.16) and wires. A single side PCB made of FR-4 material was used in the study and was designed by EasyEDA software. The PCB board is 1.6 mm thick and has 0.7mm trace clearance. It helps to reduce the complexity in connection and amount of wire used for connection.

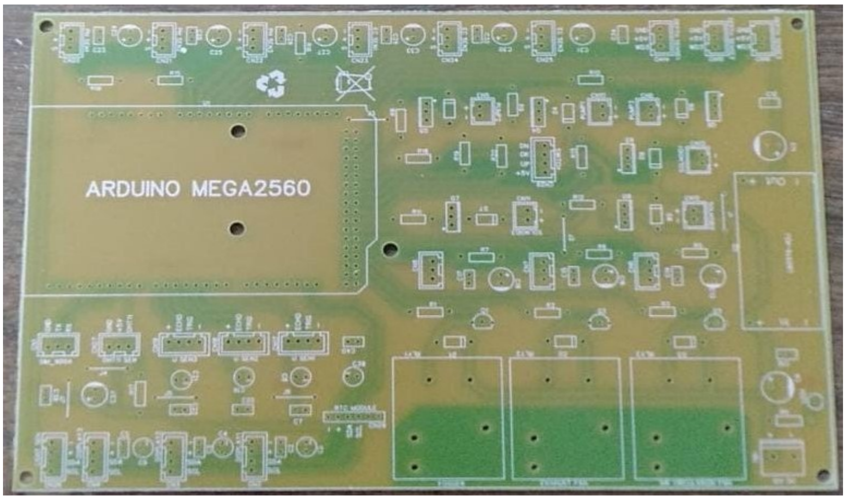


Plate 3.16 PCB

3.3.1.14 Metal box

All these components except sensors and actuators were kept inside a powder coated GI metal enclosure box (Plate 3.17). It gives protection from exposure to weather.

Plate 3.17 Metal box

3.3.1.15 Push button switch

Three push button switches (Plate 3.18) were fitted on the lid of the metal box for menu settings. Menu Settings offers several functions like setting date, time, calibration of pH sensors and EC sensors, low and high levels of ultrasonic sensors and setting of pumping and discharging time of DC pumps. Upper and lower temperature limits for the automated operation of fan and fogger and ON-OFF period of fogger can also be set using settings menu.

Plate 3.18 Push button switches

3.3.2 Software components

Software components of the automated data acquisition system include Arduino IDE software and ThingSpeak IoT cloud.

3.3.2.1 Arduino IDE software

The Arduino Integrated Development Environment (Arduino IDE) version 1.8.19 software was used to write the program for the automated data acquisition. It contains text editor for writing code, message area, text console, toolbar with buttons for common functions and a series of menus. The code written in this software was uploaded to Arduino board using a USB cable.

3.3.2.2 ThingSpeak IoT cloud

ThingSpeak is an IoT cloud platform. Sensor data can be uploaded to the cloud using this IoT cloud platform. Data can be analyzed and visualized with the help of MATLAB. MathWorks runs the ThingSpeak platform and sensor data is gathered and stored in the cloud with ThingSpeak's Web Service (REST API) and creates Internet of Things apps. It is compatible with MATLAB, Raspberry Pi, and Arduino. ThingSpeak has four channels and eight fields per channel can be added to this platform.

3.3.3 Calibration of sensors

Calibration of sensors was done to get accurate values through the data acquisition system.

3.3.3.1 Calibration of pH sensors

pH sensors were kept as a separate automated data acquisition unit and a separate microcontroller and GSM module were used. pH sensors were calibrated by immersing the probe in buffer solutions of pH 4.0 and 7.0. Usually the pH sensor was calibrated in such a ways that first upload a program for calibration to the microcontroller board and then immerse the electrode in the buffer solutions of pH 4.0 and pH 7.0. From the pH values and the corresponding voltage values find out the calibration parameters m and c of the equation $y = m x+c$, where y is the pH of the nutrient solution and x is the voltage. Then these parameters are added to the program and for the pH measurement. This procedure of calibration is difficult as frequent calibration is needed for the pH sensors for accurate measurement. Hence a sub program for calibration was added in the main program for the pH measurement, so that the relevant calibration parameters can save automatically in the EEPROM (Electrically Erasable Programmable Read-only Memory) after each calibration. Hence no need to re-upload the program for pH measurement based on the calibration parameters in each calibration. Before the measurement of pH of the nutrient solution the sensors were calibrated to save the relevant calibration parameters in the EEPROM.

Calibration was done in such a way that, after uploading the program for the pH measurement unit to the Arduino board it was connected to the laptop using a USB cable and the serial monitor of the Arduino IDE software was opened. Then commands were entered in the serial monitor for calibration. Bench I sensor was calibrated as, first entered 'CALIB PH1' in the command box of serial monitor and pressed 'ENTER' button. After displaying 'calibration mode' in the serial monitor, entered 'PH7' and pressed the 'ENTER' button. Then the pH sensor probe was inserted into the pH 7 buffer solution. After getting a stable value of voltage entered 'PH4' and pressed the 'ENTER' button. Then sensor probe was inserted into the pH 4 buffer solution. After getting the stable value of voltage entered 'END CALIB'. Thus the calibration was completed. pH sensors of Bench II and Bench III were also calibrated in the same way. The flow chart of calibration procedure is shown in Fig 3.2.

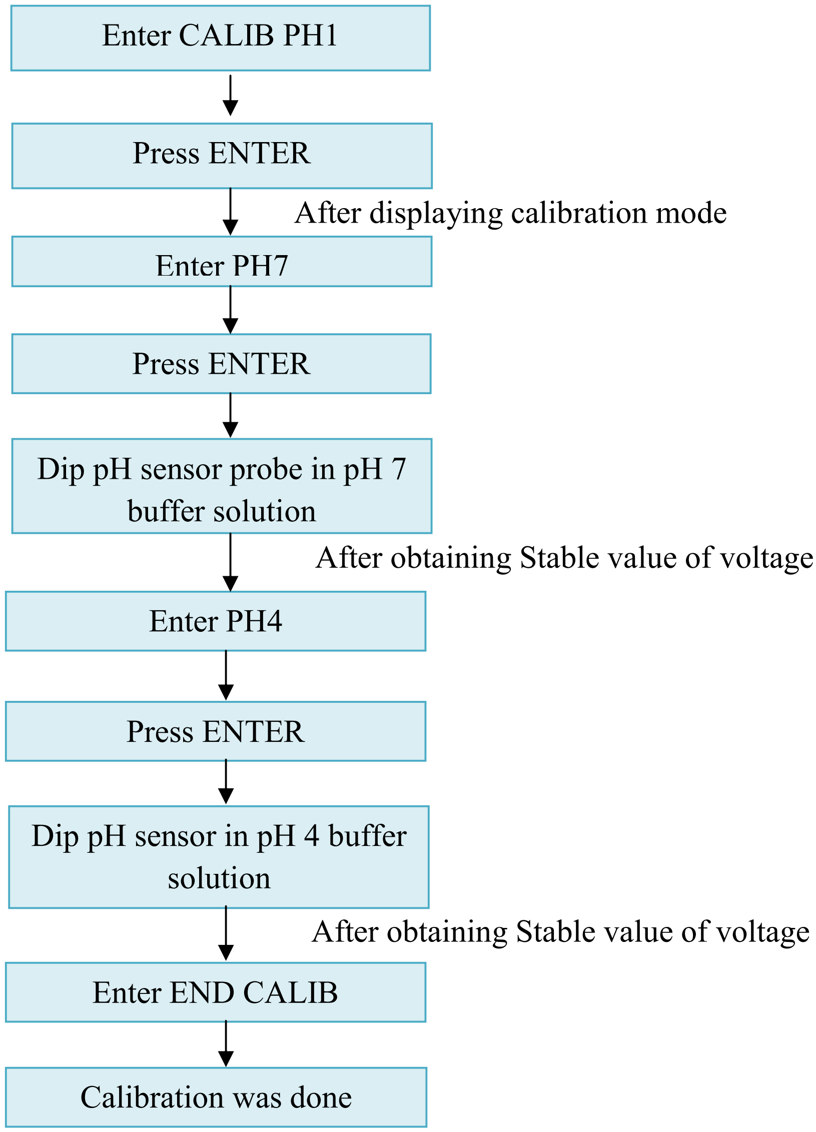


Fig. 3.2 Flow chart of the calibration of pH sensor

3.3.3.2 Calibration of EC sensors

Frequent calibration was needed for EC sensors. Hence a sub program for calibration was added in the main program such that calibrations were made easy by using push buttons. Two point calibration was done for EC sensors using buffer solutions of EC 1.413 dSm^{-1} and 12.88 $dS\ m^{-1}$. EC sensors were calibrated initially after the installation of the automation system to save the relevant calibration parameter in the EEPROM and also weekly calibration was done.

Calibration of the EC sensor was done by pressing the centre button (OK button), which led to the settings menu and selecting option for the calibration of EC sensors. Inserted probe into the standard buffer solution of EC12.88 dS $m^{-1}$and gently stirred until the values were stable and then pressed OK. After displaying the calibrated value, pressed OK button again. Washed probe with distilled water and removed water droplets by tissue paper. Same procedure was repeated by placing the probe into the standard buffer solution of EC 1.413 dS m^{-1}**.** EEPROM of the main control board has been updated with relevant parameters of calibration after the completion of two point calibration. The flow chart of calibration procedure is shown in Fig 3.3.

3.3.3.3 Calibration of temperature sensor

The DS18B20 temperature sensor was calibrated using mercury (Hg) thermometer. Water was filled in the nutrient tank and temperature of the water was observed using both sensor and Hg thermometer in a time interval of one hour. The observed readings were recorded and plotted in excel sheet with sensor reading in x axis and Hg- thermometer reading in y axis and calibration equation was arrived. This calibration equation was used in the Arduino program. All the three temperature sensors were calibrated.

3.3.3.4 Calibration of ultrasonic sensors

Calibration was done for different depths of nutrient solution by adding water to the nutrient tank. The sensor readings and scale readings of depth of water in the tank were recorded. The recorded readings were plotted in excel sheet with sensor reading in x axis and scale reading in y axis and calibration equation was arrived. This calibration equation was used in the Arduino program. All the three ultrasonic sensors were calibrated.

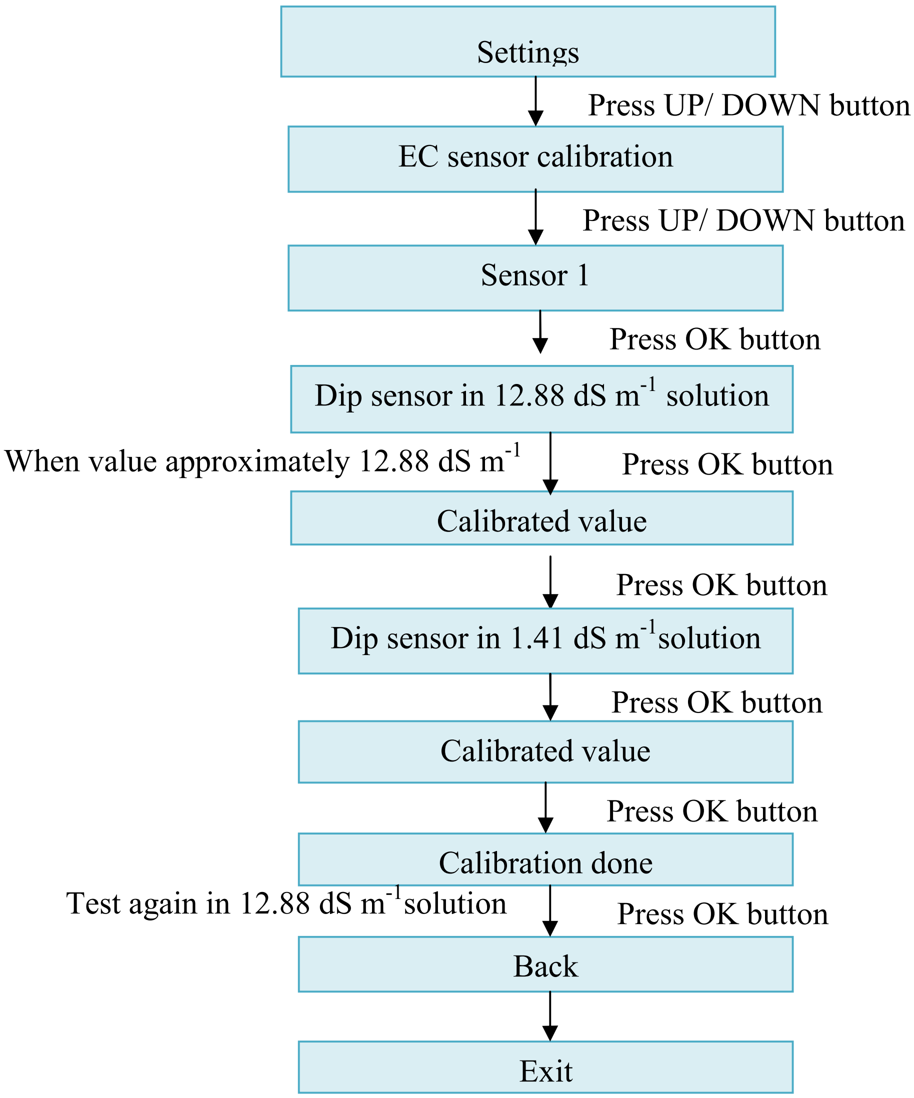


Fig. 3.3 Flowchart of calibration of EC sensor

3.3.3.5 Calibration of depth sensor

Depth sensor was fitted to the lid of the NFT channel. It was calibrated for different depths of water in channel by adjusting valves of the NFT hydroponics system. The depth of water in the channel was also measured by using a steel ruler. The observed readings were recorded and plotted in excel sheet with sensor reading in x axis and scale reading in y axis and calibration equation was arrived. This calibration equation was used in the Arduino program. All the three depth sensors were calibrated.

3.3.3.6 Calibration of air temperature and relative humidity sensor

The DHT22 sensor was calibrated by using mercury thermometer for temperature and wet and dry bulb thermometers for relative humidity as the standard reference instruments. Temperature and relative humidity inside the polyhouse were measured with DHT22 sensor and the standard reference instruments. The measured readings were recorded and plotted in excel sheet with sensor reading in x axis and standard reference instrument reading in y axis and calibration equation was arrived. This calibration equation was used in the Arduino program.

3.3.3.7 Calibration of light intensity sensor

The BH1750 light intensity sensor was calibrated with a lux meter as a standard reference instrument. Light intensity inside the polyhouse was measured in a time interval of one hour using the sensor and lux meter. The measured readings were recorded and plotted in excel sheet with sensor reading in x axis and lux meter reading in y axis and calibration equation was arrived. This calibration equation was used in the Arduino program.

3.3.4 Hardware designing

All the sensors, actuators and other components were interfaced to the Arduino MEGA board using PCB. PCB was designed based on the circuit diagram of the automated system. Fig 3.4 to Fig 3.15 shows the designed circuit diagram of each component of the automated data acquisition system with the Aurduino MEGA microcontroller.

Analog signal output pins of EC sensors of Bench I, II and III were connected to the analog pins A_3, A_4 and A_5 of Arduino MEGA microcontroller board (Fig 3.4). The digital output pins of temperature sensors of Bench I, II and III were connected to the Arduino's digital pins 33, 31 and 29 respectively. To keep the data transfer stable, 4.7 k pull-up resistor was connected between the signal and power pins for each sensor (Fig 3.5). Ultrasonic sensors were connected with the Arduino MEGA such that the TRIG pin and ECHO pin of sensors of Bench I, Bench II and Bench III were connected to the digital pins 2&3, 4&5 and 6&7 respectively (Fig 3.6). Depth sensors were connected through SDA and SCL pins with the Arduino (Fig 3.7). Data pin of air temperature and RH sensor was connected with the digital pin 9 of Arduino and a 10 k resistor was also used in the circuit (Fig 3.8). Light intensity sensor was connected through the SDA and SCL pins with the Arduino (Fig 3.9).

The relays were connected in the phase line of air circulating fan, exhaust fans and booster pumps of the foggers such that the first part of the phase line coming from the electricity supply was connected to the common pin of the relay and the next part of that line going to the actuator was connected to NO (Normally Open) pin of the relay. The relays were connected to digital pins of Arduino through a transistor for each relay (Fig 3.10). Fig 3.11 and Fig 3.12 shows the connection of DC pumps with Arduino. DC pumps were also connected to the Arduino digital pins through the transistor.

RTC modules (Fig 3.13) and LCD displays (Fig 3.14) were also connected through SDA and SCL pins with the Arduino. RX and TX pins of the GPRS module were connected the digital pins 10 and 11. In the case of push buttons UP, OK and DN buttons were connected with the digital pins 41, 43 and 45 of Arduino (Fig 3.13). The components were powered by connecting a VCC pin with the required power supply (SMPS or buck converter). The all circuit diagram was printed on the PCB.

All the components were connected to the PCB including Arduino MEGA microcontroller board. Automation system was powered by using a 12 V SMPS. It supplied power directly to buck converter, Arduino board, GPRS module, DC pumps and relays. Sensors, RTC and LCDs were connected to buck converter. Buck converter reduced voltage from 12 V to 5 V (Fig 3.15). Fig 3.16 shows the block diagram of hardware assembling of automated data acquisition system.

EC and pH sensors were interfered with each other and readings of EC and pH sensors showed error when they were connected to the same power source. Hence a separate automated data acquisition system for pH sensors was developed by connecting all components as per the circuit diagram Fig 3.17. Analog out pins of sensors of Bench I, Bench II and Bench III were connected with the Arduino UNO analog pins A_0, A_1 and A_2. The TX and RX of SIM800L GSM module was connected to digital pins 2 and 3 of Arduino UNO. These components were powered from the 5 V pin of Arduino and grounded. Fig 3.18 depicts the block diagram of the hardware assembling of automated pH data acquisition system.

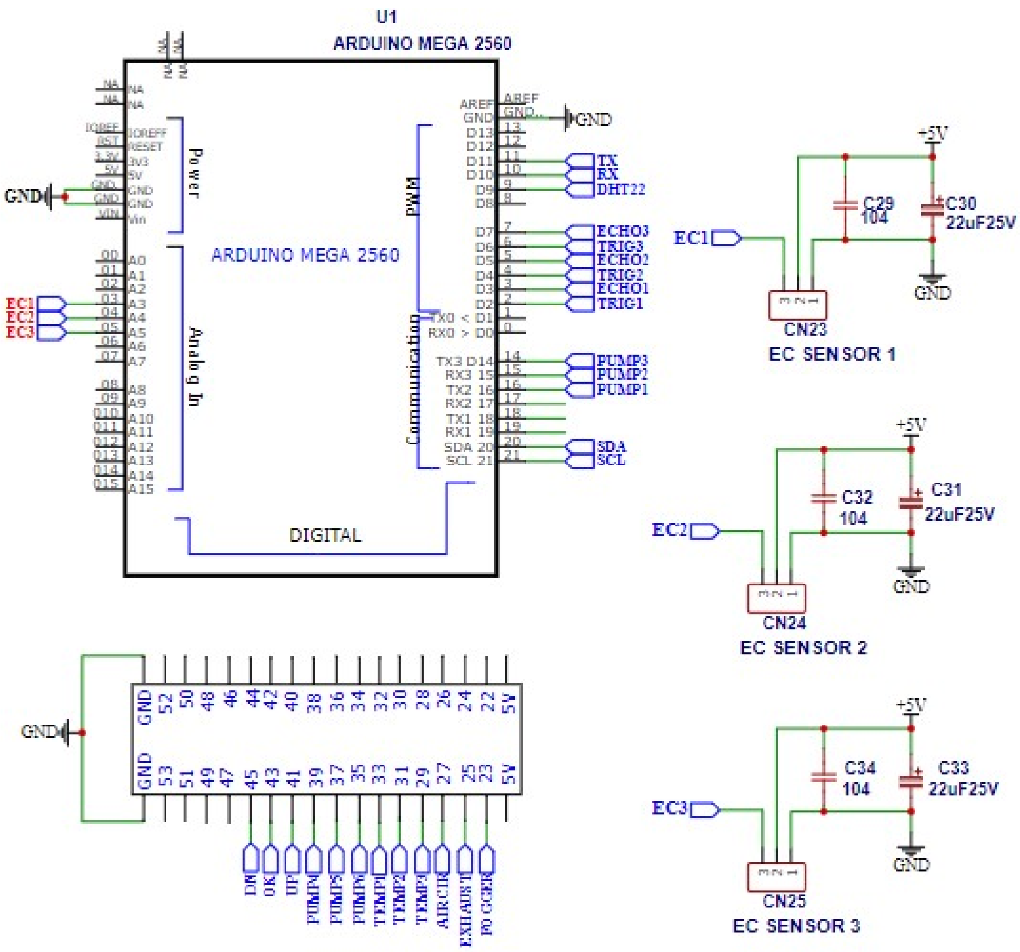


Fig. 3.4 Designed circuit diagram of EC sensors with Arduino MEGA

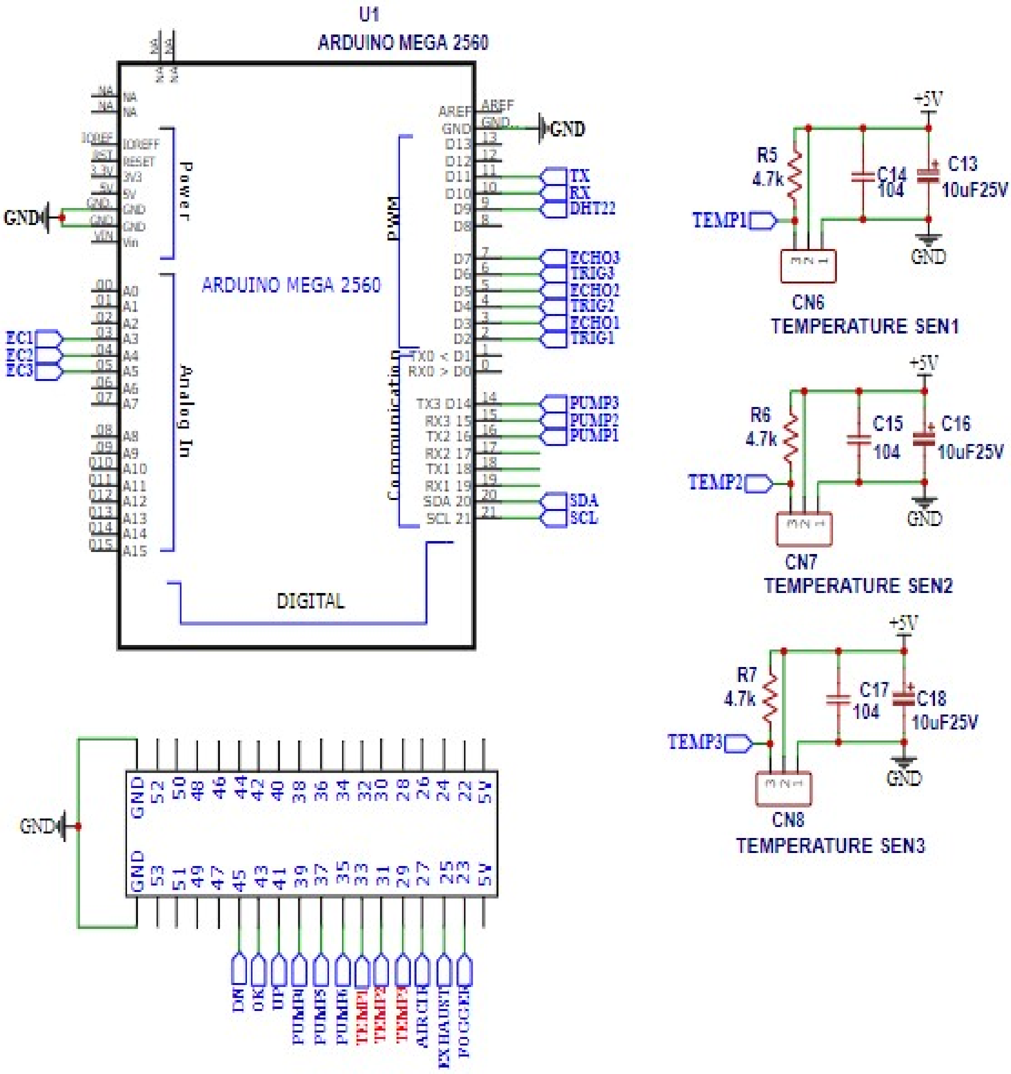


Fig. 3.5 Designed circuit diagram of temperature sensors with Arduino MEGA

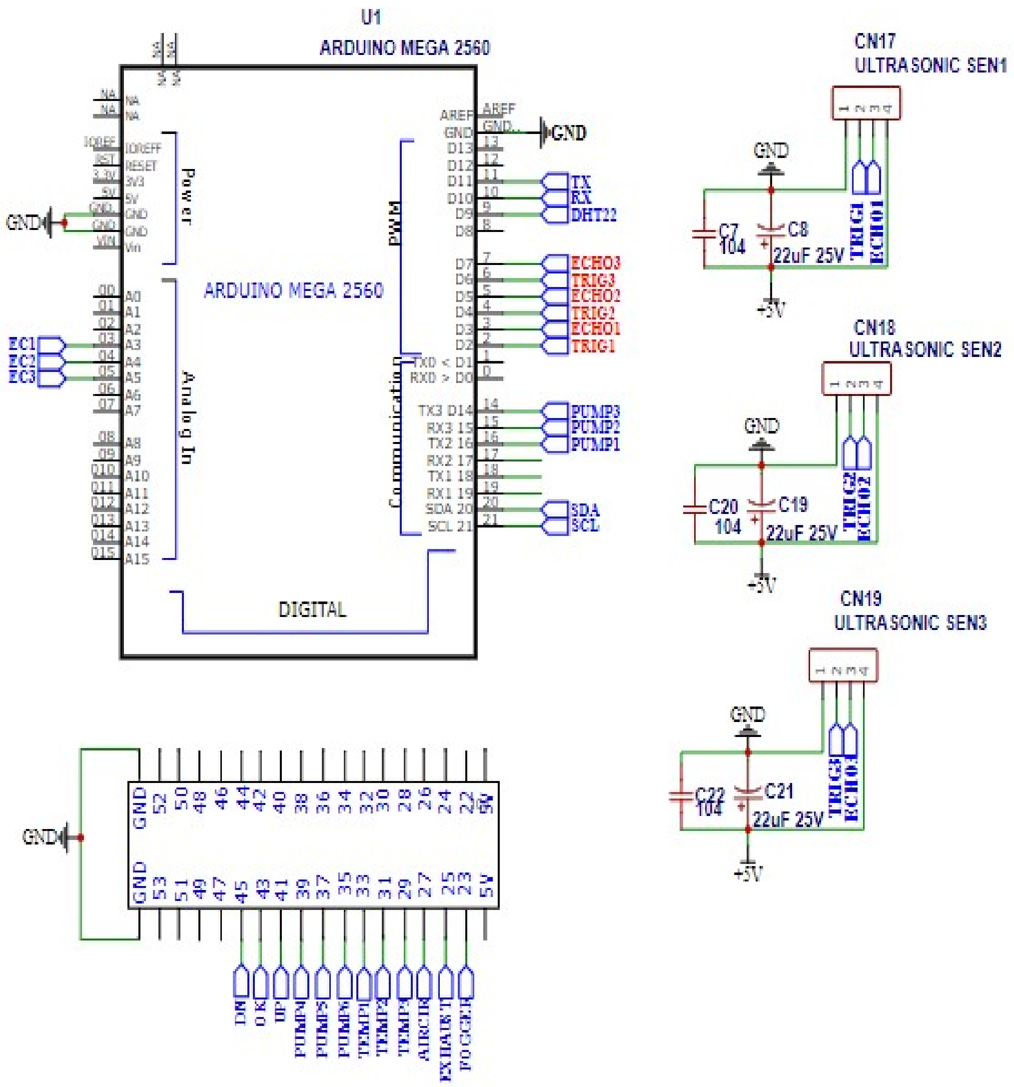


Fig. 3.6 Designed circuit diagram of ultrasonic sensors with Arduino MEGA

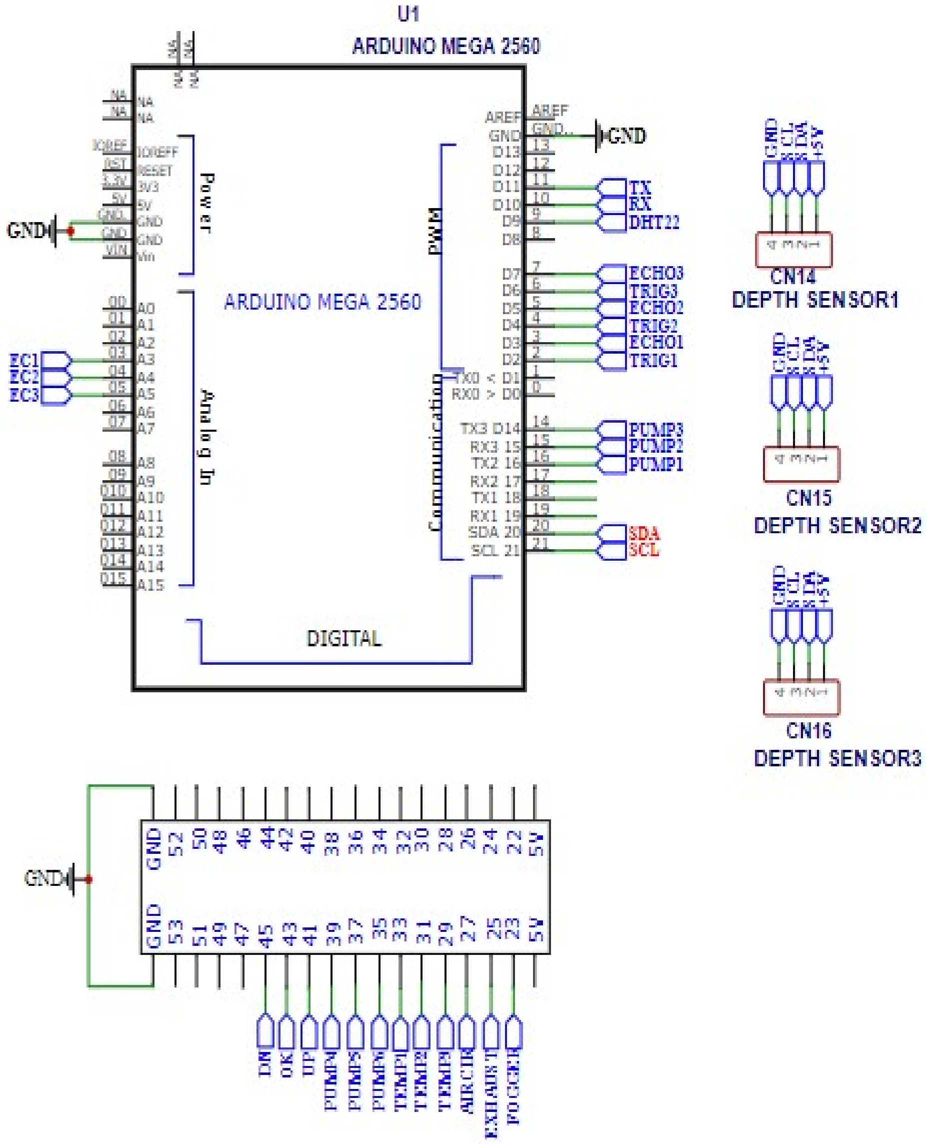


Fig. 3.7 Designed circuit diagram of depth sensors with Arduino MEGA

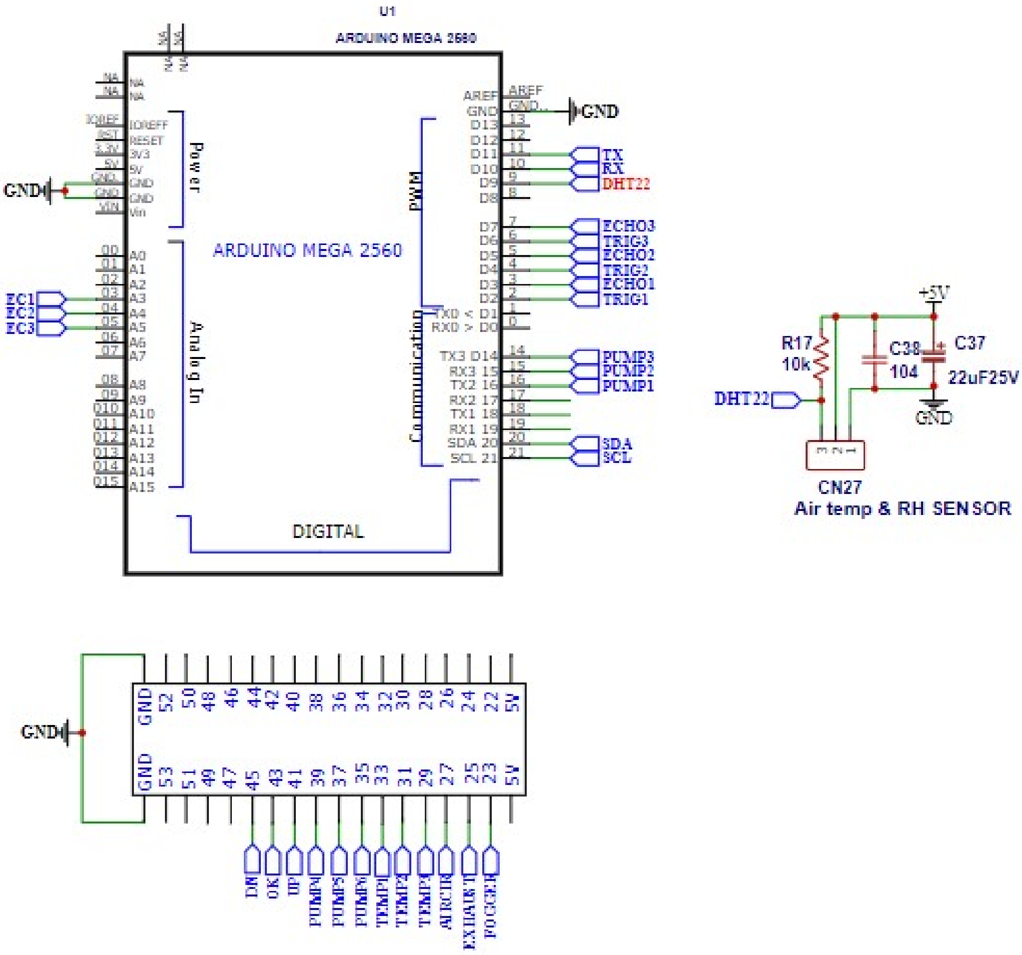


Fig. 3.8 Designed circuit diagram of air temperature and RH sensor with Arduino MEGA

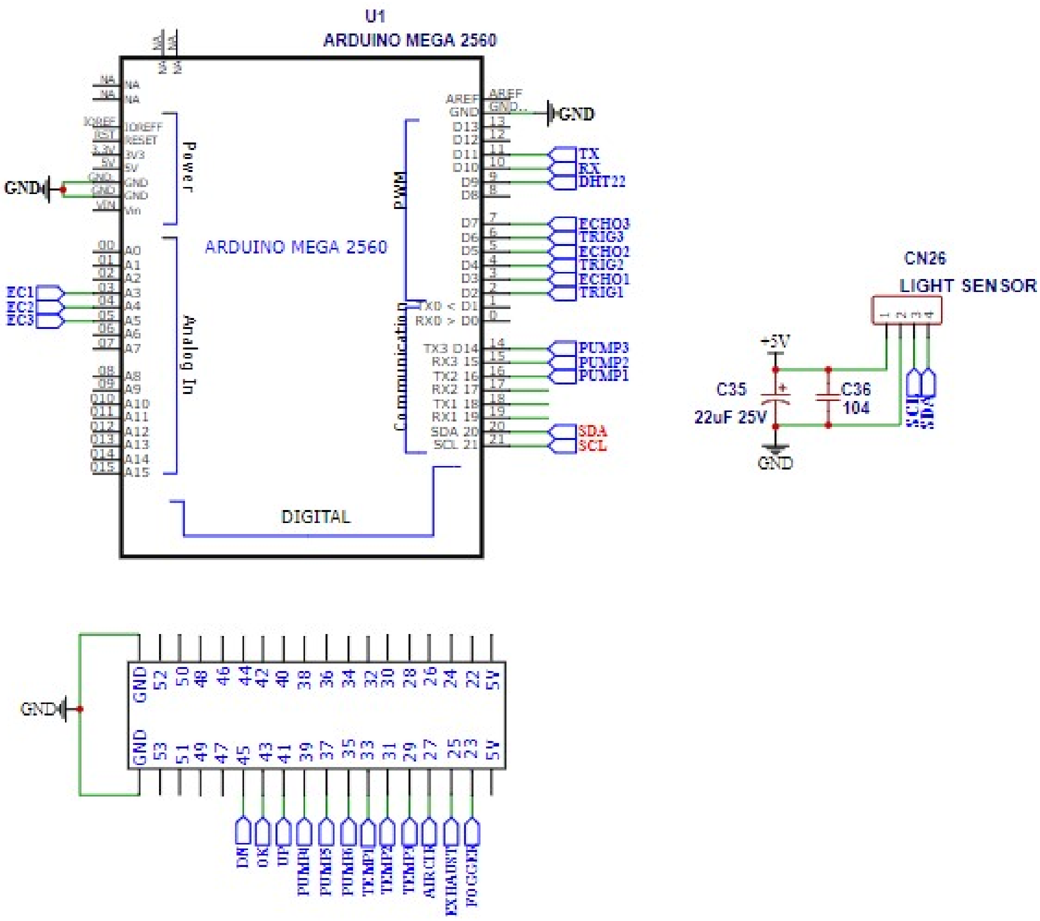


Fig. 3.9 Designed circuit diagram of light intensity sensor with Arduino MEGA

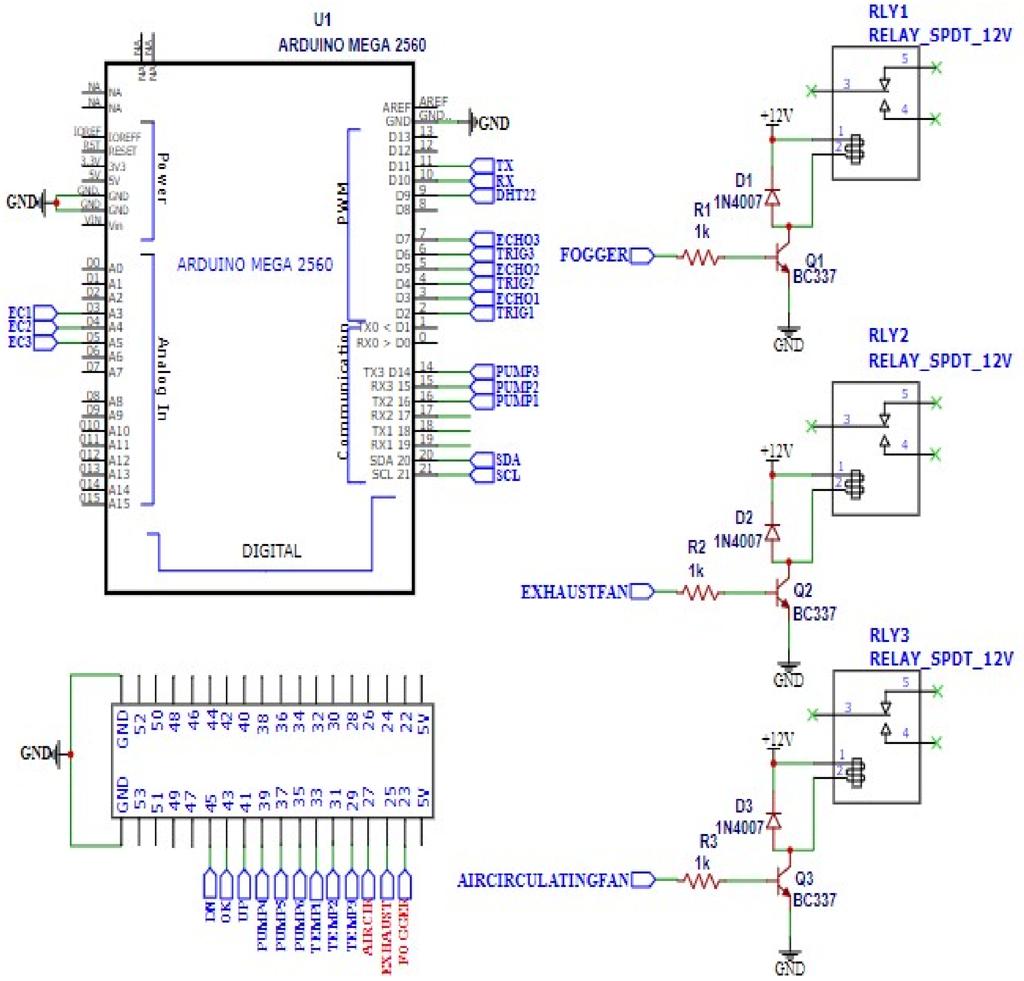


Fig. 3.10 Designed circuit diagram of air circulating fan, exhaust fans and fogger with Arduino MEGA

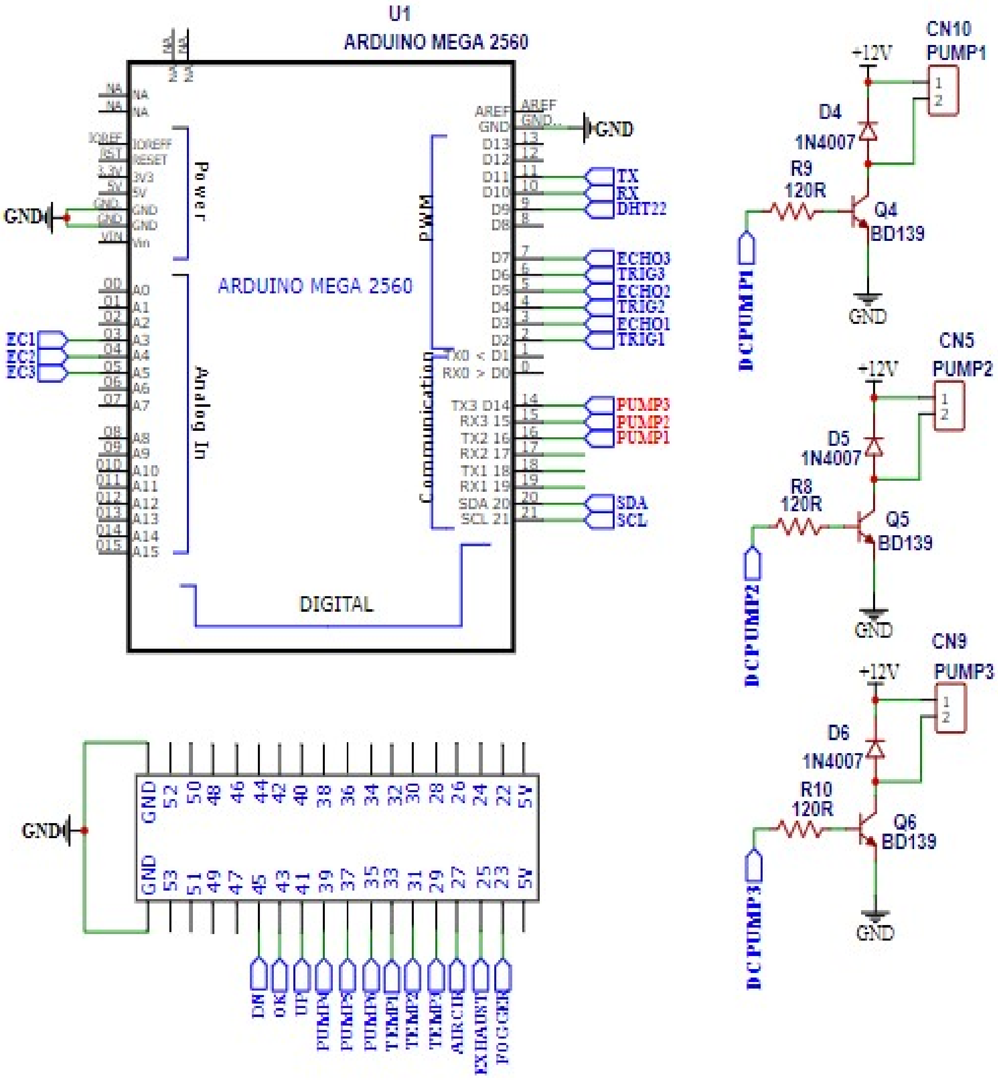


Fig. 3.11 Designed circuit diagram of DC Pumps I with Arduino MEGA

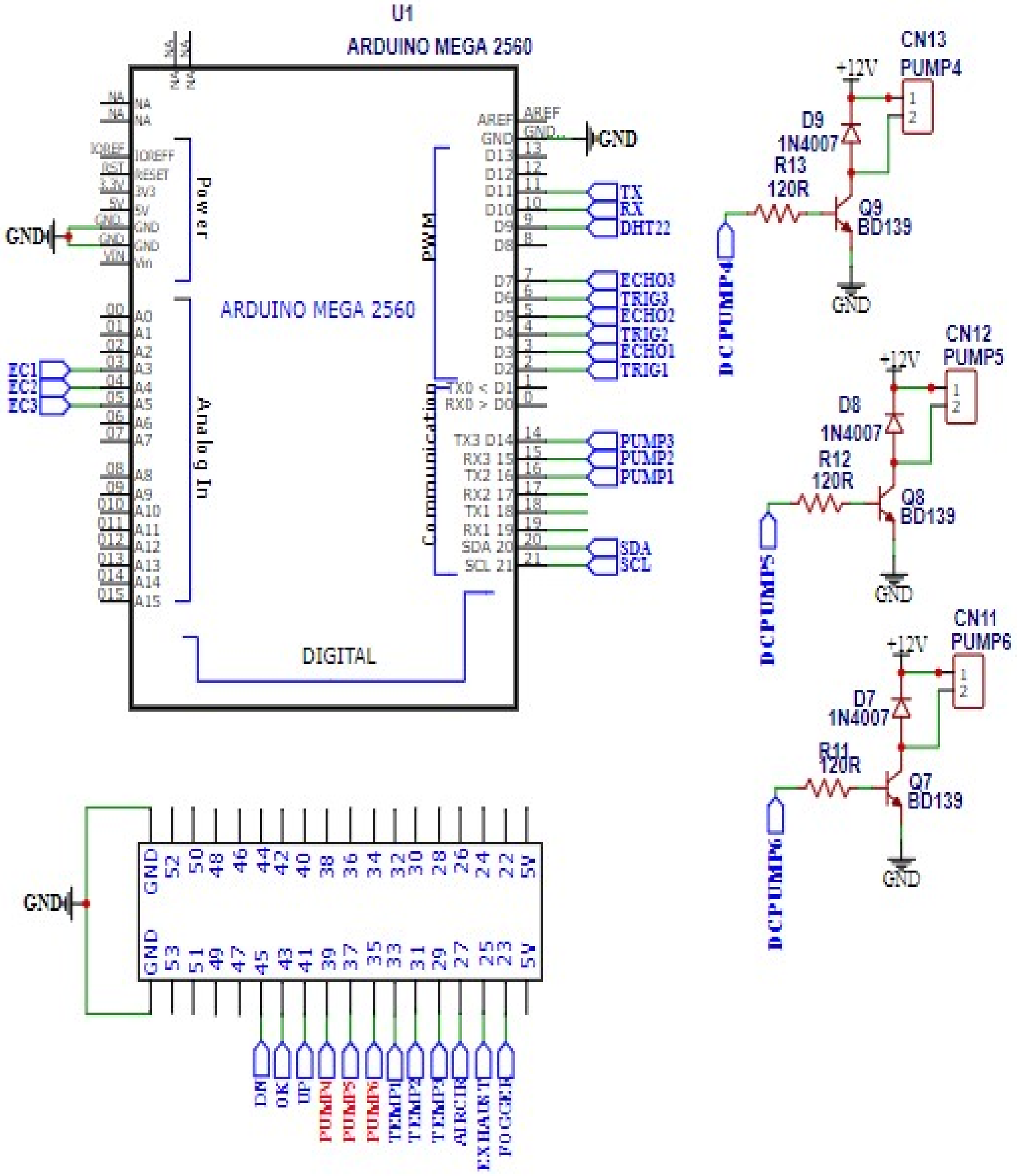


Fig. 3.12 Designed circuit diagram of DC pumps II with Arduino MEGA

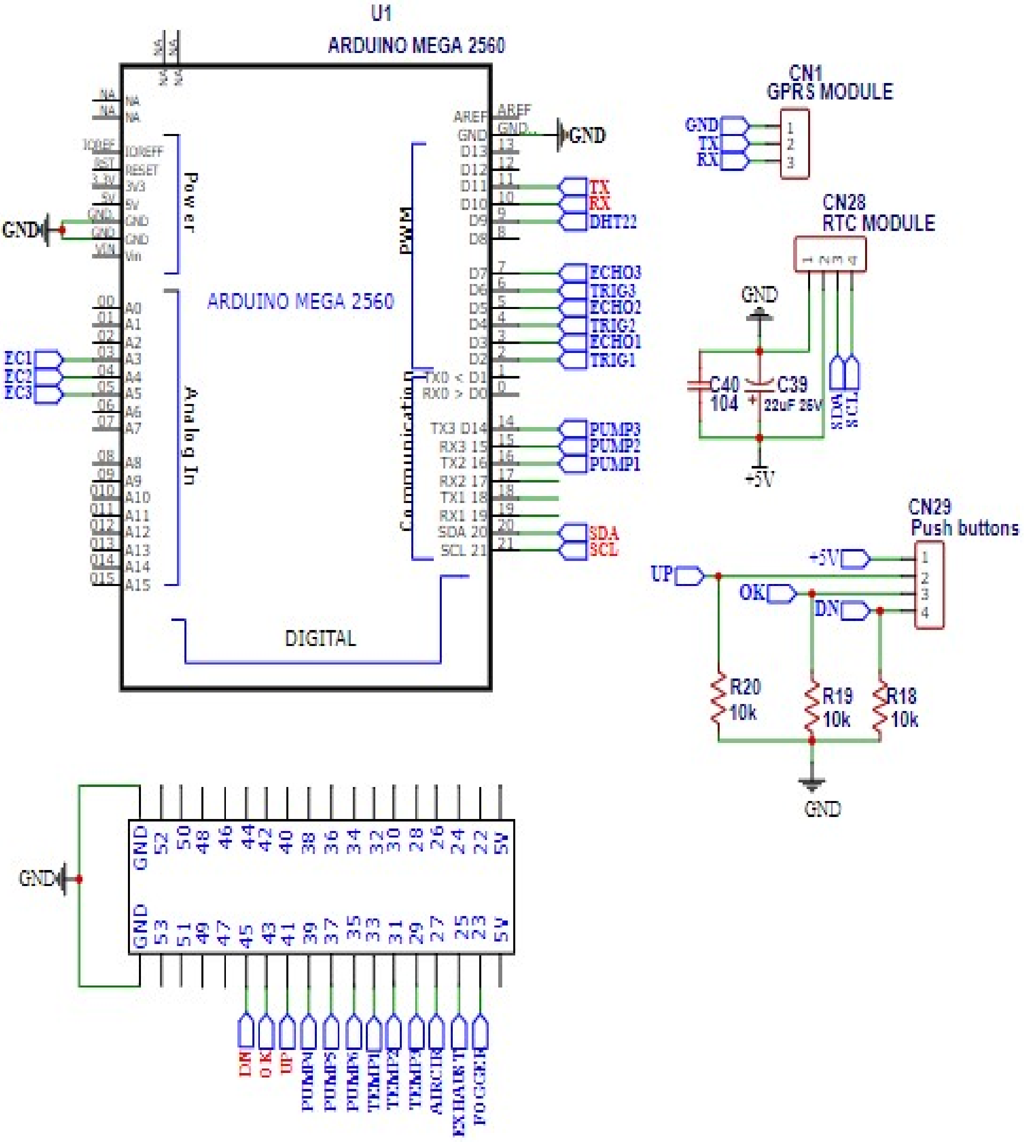


Fig. 3.13 Designed circuit diagram of GPRS module, RTC module and push buttons with Arduino MEGA

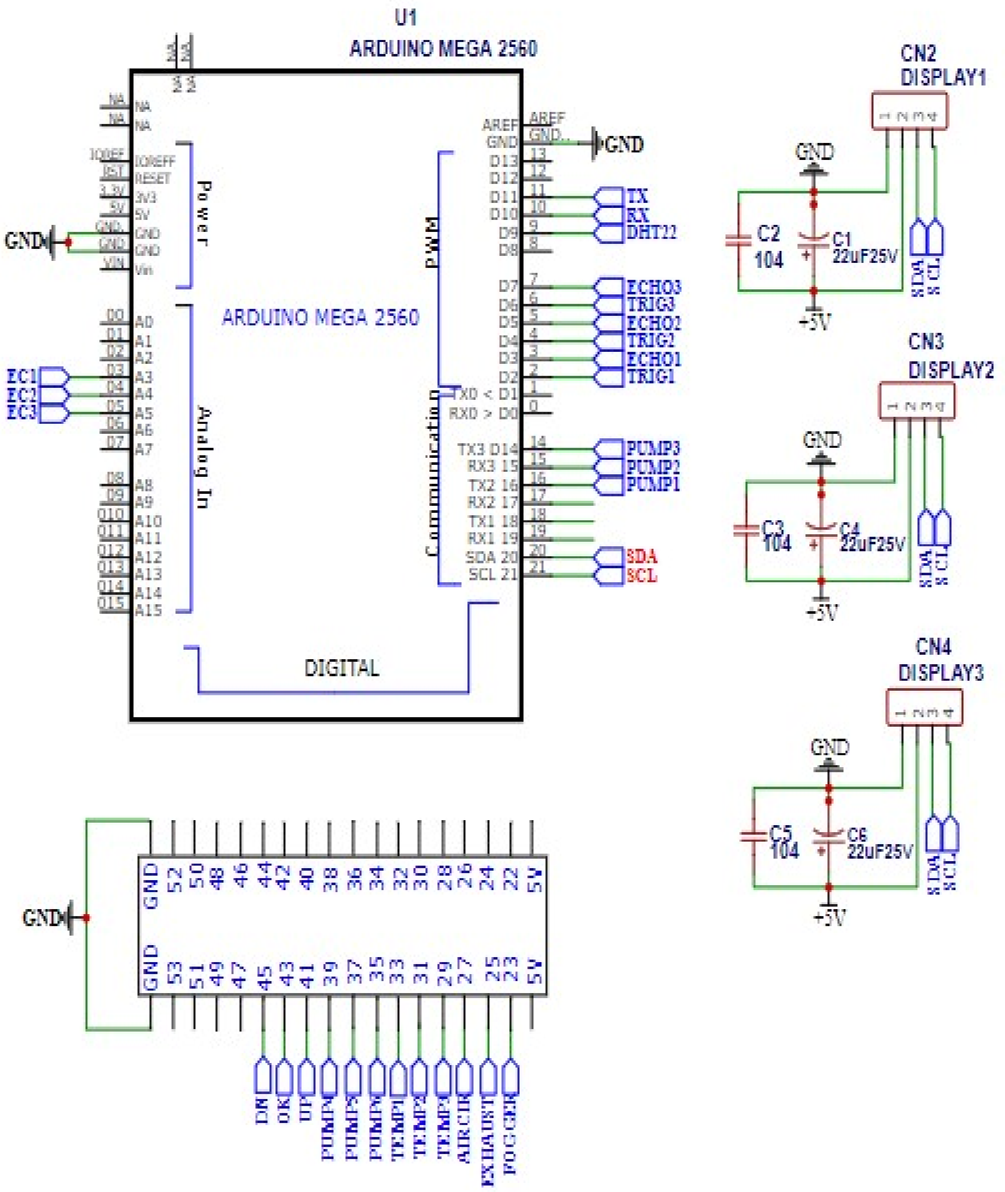


Fig. 3.14 Designed circuit diagram of LCD modules with Arduino MEGA

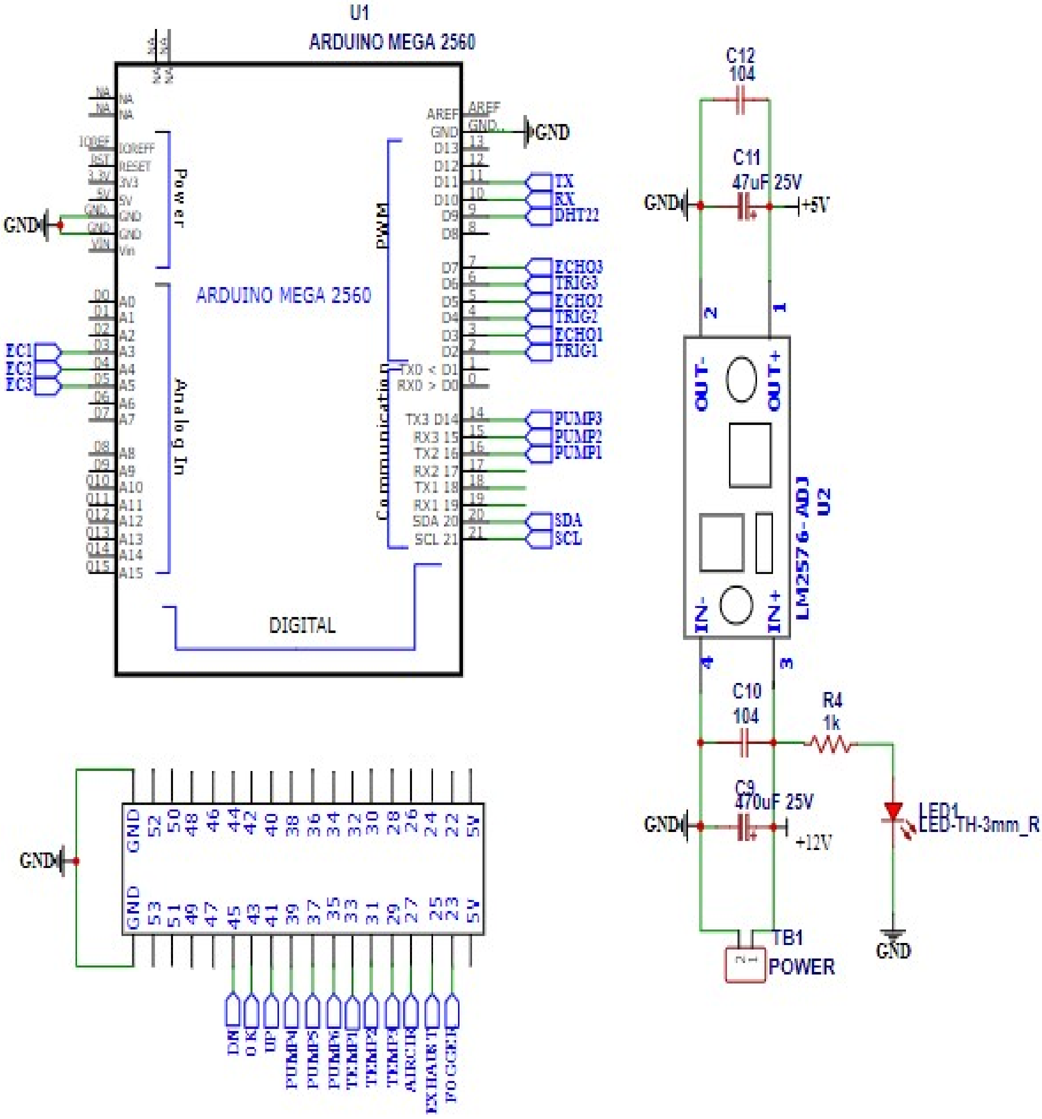


Fig. 3.15 Designed circuit diagram of SMPS and buck converter with Arduino MEGA

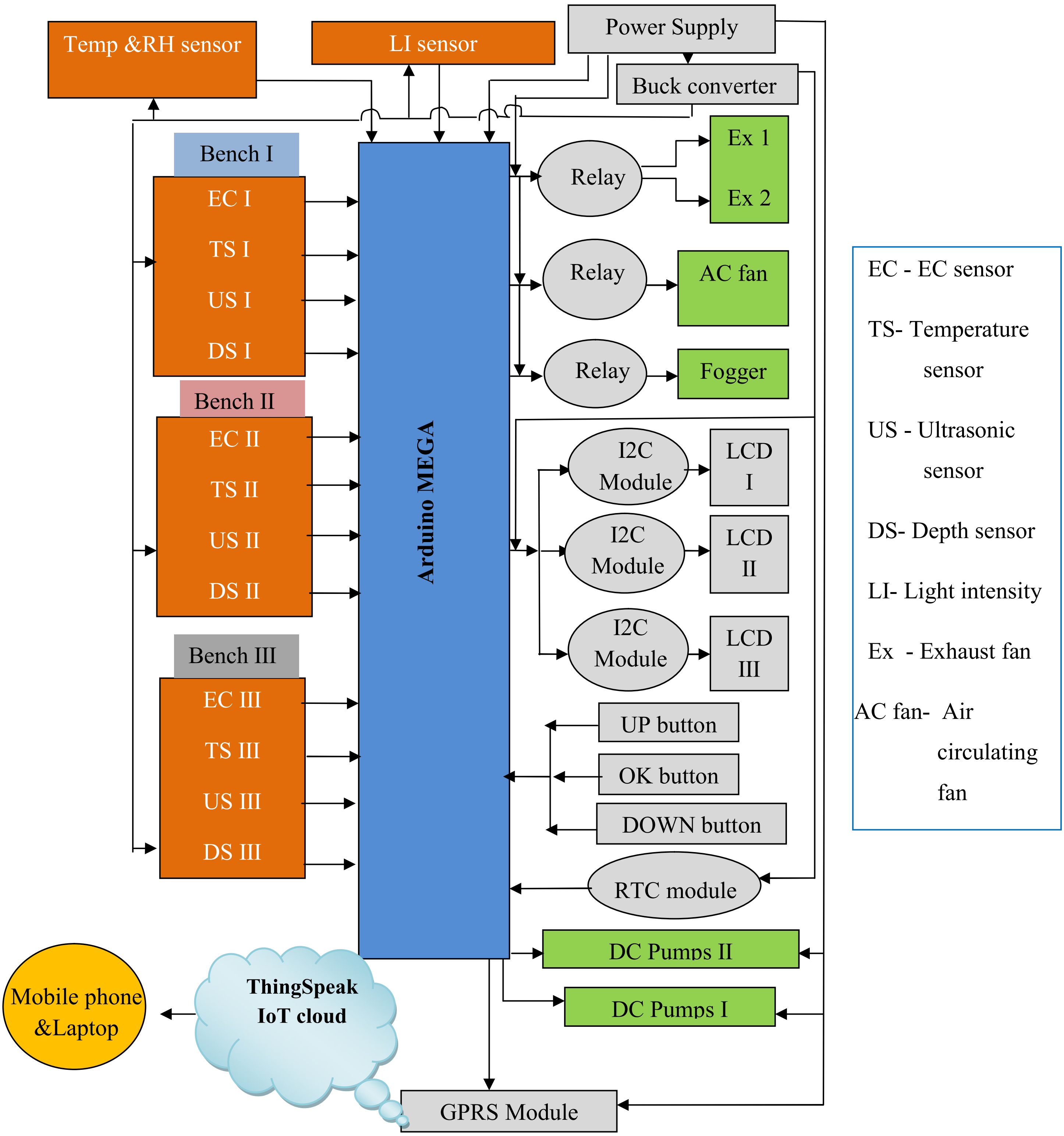


Fig. 3. 16 Hardware assembling of automated data acquisition system

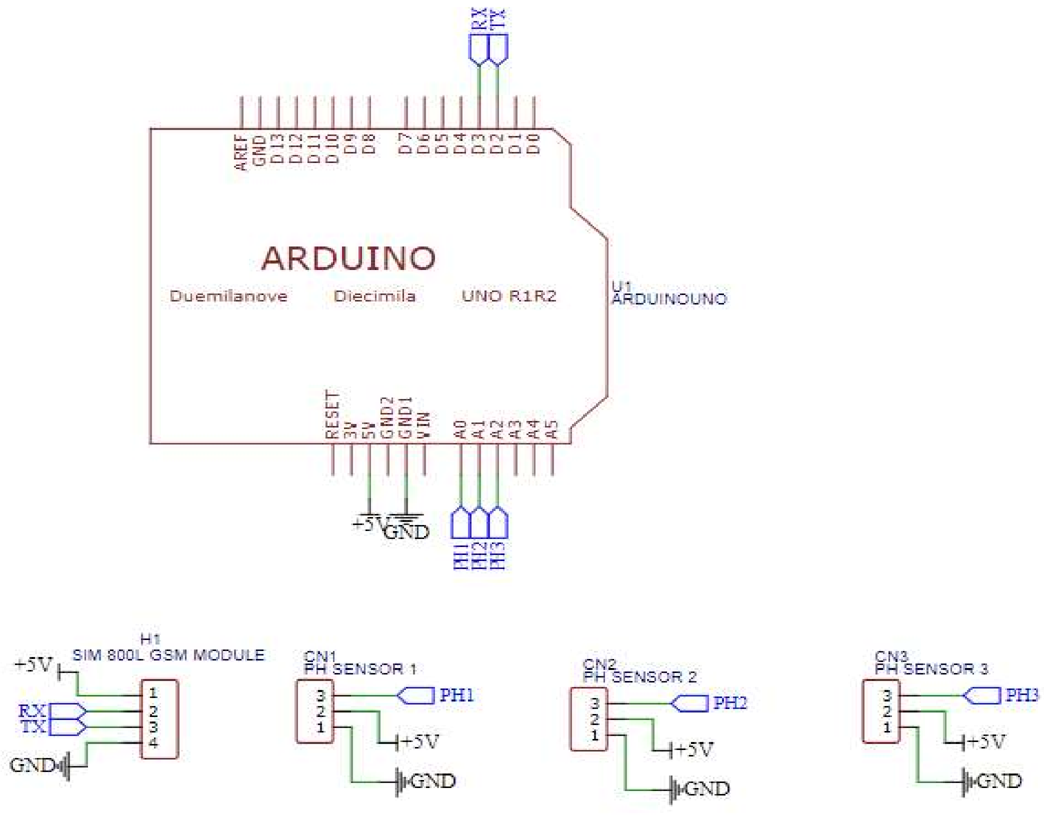


Fig. 3.17 Designed circuit diagram of automated pH data acquisition system

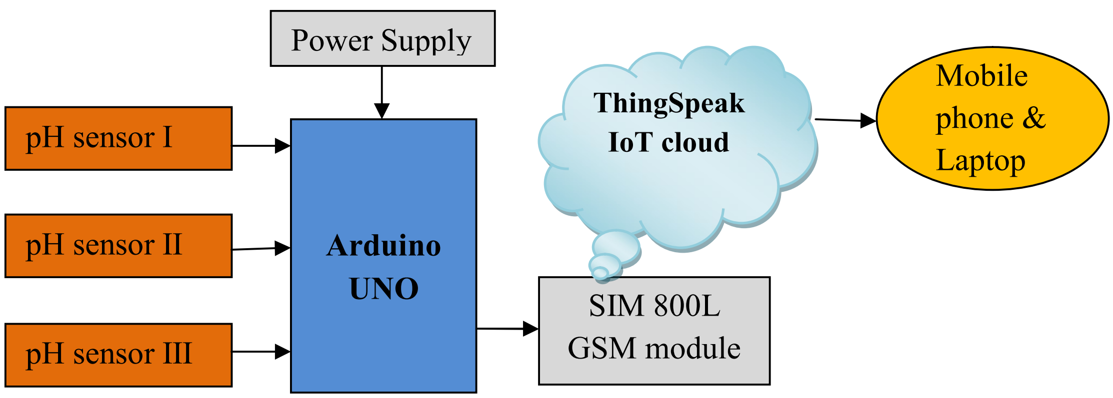


Fig. 3.18 Hardware assembling of automated pH data acquisition system

3.3.4.1 Automated monitoring system

Automated system monitors various parameters of nutrient solution and microclimate using respective sensors which include pH and EC of nutrient solution, nutrient solution temperature, depth of nutrient solution in tank and channel, light intensity, air temperature and relative humidity. Sensors measure these variable parameters and transmit the data to the Arduino MEGA microcontroller. Arduino sent these data to the ThingSpeak IoT cloud using internet from the connected GPRS module. An airtel SIM (Subscriber Identity Module) was inserted in the GPRS module, which provides the internet connection. Measured data were uploaded to ThingSpeak in a fifteen minute time interval and displayed in the LCD modules.

3.3.4.2 Automated control system

Two exhaust fans, an air circulating fan and eight foggers were used inside the polyhouse to control air temperature and relative humidity. Based on the measured values of air temperature by air temperature and RH sensor and preset threshold conditions, the microcontroller board operates fans and foggers. When the air temperature increased above 28 °C, Arduino sends signal to the relays connected to exhaust and air circulating fans to operate them and they are switched ON until temperature is reduced to 25 °C. If the air temperature increases to above 35 °C, Arduino sends a signal to relay connected to the booster pump of foggers to operate the foggers. Foggers operate for one minute then get off for next 15 minutes, repeat this process until air temperature reduces to 32 °C. Arduino transmits the ON-OFF status of fans and foggers to the ThingSpeak using internet from the connected GPRS module in a fifteen minute interval and displayed in the LCD module.

3.3.5 Software designing

Automated system was developed in such a way that it sends the data collected using sensors and working status of fans and foggers to the cloud server and make it available to the IoT cloud platform; ThingSpeak. This data can be made available for users through mobile app and web applications. It updates sensor values and status of actuators. The program for the automated data acquisition system was written in Arduino IDE.

3.3.5.1 Setting up of ThingSpeak IoT cloud

An account was created with ThingSpeak IoT cloud using user id and password (Fig 3.19). Channels were created with ThingSpeak IoT cloud for each hydroponics bench for displaying and monitoring nutrient solution parameters, climatic parameters and status of operation of fan and foggers. The first channel was named as hydroponics Bench I. Parameters namely relative humidity, temperature, light intensity , EC of nutrient solution, water temperature, and depth of nutrient solution in tank and channel of first bench, which are to be displayed were added as fields in the first channel and saved the channel (Fig. 3.20). Two more channels were created for the remaining two benches and named as hydroponics Bench II and hydroponics Bench III (Fig 3.21 and Fig 3.22). In channel two nutrient solution parameters of hydroponics Bench II was entered as fields. In channel three, ON-OFF status of fans and foggers were also added as fields along with the nutrient solution parameters of hydroponics Bench III. pH sensors were not included in the channels of Bench I, Bench II and Bench III, because separate microcontroller was used. Channel 4 named the pH sensor was created for displaying pH of all benches (Fig 3.23).

3.3.5.2 Development of Arduino IDE software program

Program for this automated data acquisition system was written in Arduino IDE in C language. Program was written such that the system monitors all the parameters and controls the working of fans and foggers and also sends the collected data and working status of fans and foggers to ThingSpeak and displays them in the LCD. EC and pH of nutrient solution were measured in one hour intervals. Data was recorded at a 15 minutes interval and was available online at https://thingspeak.com/channels registered under 'ThingSpeak'. Fig 3.24 and Fig 3.25 depicts the Flow chart for the development of program for automated data acquisition system. Fig 3.26 shows the flow chart for development of program for the automated pH data acquisition system. Figure 3.27 shows the window of the Arduino IDE where the program is written. The program written for automated data acquisition system is given in Appendix-I and II.

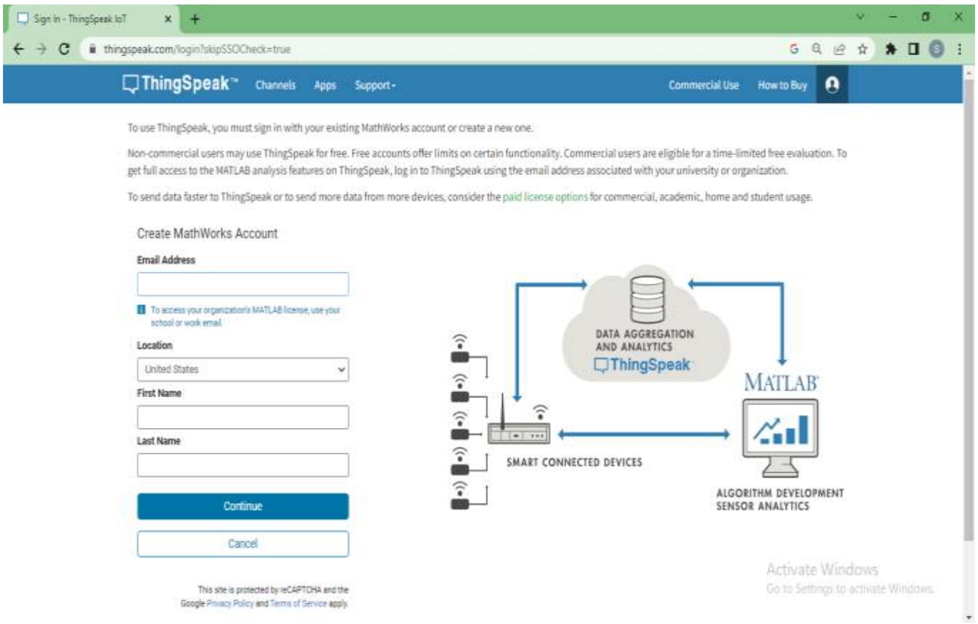


Fig. 3.19 Creation of ThingSpeak IoT cloud account

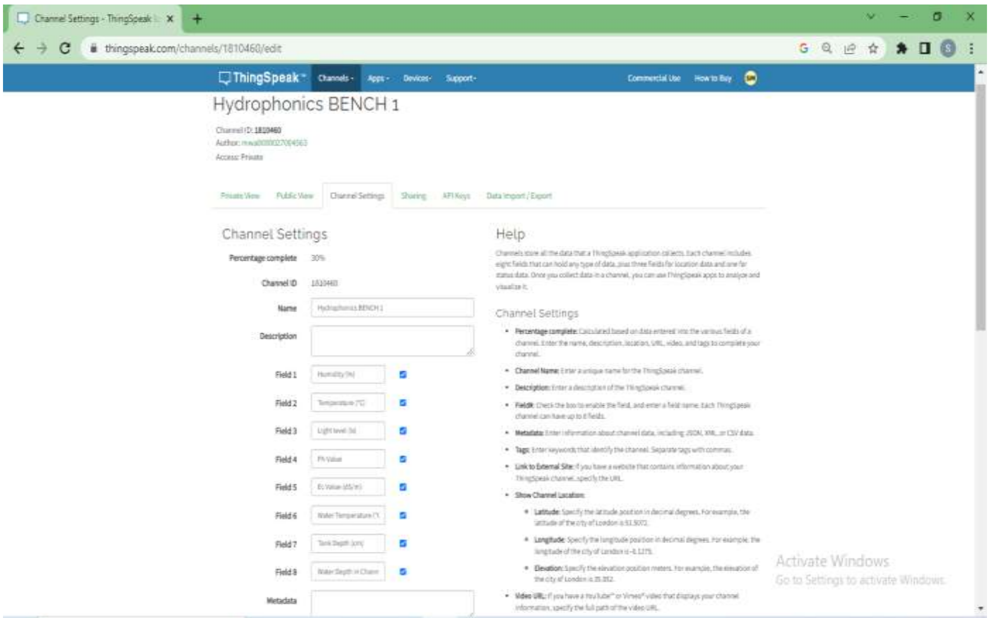


Fig. 3.20 Creation of fields in ThingSpeak IoT cloud channel for Bench I

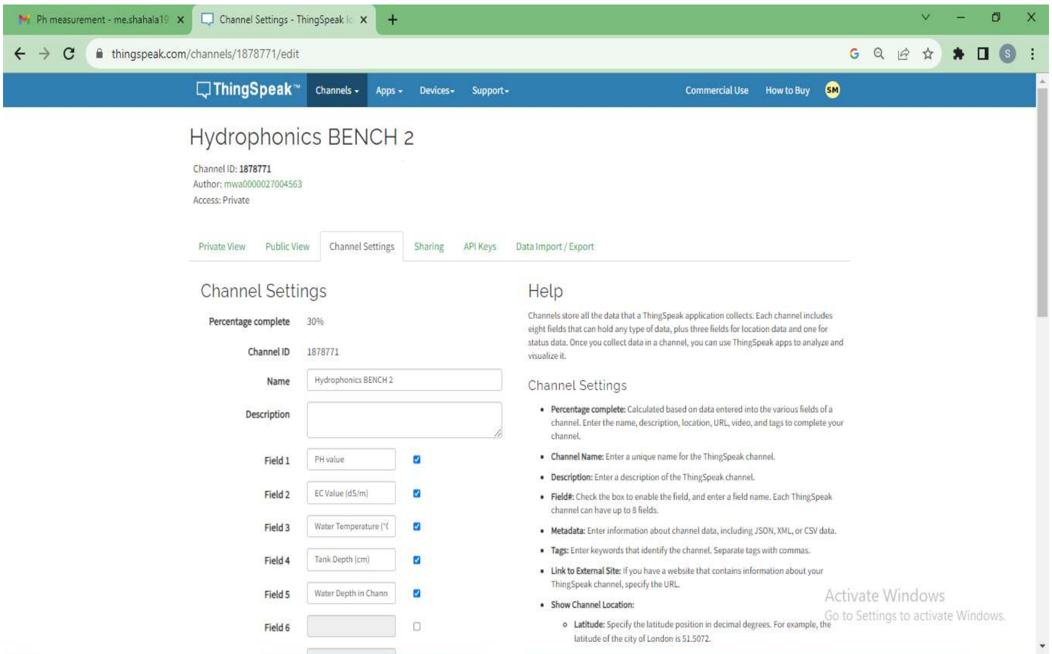


Fig. 3.21 Creation of fields in ThingSpeak IoT cloud channel for Bench II

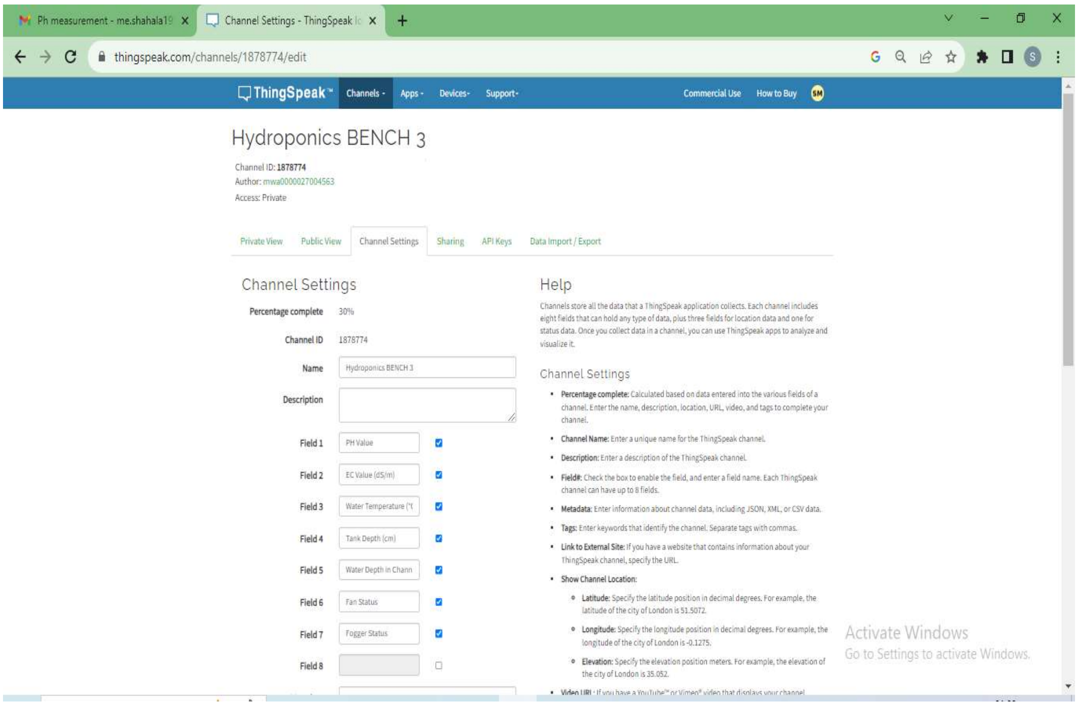


Fig. 3.22 Creation of fields in ThingSpeak IoT cloud channel for Bench III

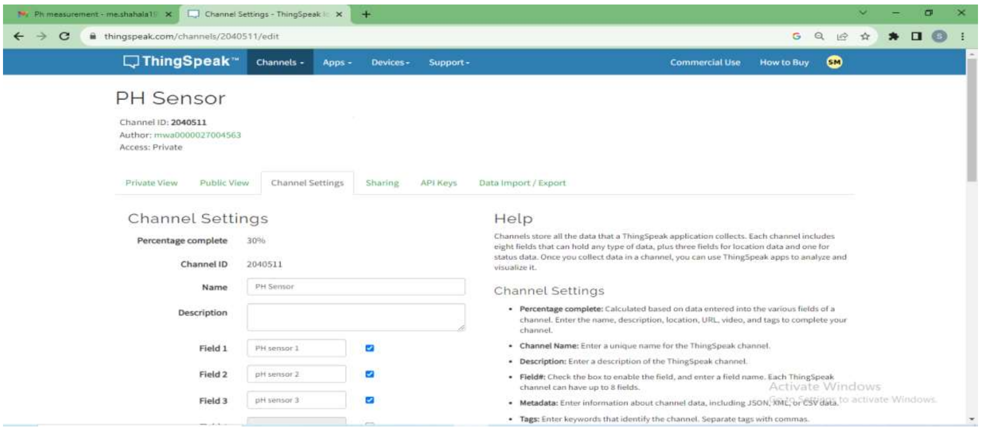


Fig. 3.23 Creation of fields in ThingSpeak IoT cloud channel for automated pH data acquisition system

3.3.6 Installation of developed automation system

The developed system was placed inside the metal box and installed at the center of three benches of hydroponics systems (Plate 3.19). Three plastic jars of 3 l capacity were fixed near the metal box in metal rings to collect nutrient solution samples pumped out for measuring pH and EC from the nutrient tanks of three different NFT systems. pH and EC sensors were kept in the jars. Holes of 2 cm diameter were made on the lids of the jar. pH and EC sensors were inserted into the solution inside the jar for measuring pH and EC. Water temperature sensors were kept in the nutrient solution in tanks. Ultrasonic sensors were fixed on the lid of the nutrient tanks and depth sensors were fixed on the lid of the NFT channel in each bench. DHT22 sensor and BH1750 sensor were hung inside the polyhouse. Positions of sensors used in the automated data acquisition system fixed are shown in Fig 3.28. Fans and booster pump for foggers were connected to relays. DC pumps for pumping of nutrient solution to the jar were attached on each tank and pumps for pumping back solution from jar to tank were fixed on the lids of the jars. The automated data acquisition system for pH of nutrient solution was kept in a box (Plate 3.20). Solar power system (1 kW) is used as the power source for the developed automation systems.

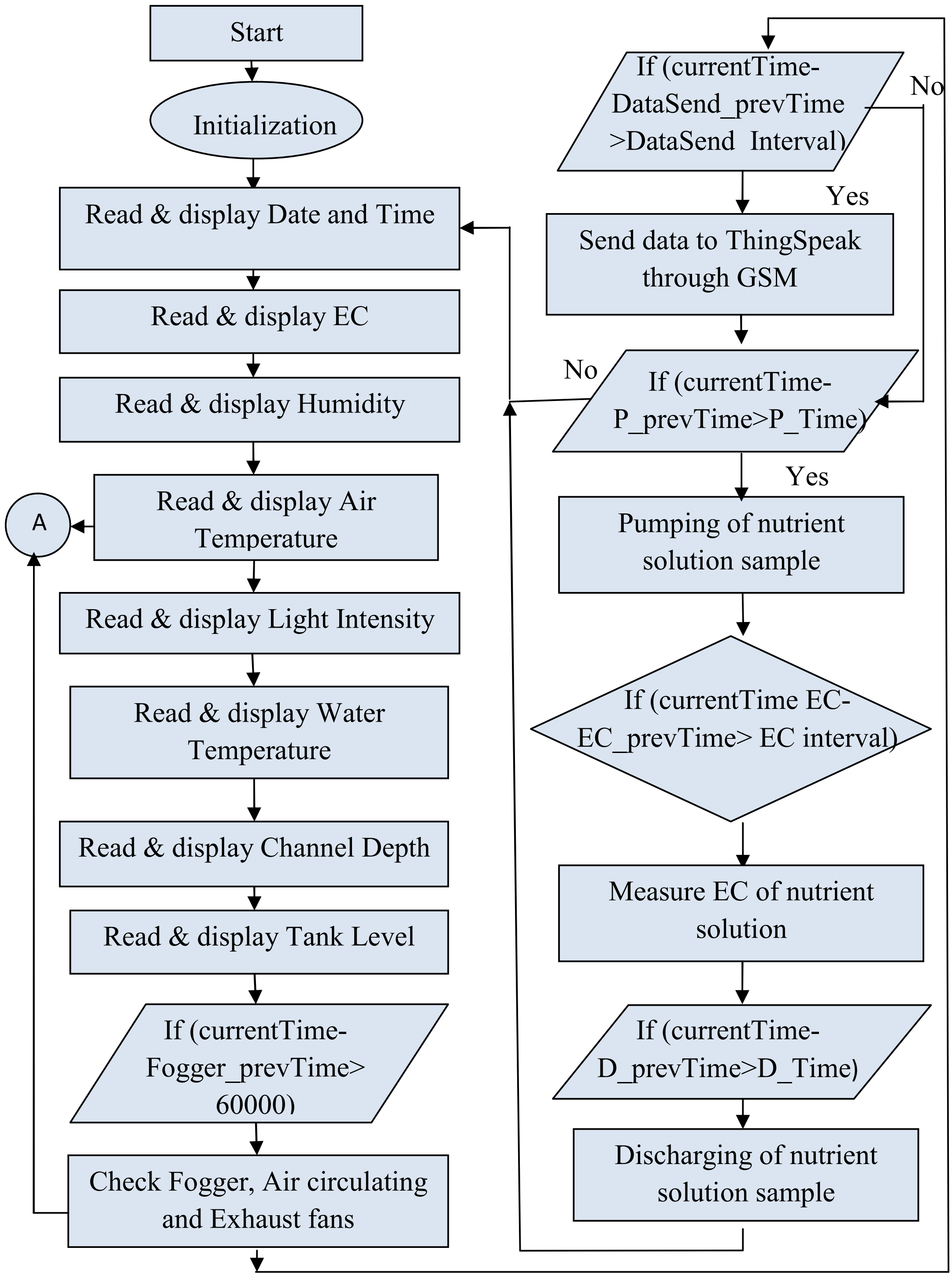


Fig. 3.24 Flow chart for programming the automated data acquisition system

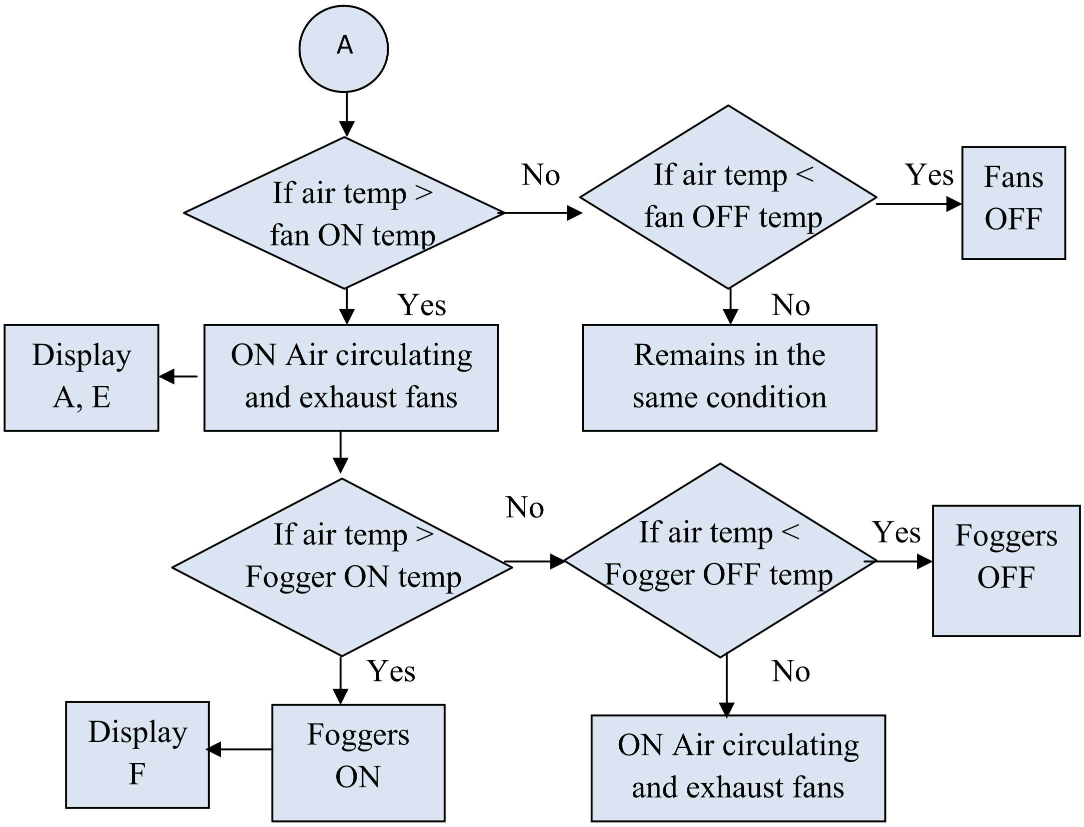


Fig. 3.25 Flow chart for programming the automated data acquisition system (continued)

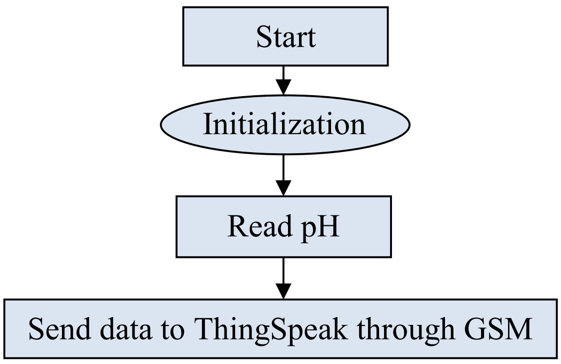


Fig. 3.26 Flow chart for programming the automated pH data acquisition system


```
int up_counter=0;
unsigned long currentTime;
unsigned long previousTime = 0;
unsigned long Ph_Ec_prevTime = 0;
unsigned long Ph_prevTime = 0;
unsigned long Ec_prevTime = 0;
unsigned long S_prevTime = 0;
unsigned long P_prevTime = 0;
unsigned long Gsm_prevTime = 0;
unsigned long DataSend_prevTime = 0;
unsigned long Fogger_prevTime = 0;
unsigned long ly=0;
float Ty=0,Hy=0;
const unsigned int Display_Interval = 5000;
const unsigned long Ph_Ec_Interval = 3600000;
const unsigned long DataSend_Interval = 900000;

#include <SoftwareSerial.h>
#include <BH1750.h>
#include <OneWire.h>
#include <DallasTemperature.h>
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <RTClib.h>
#include <EEPROM.h>
#include "DFRobot_EC.h"
#include "DHT.h"

#define ONE WIRE BUS 29
```

Fig. 3.27 Program written using Arduino IDE

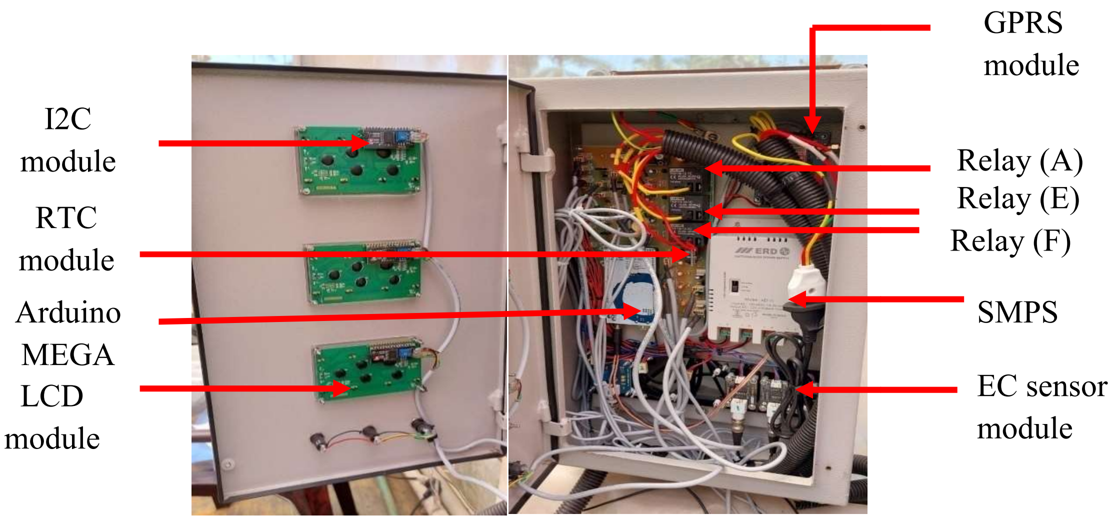


Plate 3.19 Overall set up of automated data acquisition system

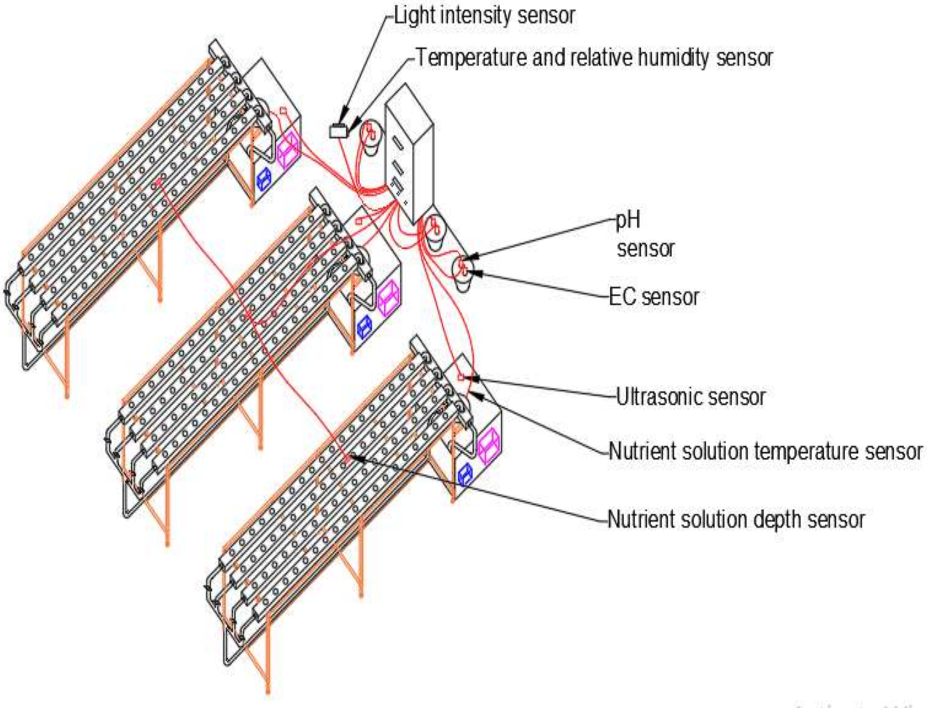


Fig. 3.28 Schematic diagram of position of sensors of automated data acquisition NFT hydroponics system

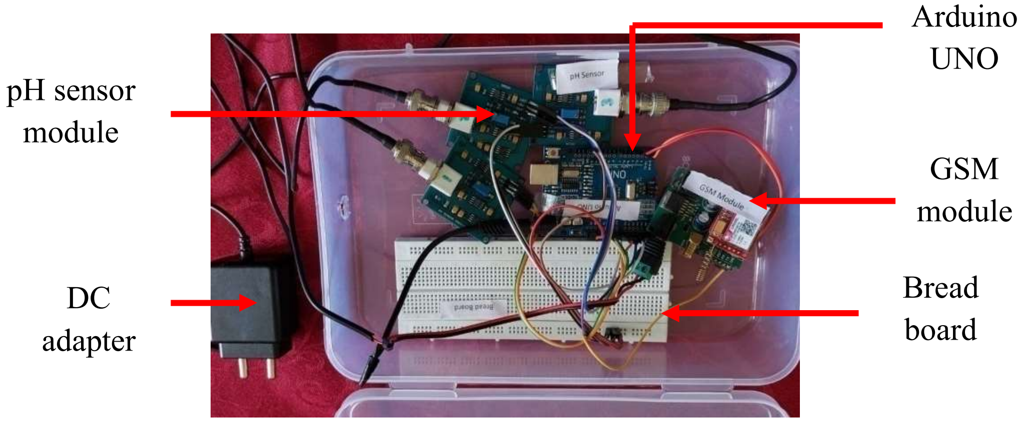


Plate 3.20 Automated pH data acquisition system

3.3.7 Working of automation system

After completing installation, program was uploaded to the Arduino MEGA board using USB cable. Power supply was provided to the automated data acquisition system. Date and time were set in the system using the Set Date & Time option in settings by pressing push buttons fixed on the box. Calibration of

EC sensors was done by selecting the EC calibration option in settings to save the relevant parameters of calibration in EEPROM. There is high level and low level as the limits of measurement distance for ultrasonic sensors. High level for ultrasonic sensor measurement was given as zero for all sensors and low level was given as 38 cm for first tank (hydroponics Bench I), 60 cm for second tank (hydroponics Bench II) and 40 cm for third tank (hydroponics Bench III) by choosing ULSC calibration in settings. Temperature ranges for working of fans and foggers and ON and OFF times of foggers were also set in the setting option. Threshold upper and lower temperature of the fans were set at 28℃ and 25 ℃ respectively, so that the fan started to work when the air temperature was higher than 28 ℃ and stopped working when air temperature got lower than 25 ℃. Foggers were operated in such a way that, when the temperature rose above 35 ℃, foggers got ON for one minute and OFF for the next 15 minutes. This procedure was repeated until the air temperature decreased below 32℃. Pumping and discharging time of DC pumps were also set. These pumps were used to pump nutrient solution to jar for pH and EC measurement and discharge nutrient solution back to nutrient tank. The prolonged immersion of pH and EC sensor probes in the nutrient solution in the tank causes corrosion of electrodes. Hence the probes were kept in a separate jar to which nutrient solution was pumped at the time of pH and EC measurement and pumped back to nutrient tank after measurement. A 5 V DC adapter was used for providing power supply to Arduino UNO of the pH sensor unit.

Automated unit of pH sensor was powered and pH sensors were calibrated to save the relevant parameters of calibration in EEPROM.

3.3.8 Testing of automated data acquisition system

Testing of the developed automated data acquisition system was done by:

i. Validation of sensor readings with standard reference instrument readings
ii. Testing the performance of the automated data acquisition system in real time monitoring of the various nutrient and climatic parameters, and

working of fan and foggers and displaying them in computer and mobile networks.

iii. Testing the performance of the automated data acquisition system for the control of air temperature and RH inside the polyhouse also checked.

Validation of pH and EC sensors were done by comparing pH sensors readings with the pH meter readings and EC sensor readings with the EC meter readings. Ten readings of sample solutions were taken for testing and collected data were plotted. Testing of temperature sensors were done by comparing sensor readings and corresponding thermometer readings of water in the nutrient solution tank. Water temperature was monitored manually for a period of one week in one hour intervals from 9 am to 5 pm and corresponding sensor readings were also recorded and plotted. Testing of ultrasonic sensors were done by comparing ultrasonic sensor readings and scale readings.

Air temperature and RH sensor was tested comparing the sensor readings and thermometer readings for air temperature and dry bulb and wet bulb thermometers readings for RH. Both air temperature and RH recorded manually in one hour intervals from 9 am to 5 pm for a period of one week and corresponding sensor readings were also recorded and plotted. Light intensity sensor was also tested similar to air temperature sensor, here sensor readings were compared with lux meter readings in one hour intervals from 9 am to 5 pm for a period of one week and plotted.

The performance of the developed system in real time monitoring and displaying various parameters was observed by checking the uploading of various nutrient solution and climatic data and ON- OFF status of fan and fogger in ThingSpeak IoT cloud platform. The performance of the automated control part of the developed system was evaluated by comparing the air temperature and RH inside and outside the polyhouse.

3.4 EVALUATION OF AUTOMATED DATA ACQUISITION NFT HYDROPONICS SYSTEM UNDER DIFFERENT FLOW RATES

The developed automated data acquisition system is evaluated with crop and under different flow rates. Three treatments of different flow rate T_1 (60 l/h), T_2 (120 l/h) and T_3 (180 l/h) were studied in terms of various crop parameters, water consumption and nutrient use. T_1 is for Bench I, $T_2$is for Bench II and T_3 is for Bench III. Experimental design was Completely Randomized Design (CRD), each treatment consists of five replications and six plants were taken in one replication.

3.4.1 Setting of flow rates

The setting of different flow rates of each bench was done by collecting water from each channel for one minute at the inlet section and was measured. Valve of each channel was adjusted such that the flow rate through the channel would be 60 l/h, 120 l/h and 180l/h for Bench I, Bench II, and Bench III respectively. Table 3.5 shows the flow rate in different treatments.

Table 3.5 Flow rates of different treatments maintained in Bench I, Bench II and Bench III

Sl. No	Benches	Treatment	Flow rate (l/h)
1	Bench I	T_1	60
2	Bench II	T_2	120
3	Bench III	T_3	180

3.4.2 Planting of test crop

NFT hydroponics systems are mainly used for growing leafy vegetables. The test crop selected for the study was Spinach (*Spinacia oleracea*) and the variety was Pusa Bharati. Seeds were sown in pro tray filled with potting mixture of coir pith and perlite in the ratio 3:2 on 05-12-2022. Two weeks old seedlings were transplanted (Plate 3.21) to NFT hydroponics channels on 20-12-2022. In each pot two seedlings were transplanted.

Plate 3.21 Transplanting of two week old seedlings to the net pots in NFT channel

3.4.3 Preparation of nutrient solution

All the tanks were filled with water. Tank of Bench I was filled with 90 l of water to a depth of 20 cm. Tank of Bench II was filled with 110 l of water to a depth of 25 cm and Bench III tank was filled to a depth of 15 cm with 185 l of water. These depths of water in each tank were maintained to keep constant flow rate in each bench. Nutrient solution was prepared by mixing both A and B parts of the stock solution in the water. A commercial nutrient solution, 'Plant me' was used. Equal amounts of both parts of the solution were taken separately and mixed with water in the tank one by one. Mix required amount of stock solution in each tank to get the sufficient concentration of nutrient solution as different amount of water filled in each tank. After mixing thoroughly TDS and pH of nutrient solution were checked using AP-1 TDS meter (Plate 3.22) and HANNA portable pH meter (Plate 3.23). When one ml of part A and part B mixed in one liter of water gives 189 ppm.

Plate 3.22 Measuring of TDS of nutrient solution using AP-1 TDS meter

Plate 3.23 Measuring of pH of nutrient solution using HANNA portable pH meter

3.4.4 Fertigation scheduling

Nutrient solution was given to the crop just after transplanting. Fertigation scheduling was based on electrical conductivity (EC) and pH of the nutrient solution. EC and pH of the nutrient solution provided was monitored daily.

Fertigation scheduling was done such that if EC of the nutrient solution is less than the required value stock solution is added to the nutrient tank and water is added if EC is higher than the required value. pH up and down solution was used to maintain the pH in the required range. The permissible range of EC of nutrient solution for the cultivation of spinach in NFT hydroponics system is 1.8- 2.1 dS m^{-1}, but during the early stage of growth low level of EC was maintained. Initially EC of the nutrient solution maintained was 0.3 dS m^{-1} during the first week. Gradually it was increased to 1.2 dS m^{-1} during the second week and 1.8 dS m^{-1} during the third week. Thereafter EC of 2.1 dS m^{-1} was maintained till the final harvest. Table 3.6 gives the EC level maintained at different weeks of crop period. pH of nutrient solution was monitored daily and maintained between 5.5 and 6.5 during the entire crop period.

3.4.5 Harvesting of crop

First harvesting of the crop was done 32 days after transplanting. Total 6 harvests were done. Final harvest was on 14-03-2023.

Table 3.6 EC level maintained for Spinach during crop period

Sl. No	Weeks after transplanting	EC level (dS m^{-1})
1	Week 1	0.3
2	Week 2	1.2
3	Week 3	1.8
4	Week 4 onwards	2.1

3.4.6 Biometric observations

Three pots having two plants were randomly selected for the measurement of crop parameters in each replication. Plant height, number of leaves, root length and yield were measured in each harvest and dry weight of root was measured after final harvest. Water consumption and nutrient use were also calculated.

3.4.6.1 Plant height (cm)

The height of observation plants was measured using a steel ruler from the top of supporting media (clay balls) to the top of the plant and expressed in cm. Measurement was taken before each harvest.

3.4.6.2 Number of leaves

Number of leaves was noted before each harvest from the selected observation plants.

3.4.6.3 Root length (cm)

Root length was measured using steel ruler and expressed in cm.

3.4.6.4 Dry weight of root (g)

Dry weight of the root was measured after the final harvest.

3.4.6.5 Yield

Average yield of different replications was measured and total yield of each treatment was estimated during each harvest.

3.4.6.6 Number of survival plants

Number of plants survived was noted during the experiment.

3.4.6.7 Water consumption

Water used by the crop was calculated by dividing the total volume of nutrient solution by total yield. Total volume of nutrient solution was estimated by summing up the quantity of nutrient solution added to the tank during the crop period.

$$\text{Water used by crop} = \frac{\text{Total volume of nutrient solution used (l)}}{\text{Total yield (kg)}}$$

3.4.6.8 Nutrient use

Nutrient use was calculated by dividing stock solution used by total yield.

$$\text{Nutrient used by crop} = \frac{\text{Total stock solution used (l)}}{\text{Total yield (kg)}}$$

3.4.7 Statistical analysis

Data were statistically analyzed using Web Agri Stat Package 2.0 (WASP 2.0).

3.5 STUDY OF NUTRIENT SOLUTION AND MICROCLIMATIC STATUS

Various nutrient solution parameters and microclimatic parameters were continuously monitored by using the developed automated data acquisition system. Nutrient solution parameters include pH, EC, nutrient solution temperature, depth of nutrient solution in tank and channel and microclimatic parameters include air temperature, RH and light intensity.

3.5.1 Monitoring of nutrient solution parameters

Following parameters of nutrient solution were recorded using the automated data acquisition system in a 15 minutes interval and expressed as average daily data during the crop period.

3.5.1.1 pH of nutrient solution

pH of nutrient solution measured by pH sensor and recorded in one hour interval using automated data acquisition system.

3.5.1.2 Electrical Conductivity

Electrical conductivity of the nutrient solution measured by EC sensor and recorded using automated data acquisition system in one hour interval.

3.5.1.3 Nutrient solution temperature

Temperature of the nutrient solution was measured by DS18B20 temperature sensor and recorded automatically in a 15 minutes interval.

3.5.1.4 Depth of nutrient solution in tank

Depth of nutrient solution in the tank was measured by using ultrasonic sensor and recorded in a 15 minutes interval using automated data acquisition system.

3.5.1.5 Depth of nutrient solution in channel

Depth of flow of nutrient solution in the channel was recorded in a 15 minutes interval using the automated data acquisition system.

3.5.2 Monitoring of climatic parameters

Climatic parameters were recorded using the automated data acquisition system in a 15 minutes interval and expressed as hourly average data during the crop period.

3.5.2.1 Air temperature and Relative humidity

Air temperature and relative humidity inside the polyhouse were measured using DHT22 air temperature and RH sensor and recorded using the automated data acquisition system in an interval of 15 minutes.

3.5.2.2 Light intensity

Light intensity inside the polyhouse was measured by the sensor BH1750 light intensity sensor and recorded using automated data acquisition system in 15 minutes interval.

Result and Discussion

CHAPTER IV
RESULT AND DISCUSSION

The objectives of the study were to develop an automated data acquisition NFT hydroponics system, evaluation of the performance of the developed system for different flow rates and study of microclimate and nutrient solution status. Results obtained from the study are discussed in this chapter.

4.1 DESIGN AND INSTALLATION OF NFT HYDROPONICS SYSTEM

Three benches of NFT hydroponics system were installed in the polyhouse (Plate 4.1). Each bench consists of four NFT hydroponics channels; a constant flow of nutrient solution was maintained in the channels of each bench. Net cups were placed in the channels to hold the plants. Nutrient tanks of 150, 200 and 500 l capacities were placed at the outlet side of the NFT systems of Bench I, Bench II and Bench III respectively. Pumps of 55 watts, 2.5 m head and 2000 l/h capacity were used to pump nutrient solution in each bench. Aeration of the nutrient solution was provided by an aerator and working of the pump was controlled by a timer.

Plate 4.1 NFT hydroponics system installed in the polyhouse

Nutrient solution was pumped from the tank by a submersible pump to the NFT channels through the supply pipe. At the outlet side of the supply pipe, valves were provided to control the rate of flow through the NFT channels. Slope of 1% is provided to the NFT channel so that the nutrient solution flows freely through the channels. Nutrient solutions from the NFT channels were collected in the outlet channel and from there it returned to the same solution tank. Then it is again recirculated to the channels.

4.2 DEVELOPMENT AND INSTALLATION OF IoT BASED AUTOMATED DATA ACQUISITION SYSTEM

Developed automated data acquisition system monitored in real time the parameters of nutrient solution such as electrical conductivity, pH, nutrient solution temperature, depth of nutrient solution in the tanks and channels and also monitored in real time microclimatic parameters in polyhouse including air temperature, relative humidity and light intensity. The system operated devices such as exhaust fans, air circulating fan and foggers to control air temperature and humidity inside the polyhouse. Gathered data were accessed and displayed in a system and mobile using an IoT platform called ThingSpeak.

4.2.1 Calibration of sensors

Calibration of sensors was done to get accurate data.

4.2.1.1 Calibration of pH sensors

Calibration of pH sensors was done using standard buffer solutions every week as per the procedure in 3.3.3.1. The system automatically calculated the m and c values of the straight line equation $y= m x + c$, from voltage reading by pH sensor and corresponding pH of the standard buffer solutions, where y is the pH of the nutrient solution and x is the voltage. The relevant calibration parameters were automatically saved to EEPROM of the Arduino UNO board and calculated the pH sensor output.

4.2.1.2 Calibration of EC sensors

Calibration of EC sensors was done using standard buffer solutions every week as per the procedure in 3.3.3.2. The system automatically calculated the m and c values of the straight line equation y= m x + c, from voltage reading by EC sensor and corresponding EC of the standard buffer solutions, where y is the EC of the nutrient solution and x is the voltage. The relevant calibration parameters were automatically saved to EEPROM of the Arduino MEGA board and calculated the EC sensor output.

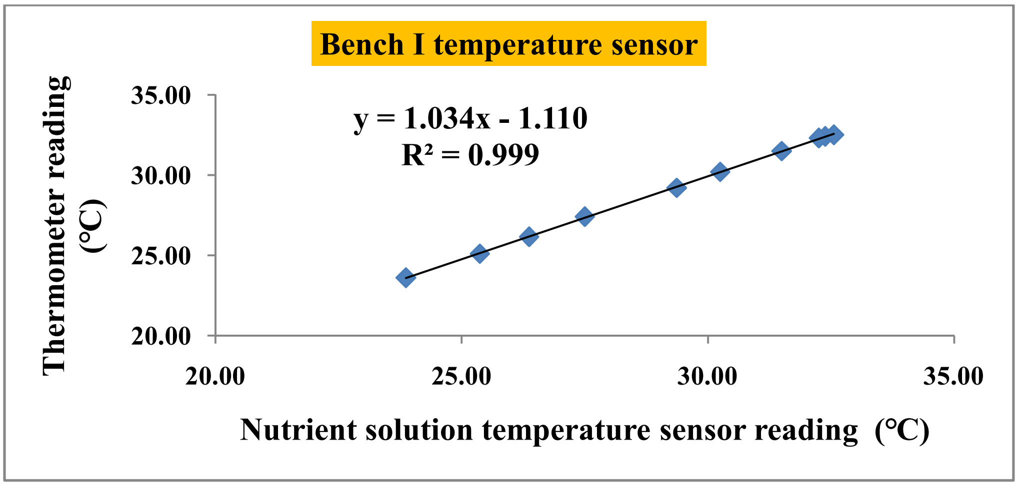
4.2.1.3 Calibration of temperature sensor

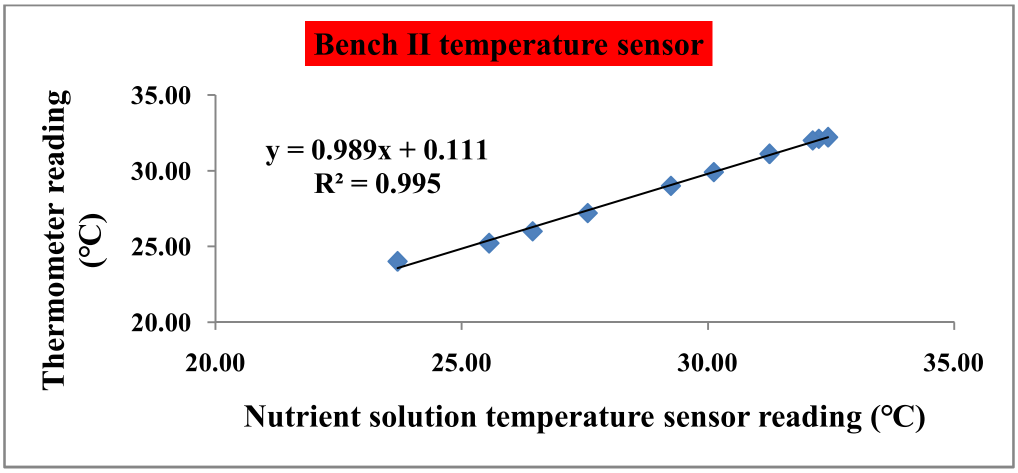
Calibration of DS18B20 temperature sensors were done as per the procedure in 3.3.3.3. Analysis of data showed that nutrient solution temperature sensor of Bench I has an error of ±0.46 per cent and RMSE value of 0.16, sensor of Bench II has an error of ±0.94 per cent and RMSE value of 0.28 and that of Bench III has an average error of ±1.17 per cent and RMSE value of 0.33. Graphs were plotted (Fig 4.1) using the obtained data of each bench, where thermometer readings were taken as y and sensor readings were taken as x. Calibration equations (4.1, 4.2 and 4.3) were derived and shown in the Fig 4.1. Calibration equations were added in the program to get more accurate values of nutrient solution temperature sensors of Bench I, II and III respectively.

$$y = 1.034x - 1.110 \quad (4.1)$$

$$y = 0.989x + 0.111 \quad (4.2)$$

$$y = 1.017x - 0.822 \quad (4.3)$$





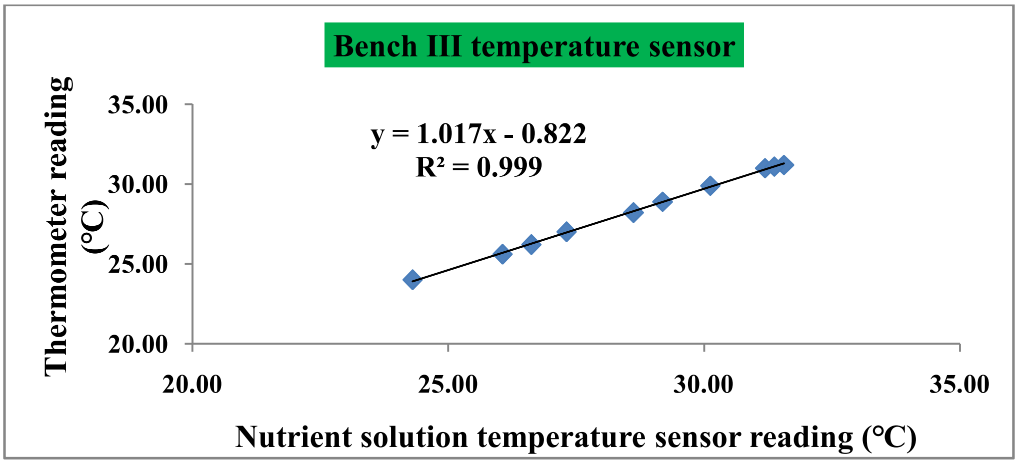


Fig. 4.1 Calibration of temperature sensors (DS18B20)

4.2.1.4 Calibration of ultrasonic sensors

Calibration of ultrasonic sensors was done as per the procedure in 3.3.3.4. From the data obtained it was calculated that ultrasonic sensor of Bench I has an average error of ±1.03 per cent and RMSE value of 0.31, sensor of Bench II has ±1.41 percent average percentage error and RMSE value of 0.33 and sensor of Bench III has an average percentage error of ±5.24 per cent and RMSE value of 0.96. Graphs were plotted (Fig 4.2) using the obtained data of each bench, where scale readings were taken as y and sensor readings were taken as x. Calibration equations (4.4, 4.5 and 4.6) derived from the graphs were incorporated in the program to get more accurate sensor readings.

$$y = 0.968x + 0.773 \qquad 4.4$$

$$y = 1.052x - 0.768 \qquad 4.5$$

$$y = 0.939x + 1.935 \qquad 4.6$$

4.2.1.5 Calibration of depth sensors

Nutrient solution depth sensor was calibrated as per procedure in 3.3.3.5. Fig 4.3 presents the graph plotted between the sensor and manual readings and calibration equation (4.7) is arrived.

$$y = x \qquad 4.7$$

From the data it was clear that these sensors showed accurate readings for depth of nutrient solution in all three benches. Hence they have zero percent error.

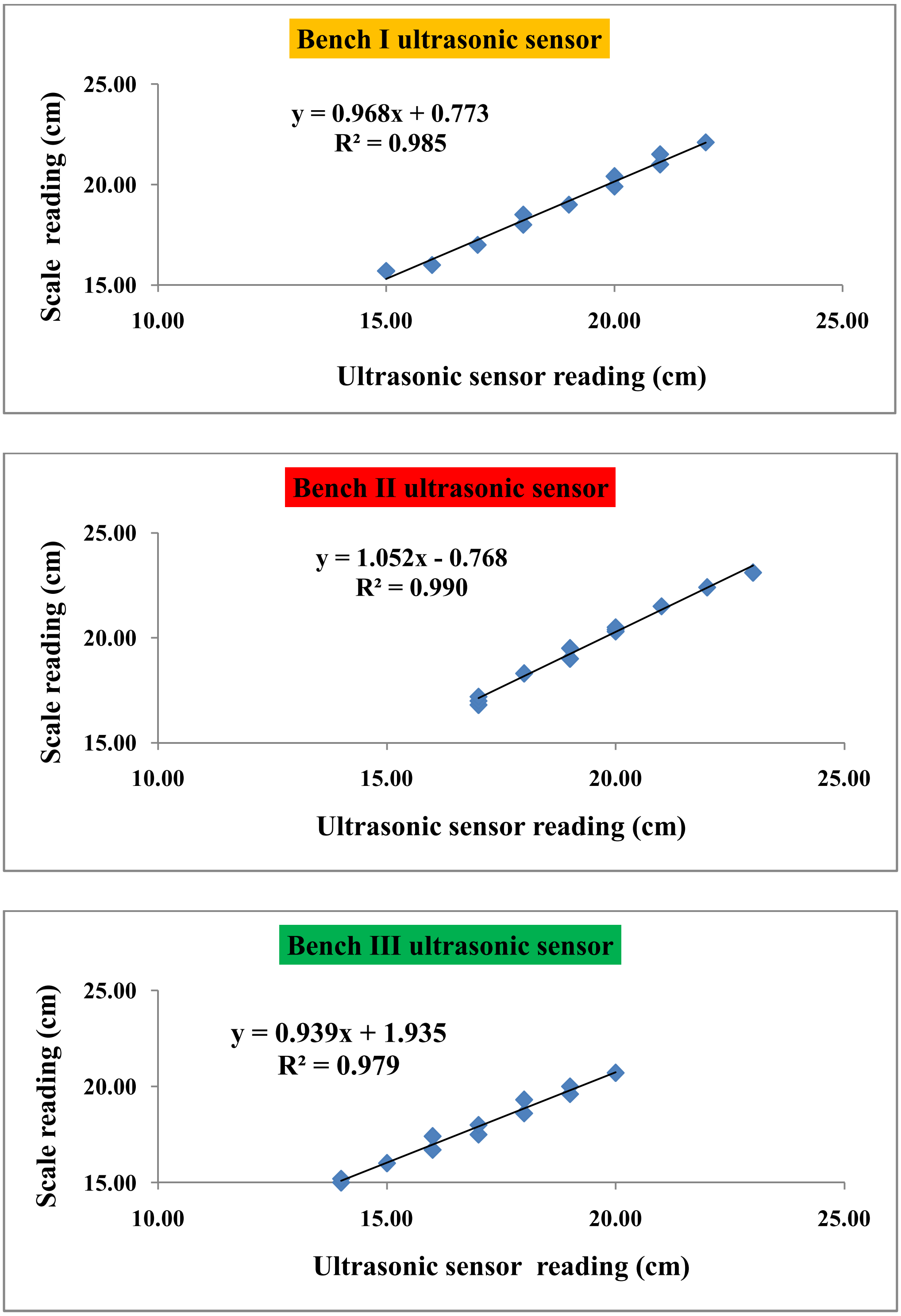


Fig. 4.2 Calibration of ultrasonic sensors

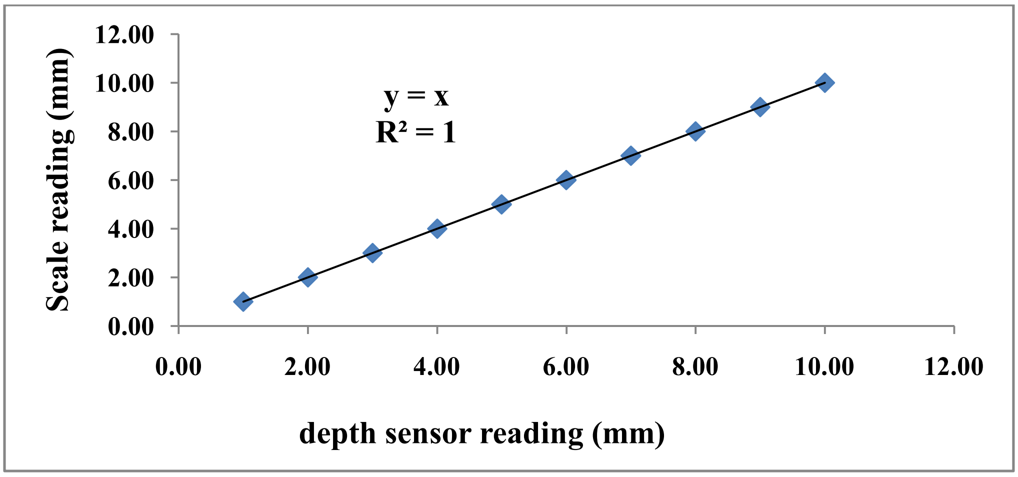


Fig. 4.3 Calibration of depth sensor

4.2.1.6 Calibration of air temperature and RH sensor

The DHT22 sensor was calibrated as per the procedure 3.3.3.6. It was found that the sensor shows an error of ±9.01 per cent and RMSE value of 3.06 in the measurement of air temperature. Calibration equation (4.8) was derived and shown in the Fig. 4.4. Calibration equation was added in the program to get more accurate temperature reading by the sensor.

$$y = 0.546x + 13.53 \qquad 4.8$$

The plot of sensor readings and relative humidity estimated from wet and dry bulb thermometer readings were shown in Fig 4.5. Sensor shows an error of ±1.88 per cent and RMSE of 1.63. A straight line was fitted to the data to get the calibration equation (4.9), relating sensor readings and measured relative humidity. This equation was included in the program to get accurate relative humidity reading by the sensor.

$$y = 0.693x + 19.27 \qquad 4.9$$

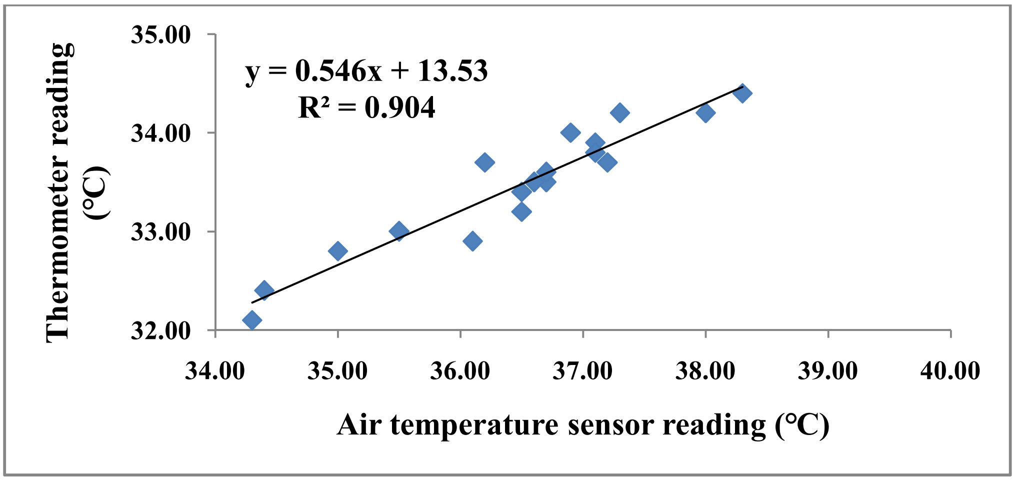


Fig. 4.4 Calibration of DHT22 sensor for air temperature

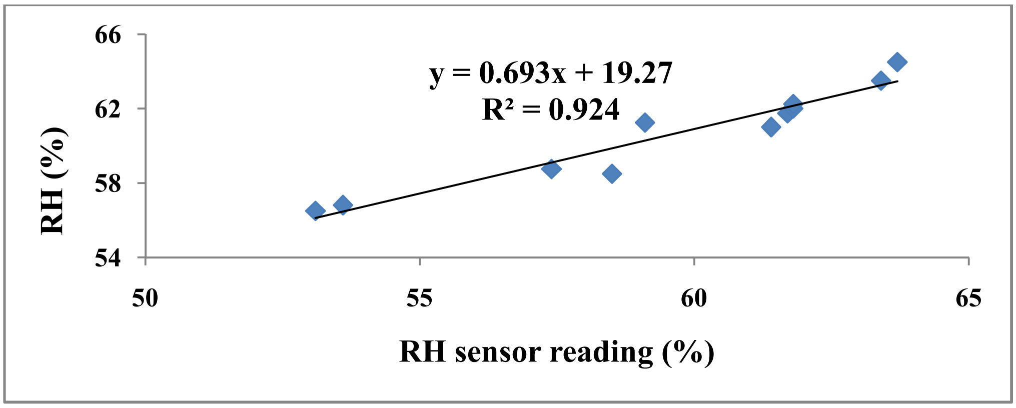


Fig. 4.5 Calibration of DHT22 sensor for RH

4.2.1.7 Calibration of light intensity sensor

Light intensity sensor (BH1750) was calibrated as per the procedure 3.3.3.7 by comparing readings of sensor and lux meter. From the data the sensor showed an average error of ±7.95 per cent and RMSE value of 625.03. Fig 4.6 presents the comparison of readings obtained from BH1750 light intensity sensor and lux meter. A straight line is fitted to the data to get the calibration equation (4.10), which was included in the program to get more accurate readings.

$$y = 1.059x - 4.442 \qquad 4.10$$

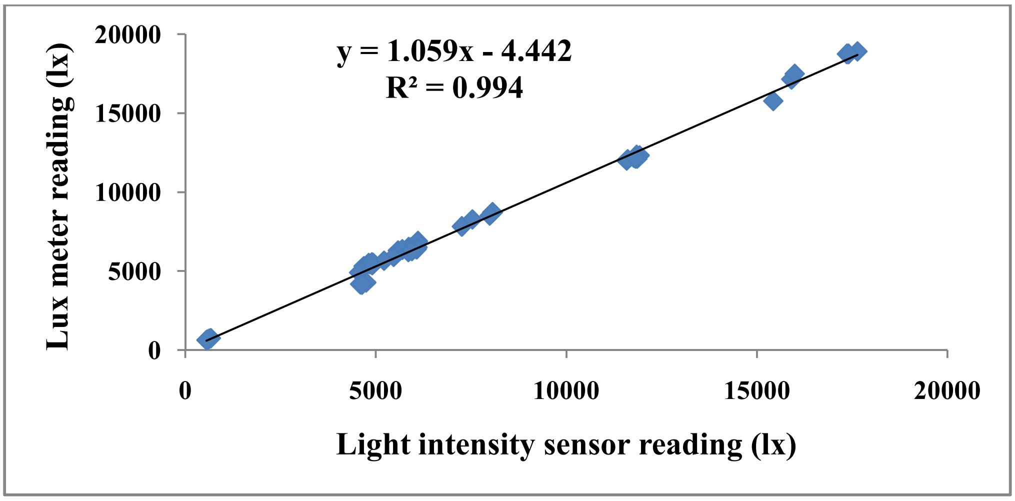


Fig. 4.6 Calibration of light intensity sensor (BH1750)

4.2.2 Installation and testing of automated data acquisition system

The overall set up of the developed automated data acquisition system was installed inside the polyhouse at the center of the three benches of NFT hydroponics system (Plate 4.2).

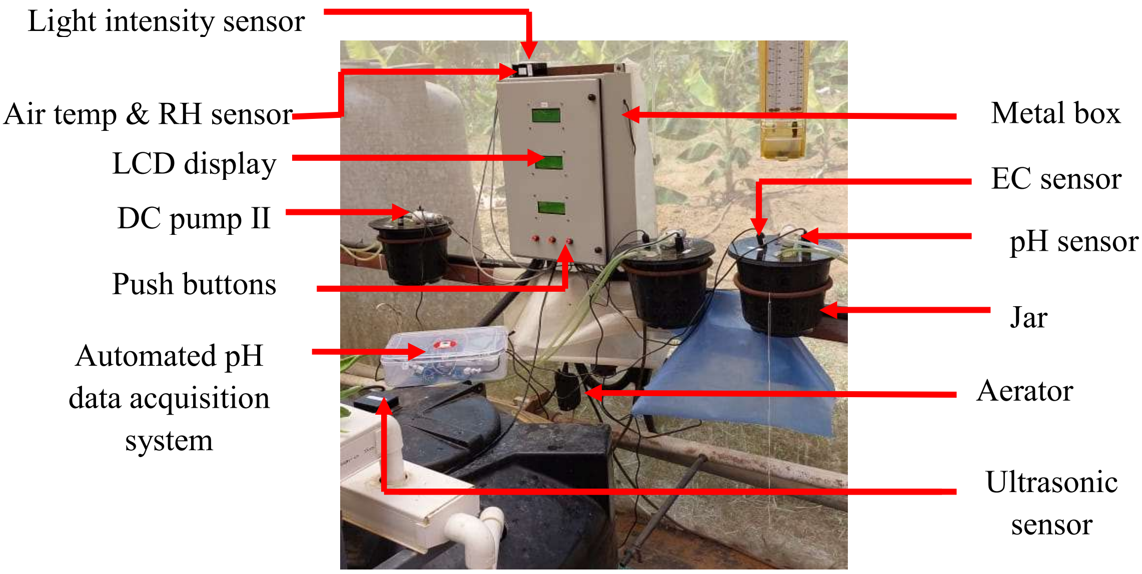


Plate 4.2 Overall set up of automated data acquisition system

4.2.2.1 Validation of sensors

Validation of the pH sensor was done by comparing sensor output values with the pH meter values. Ten pH readings of sample solutions were taken for testing. Collected data were plotted as shown in Fig 4.7. pH sensor of Bench I shows an error of ±3.73 per cent and RMSE of 0.22, that of Bench II has an average percent error of ±1.39 and RMSE of 0.10 and pH sensor of Bench III has an average percent error of ±3.61 and RMSE of 0.22. Low percentage error and RMSE values of three pH sensors show that sensors are accurate for pH measurement.

Validation of EC sensors were carried out by comparing the sensor's output with measured EC values from electrical conductivity meter. Ten readings were taken for testing of EC sensors and collected data were plotted and shown in Fig 4.8. From the obtained data it is calculated that the sensor has ±19.47 percent error and RMSE value of 0.26 for Bench I EC sensor. Bench II EC sensor has a percentage error of ±19.60 and RMSE of 0.22 whereas Bench III EC sensor has an average error of ±19.67 per cent and RMSE value of 0.39. All the EC sensors have shown average percentage error less than 20 percent and RMSE value of less than 0.5 which enable the EC sensors suitable for EC measurement.

Validation of nutrient solution temperature sensors were conducted by comparing sensor readings and corresponding thermometer readings of water in the nutrient tank. Water temperature was monitored manually for a period of one week in one hour intervals from 9 am to 5 pm and corresponding sensor readings were also taken and plotted as shown in Fig 4.9. Test result shows that percentage error of sensors of Bench I, II and III reduced after calibration to ±0.30, ±0.72 and ±1.01 per cent with RMSE value of 0.12, 0.22 and 0.31 respectively. Hence it is inferred that nutrient solution temperature sensors are accurate for measurement.

Validation of ultrasonic sensors was done by comparing ultrasonic sensor readings and scale readings after calibration. Comparison of ultrasonic sensor readings and scale readings was shown in Fig 4.10. It resulted that sensors could work properly with a very less percentage error of ±1.00, ±1.03 and ±1.93 per cent for sensors of Bench I, II and III with RMSE value of 0.16, 0.23 and 0.25 respectively.

The DHT22 sensor was tested for both air temperature and RH readings by comparing the sensor readings and thermometer readings for air temperature and dry bulb and wet bulb thermometer readings for RH. Both air temperature and RH recorded manually in one hour intervals from 9 am to 5 pm for a period of one week and corresponding sensor readings were also taken and plotted as shown in Fig 4.11 and Fig 4.12 respectively. Test results showed that air temperature reading has significant reduction in error to ±3.37 per cent with RMSE value of 1.14, whereas RH reading has an error of ±1.81 per cent with RMSE value of 1.10. Hence it is inquired that the temperature and humidity sensor gives accurate measurements.

Light intensity sensor was also tested similar to air temperature sensor, here sensor readings were compared with lux meter readings (Fig 4.13). Test results indicated that error in the sensor reading reduced to ±2.54 per cent with RMSE value 222.27.

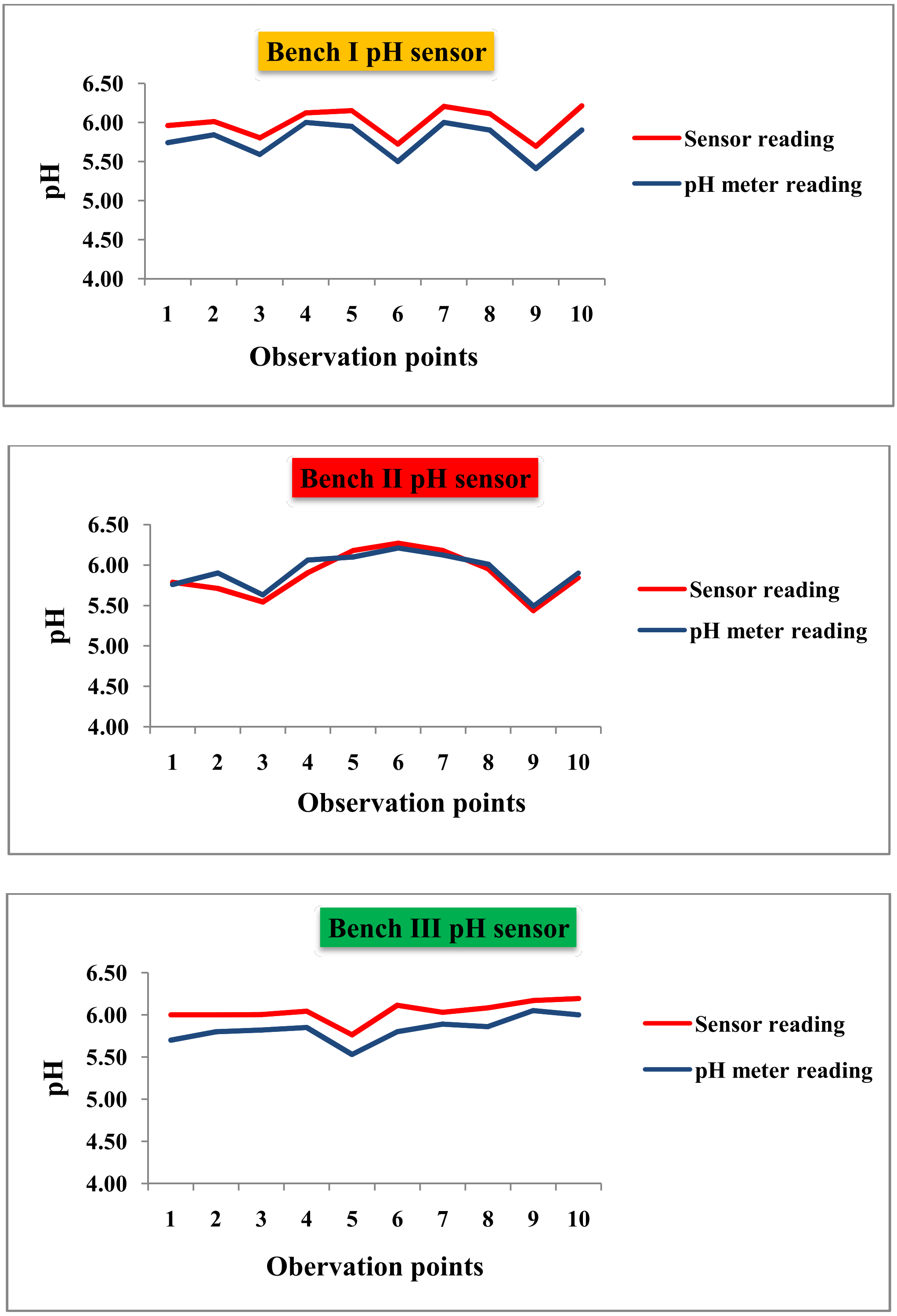


Fig. 4.7 Validation of pH sensors

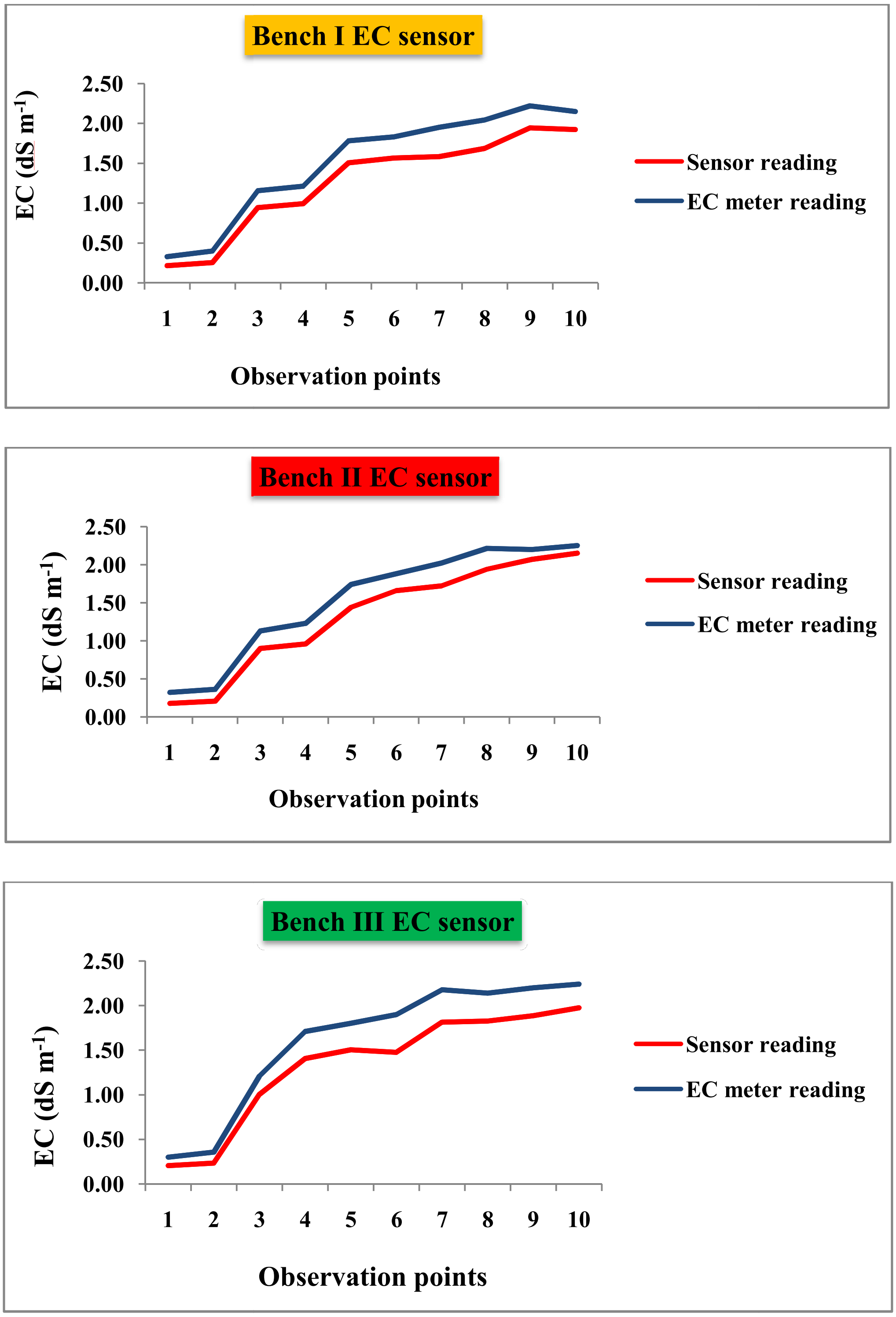


Fig. 4.8 Validation of EC sensors

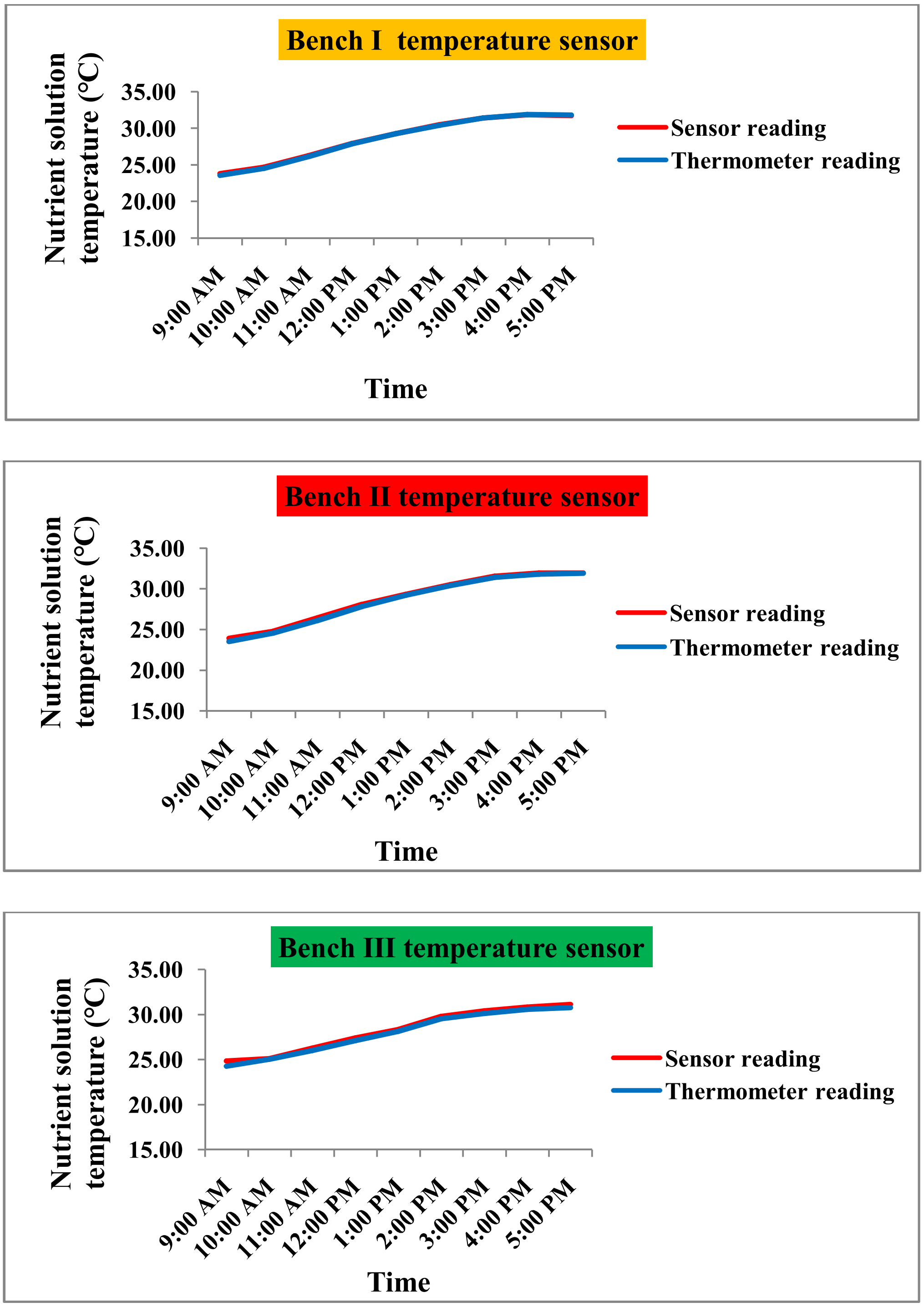


Fig. 4.9 Validation of temperature sensors

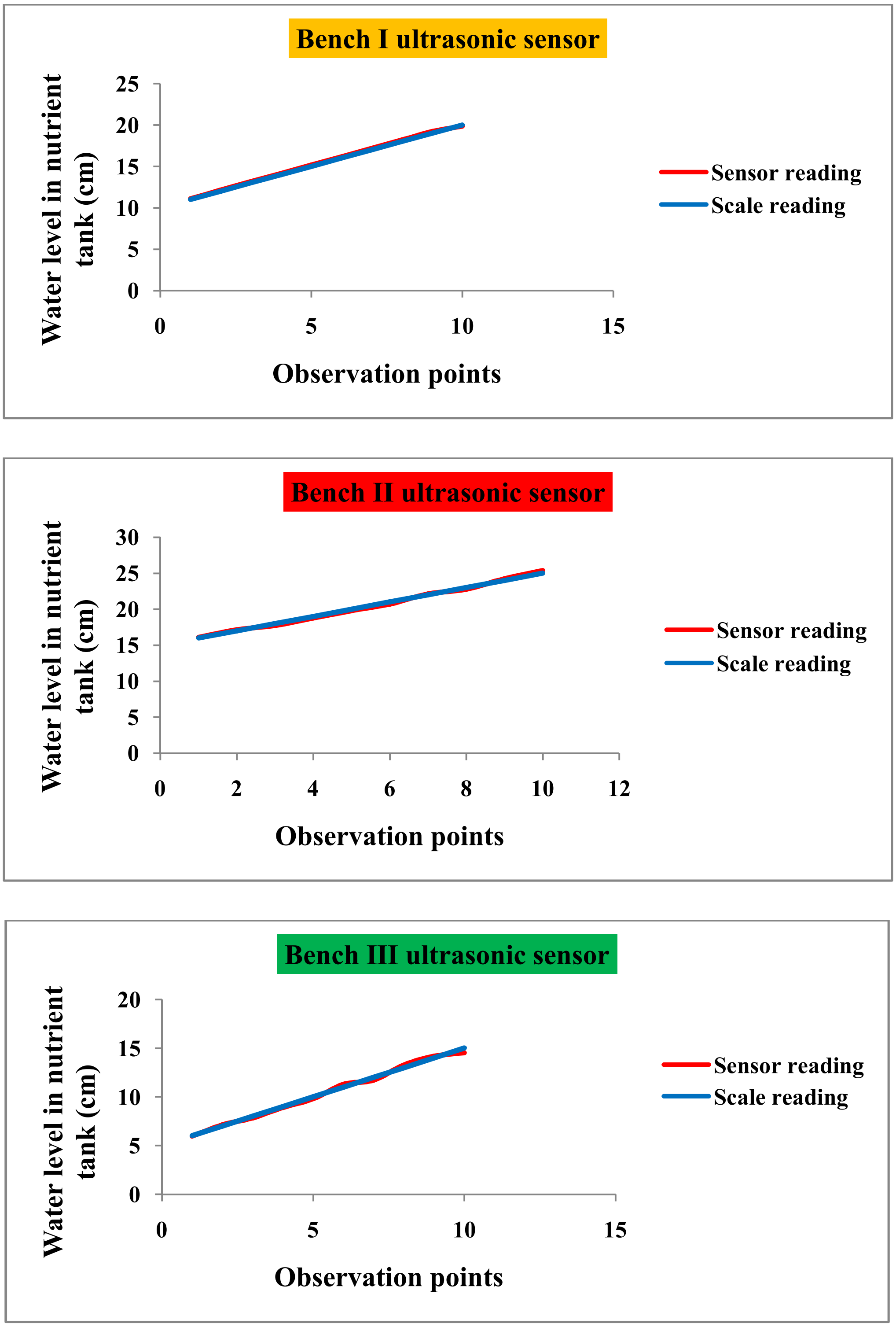


Fig. 4.10 Validation of ultrasonic sensors

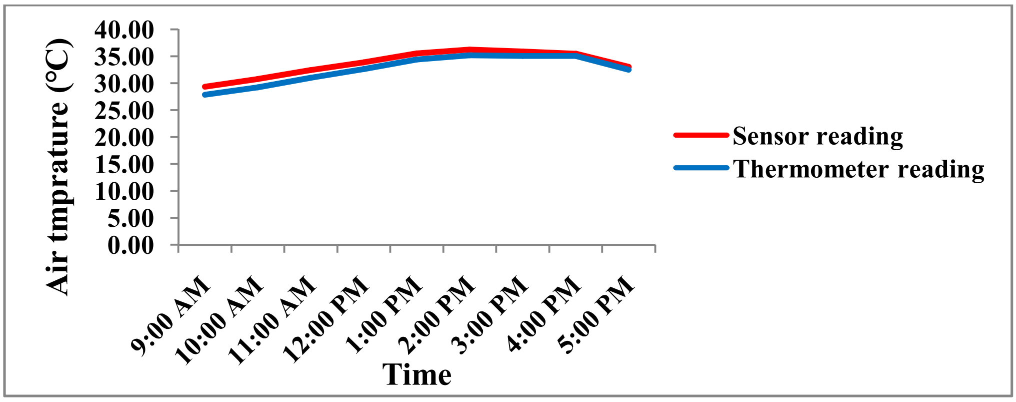


Fig. 4.11 Validation of air temperature and RH sensor for air temperature

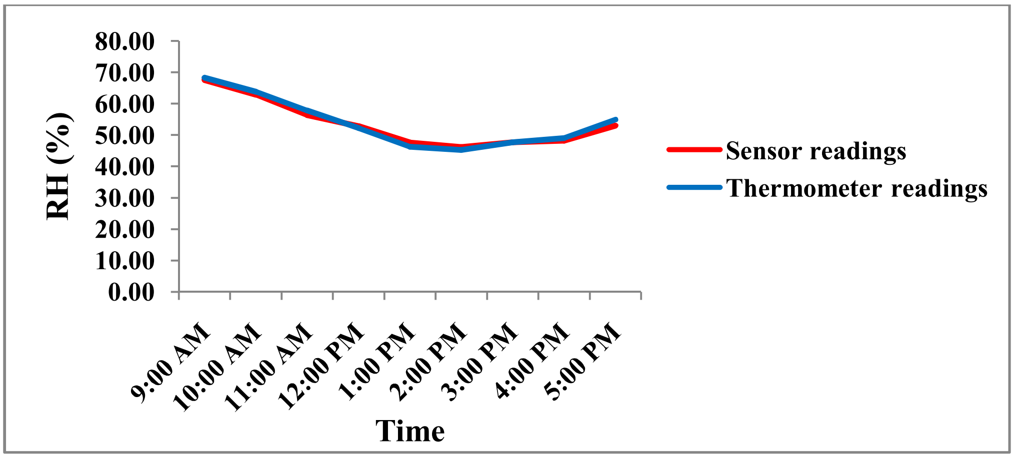


Fig. 4.12 Validation of air temperature and RH sensor for RH

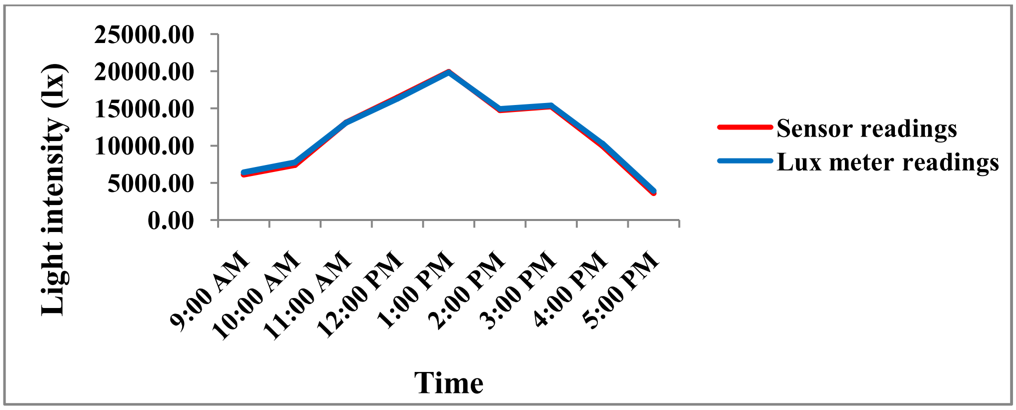
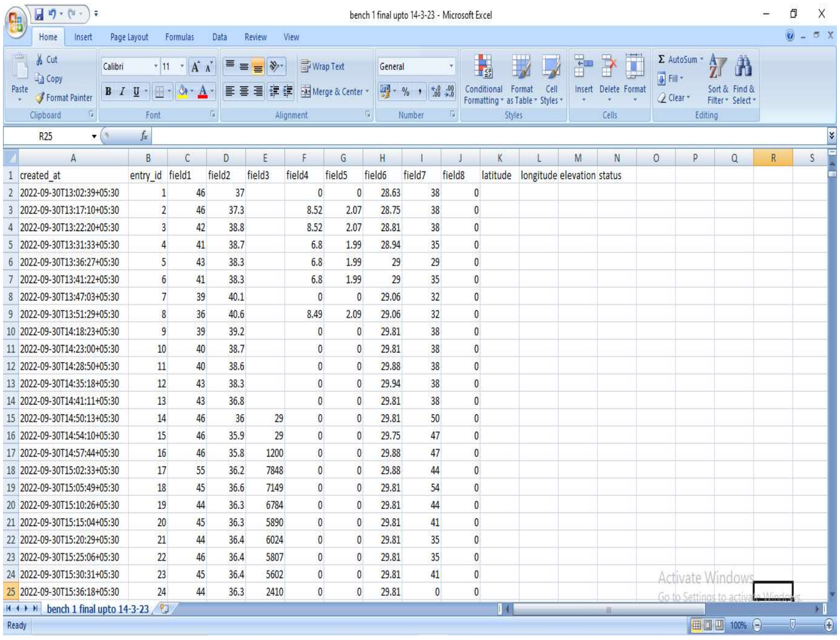


Fig. 4.13 Validation of light intensity sensor

4.2.2.2 Testing of automated data acquisition system for real time monitoring

Sensors, actuators, Arduino board and other components are interfaced to PCB and installed the automated system inside the polyhouse. Various parameters of nutrient solution such as electrical conductivity, pH, nutrient solution temperature, depth of nutrient solution in tank and channel were automatically monitored by the developed system. It also monitored different micro climatic parameters including air temperature, relative humidity and light intensity. Measured data were uploaded to ThingSpeak IoT cloud in fifteen minutes time interval. The data were monitored in ThingSpeak in the excel data sheet format and shown in figures (Fig 4.14) and also displayed graphically as shown in Figures (Fig 4.15 to Fig 4.17) for each bench. Fig 4.18 shows the display pH of nutrient solution in each bench. Plate 4.3 shows data monitoring using ThingSpeak in mobile phone.

pH and EC of nutrient solution of Bench I, II and III were also displayed in three different LCDs (Plate 4.4). Here pH values of Bench I, II and III were displayed as zero, since pH sensors were kept as a separate automation unit and these were not connected with the LCDs of main automation unit. Nutrient solution temperature, depth of nutrient solution in channel and tank of Bench I, II and III were displayed in three different LCDs and microclimatic parameters including humidity, air temperature and light intensity were also displayed in LCDs in real time (Plate 4.5). Plate 4.6 shows the three LCDs of the automation system. Date and time were displayed in all three LCDs initially, after that pH and EC of nutrient solution of Bench I, II and III were displayed in LCD I, II and III respectively. Microclimatic parameters including RH, air temperature and light intensity were displayed in all three LCDs, whereas nutrient solution temperature, depth of nutrient solution in channel and tank of Bench I, II and III were displayed in LCD I, II and III respectively.



created_at	entry_id	field1	field2	field3	field4	field5	field6	field7	field8	latitude	longitude	elevation	status
2022-09-30T13:02:39+05:30	1	46	37		0	0	28.63	38	0				
2022-09-30T13:17:10+05:30	2	46	37.3		8.52	2.07	28.75	38	0				
2022-09-30T13:22:20+05:30	3	42	38.8		8.52	2.07	28.81	38	0				
2022-09-30T13:31:33+05:30	4	41	38.7		6.8	1.99	28.94	35	0				
2022-09-30T13:36:27+05:30	5	43	38.3		6.8	1.99	29	29	0				
2022-09-30T13:41:22+05:30	6	41	38.3		6.8	1.99	29	35	0				
2022-09-30T13:47:03+05:30	7	39	40.1		0	0	29.06	32	0				
2022-09-30T13:51:29+05:30	8	36	40.6		8.49	2.09	29.06	32	0				
2022-09-30T14:18:23+05:30	9	39	39.2		0	0	29.81	38	0				
2022-09-30T14:23:00+05:30	10	40	38.7		0	0	29.81	38	0				
2022-09-30T14:28:50+05:30	11	40	38.6		0	0	29.88	38	0				
2022-09-30T14:35:18+05:30	12	43	38.3		0	0	29.94	38	0				
2022-09-30T14:41:11+05:30	13	43	36.8		0	0	29.81	38	0				
2022-09-30T14:50:13+05:30	14	46	36	29	0	0	29.81	50	0				
2022-09-30T14:54:10+05:30	15	46	35.9	29	0	0	29.75	47	0				
2022-09-30T14:57:44+05:30	16	46	35.8	1200	0	0	29.88	47	0				
2022-09-30T15:02:33+05:30	17	55	36.2	7848	0	0	29.88	44	0				
2022-09-30T15:05:49+05:30	18	45	36.6	7149	0	0	29.81	54	0				
2022-09-30T15:10:26+05:30	19	44	36.3	6784	0	0	29.81	44	0				
2022-09-30T15:15:04+05:30	20	45	36.3	5890	0	0	29.81	41	0				
2022-09-30T15:20:29+05:30	21	44	36.4	6024	0	0	29.81	35	0				
2022-09-30T15:25:06+05:30	22	46	36.4	5807	0	0	29.81	35	0				
2022-09-30T15:30:31+05:30	23	45	36.4	5602	0	0	29.81	41	0				
2022-09-30T15:36:18+05:30	24	44	36.3	2410	0	0	29.81	0	0				

Fig. 4.14 Data of channel 1 downloaded in excel format from ThingSpeak

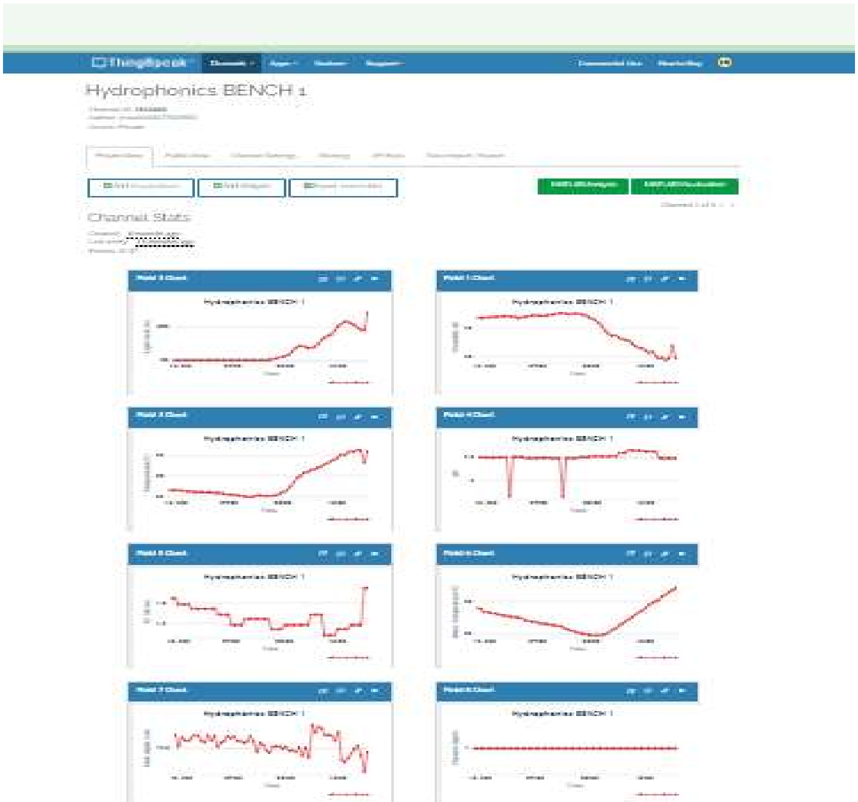


Fig. 4.15 Monitoring of real time data of Bench I in computer from ThingSpeak

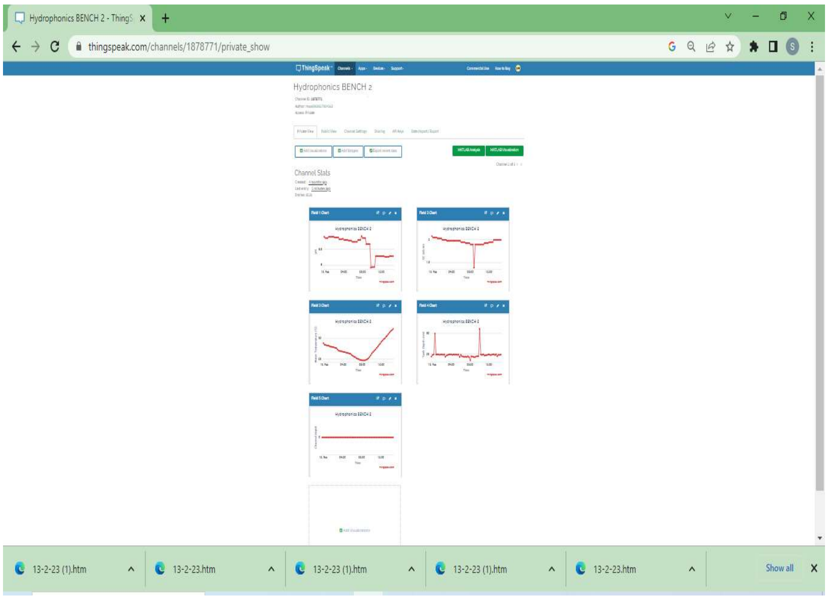


Fig 4.16 Monitoring of real time data of Bench II in computer from ThingSpeak

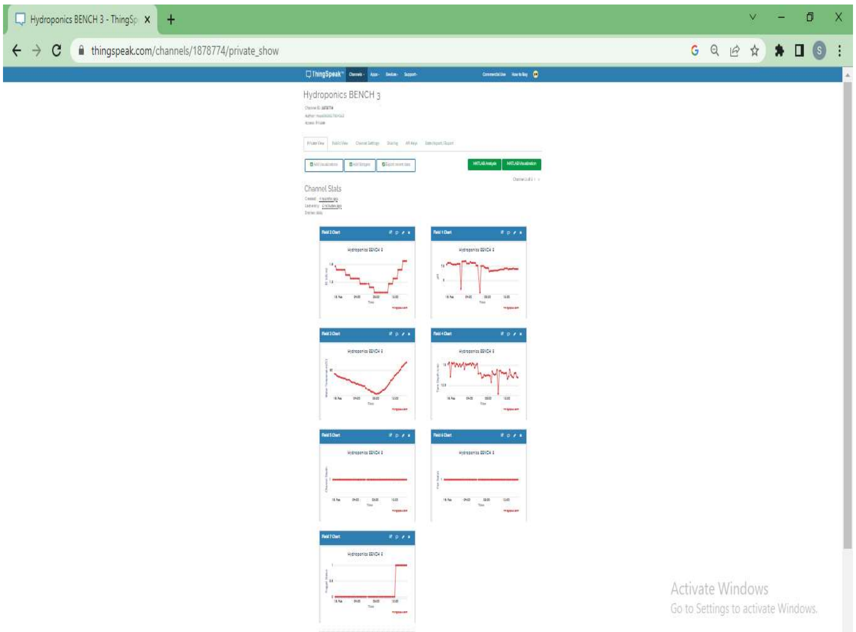


Fig 4.17 Monitoring of real time data of Bench III in computer from ThingSpeak

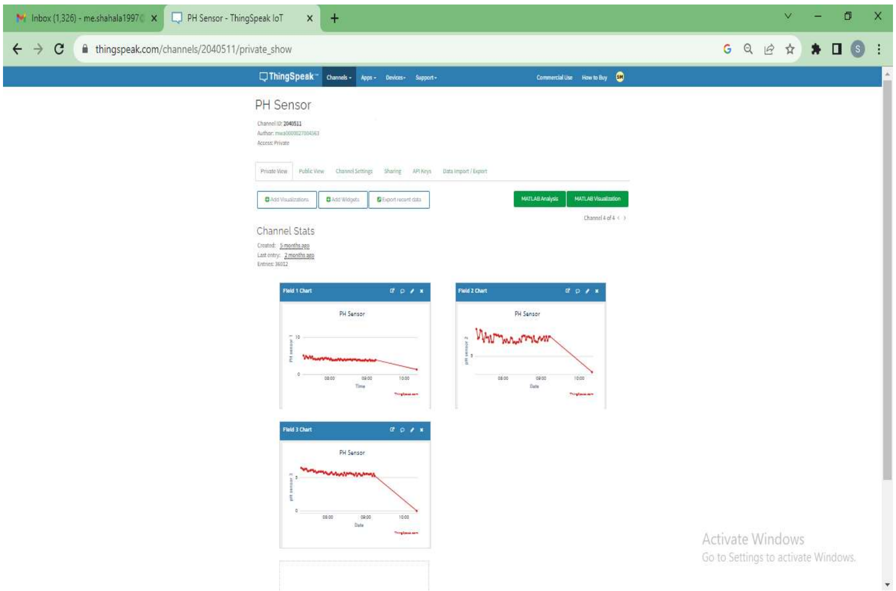


Fig 4.18 Monitoring of real time pH of nutrient solution in computer from ThingSpeak

Plate 4.3 Monitoring of real time data in mobile phone from ThingSpeak

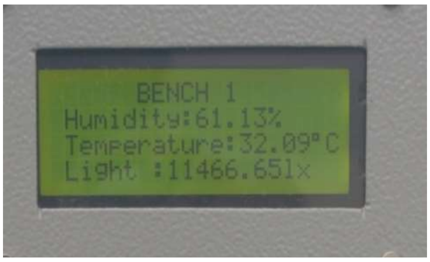
a.

b.

c.

Plate 4.4 LCD display of pH and EC of (a) Bench I, (b) Bench II, (c) Bench III

a.



b.

c.

d.

Plate 4.5 LCD showing (a) Humidity, air temperature and light intensity inside polyhouse, (b) Water temperature, nutrient solution depth in channel and tank of Bench I, (c) Water temperature, nutrient solution depth in channel and tank of Bench II, (d) Water temperature, nutrient solution depth in channel and tank of Bench III.

Plate 4.6 Three LCD displays of automated data acquisition system

4.2.2.3 Testing of the automated data acquisition system for the control of air temperature and RH

The performance of the automation system was tested by comparing air temperature and relative humidity inside and outside the polyhouse. Average readings of air temperature and relative humidity in a two hour interval for two weeks were taken and shown in Table 4.1. It was found that the difference in the air temperature and RH readings between outside and inside the polyhouse was less during the day. During morning hours of 9 am and 11am air temperature was more inside the polyhouse than outside. Whereas during the later hours the inside temperature was less than that of outside polyhouse (Fig 4.19). This is because foggers also started to operate along with fans when the temperature rose to 35 ℃ and reduced the temperature inside the polyhouse. Hence air temperature inside the polyhouse becomes less than outside temperature during peak hours (1 to 3 pm). Similar trend was also found in relative humidity where RH was found less inside the polyhouse at the time of 9 am and 11 am whereas more at 1 pm, 3 pm and 5 pm compared to RH outside the polyhouse (Fig 4.20). During 9 am air temperature inside the polyhouse was 2.4 percent higher than the outside temperature. By 11 am the difference between inside and outside temperature was decreased to 1.4 % due to the continuous operation of fans. It was found that from 1 pm to 5 pm the inside air temperature was 1-1.6 percent less than that of outside the polyhouse due to the operation of foggers along with the fans. Similarly, RH inside the polyhouse was 7.4-7.9 percent less than the RH outside the polyhouse during the morning hours of 9-11 am. It was found that during the hours of 1-5 pm, the RH inside the polyhouse was 0.6-3 percent higher than the RH outside the polyhouse due to the operation of foggers.

Table 4.1 Air temperature and RH readings inside and outside of polyhouse

Sl. No	Time	Temperature (°C)			Relative humidity (%)		
		Inside	Outside	Difference (%)	Inside	Outside	Difference (%)
1	9:00 AM	30.87	30.14	-2.4	59.81	64.92	7.9
2	11:00 AM	34.85	34.38	-1.4	45.70	49.36	7.4
3	1:00 PM	37.32	37.92	1.6	41.46	40.60	-2.1
4	3:00 PM	38.21	38.58	1.0	45.17	44.89	-0.6
5	5:00 PM	34.53	35.00	1.4	51.75	50.23	-3.0

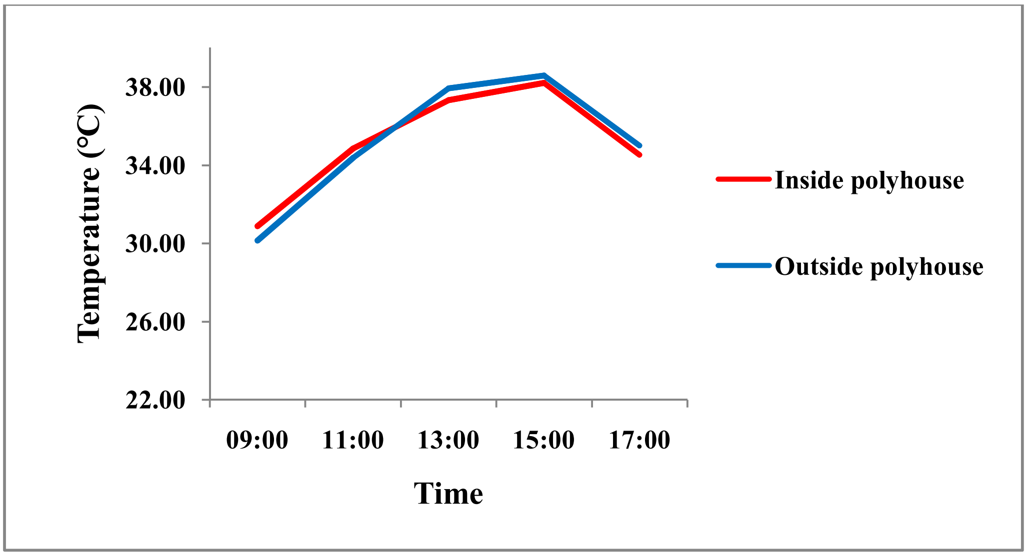


Fig. 4.19 air temperature inside and outside polyhouse

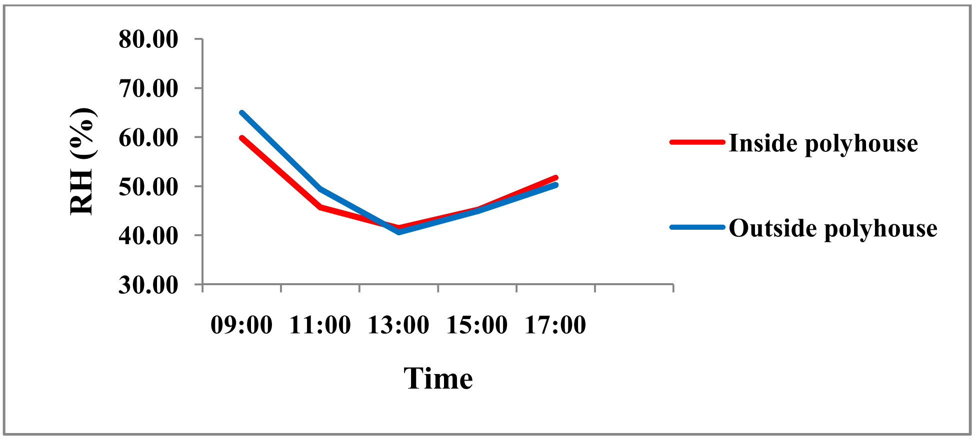


Fig. 4.20 RH inside and outside polyhouse

4.3 EVALUATION OF AUTOMATED DATA ACQUISITION NFT HYDROPONICS SYSTEM WITH CROP AND UNDER DIFFERENT FLOW RATE

Evaluation of the developed automated data acquisition NFT hydroponics system was done for the cultivation of spinach under different flow rates.

4.3.1 Evaluation of automated data acquisition system with crop

Various parameters of nutrient solution such as electrical conductivity, pH and nutrient solution temperature, depth of nutrient solution in tank and channel of Bench I, Bench II and Bench III were automatically monitored by the developed system during the crop period. It also monitored different micro climatic parameters including air temperature, relative humidity and light intensity.

4.3.1.1 pH of nutrient solution

pH of the nutrient solution was measured in one hour intervals and recorded using the automated data acquisition system. pH levels of nutrient solutions of different benches were displayed in the ThingSpeak as shown in Fig 4.21 and it shows some error in recorded pH value, it is due to the measurement of EC sensor and pH sensor at the same time. By clicking on each data point, information about the value of parameter, day, date and time at the measurement was taken. Fig 4.22 shows continuous monitoring of pH of nutrient solutions of different benches for one week during crop period. It shows that pH was maintained at 5.5-6.5 in all three systems and shows some fluctuations in readings. pH was maintained by adding pH up and down solutions to the nutrient solution.

Fig. 4.21 Monitoring of real time pH of nutrient solution in computer from ThingSpeak IoT cloud

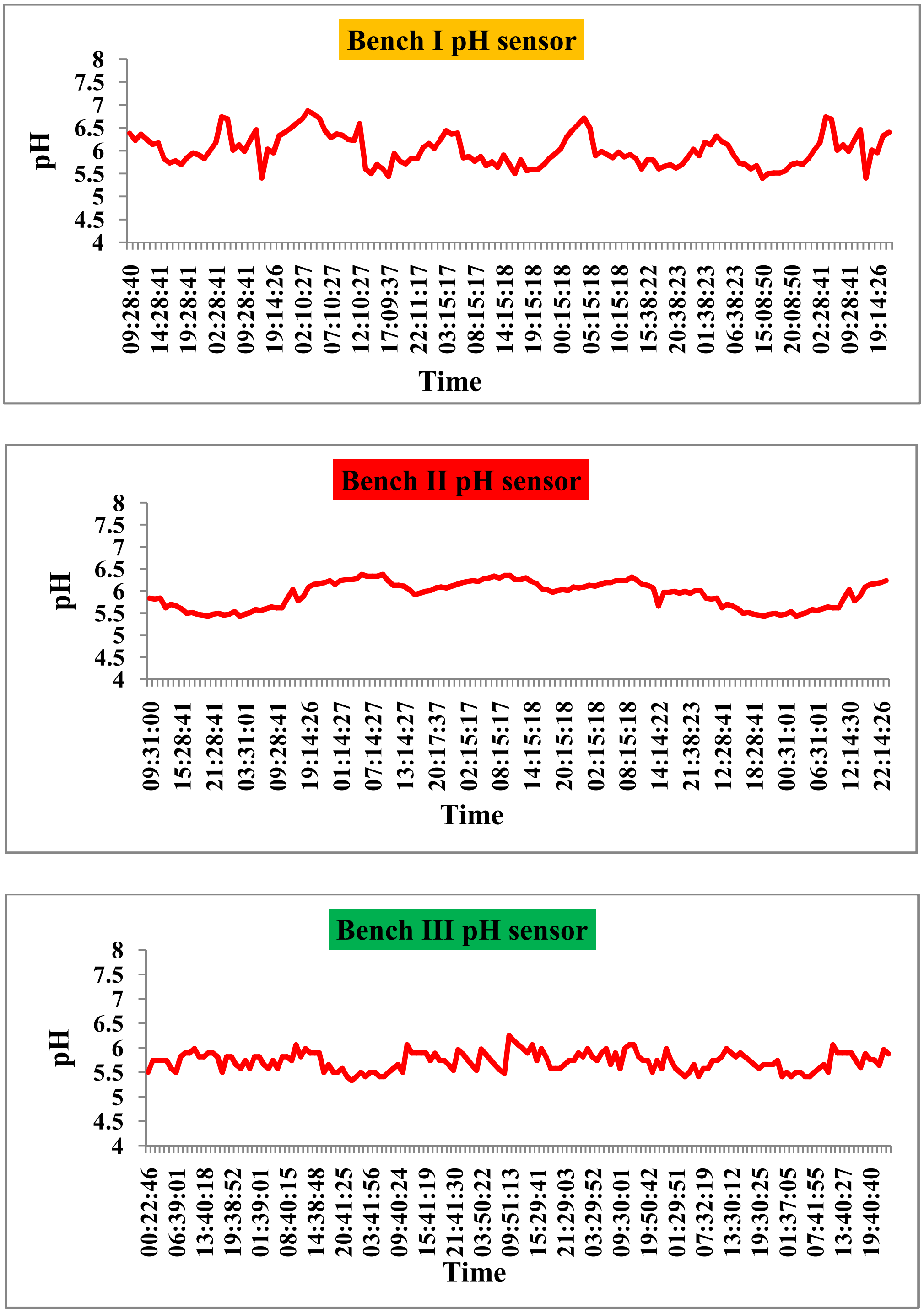


Fig. 4.22 Real time monitoring of pH of nutrient solution for one week (29-12-2022 to 04-01-2023)

4.3.1.2 Electrical conductivity of nutrient solution

Electrical conductivity was measured by the developed system in one hour interval and data was uploaded to ThingSpeak in every 15 minute interval. The monitored EC of the nutrient solution is displayed using the ThingSpeak platform as shown in Fig 4.23 and it indicates that EC of nutrient solution decreased as the plants absorbed the nutrients and during day time EC of nutrient solution also increased due to loss of water through evaporation and transpiration. ThingSpeak displays EC value, day, date and time of measurement by clicking on each data point. Fig 4.24 shows the continuous data acquisition of EC of nutrient solution of different benches for one week during crop period. It presents the decrease and increase in the EC level of the nutrient solution. The increase in the EC level is due to the addition of nutrient stock solution to the solution in the tank and also due to the loss of water due to evaporation and transpiration.

4.3.1.3 Nutrient solution temperature

Temperature of the nutrient solution was continuously monitored by DS18B20 nutrient solution temperature sensor. The trend of nutrient solution temperature data at different times was obtained from ThingSpeak graphs as shown in Fig 4.25. Graphical presentation of data in ThingSpeak helps in easy interpretation of the data. Fig 4.26 presents one week continuous data acquisition of nutrient solution temperature of Bench I, Bench II and Bench III. It shows the hourly variation of nutrient solution temperature in a day and also shows day to day variation in temperature. The temperature increases to maximum in the evening and the decreases to a minimum in the morning in all 3 benches. There is not much variation between the nutrient solution temperatures of the three benches.

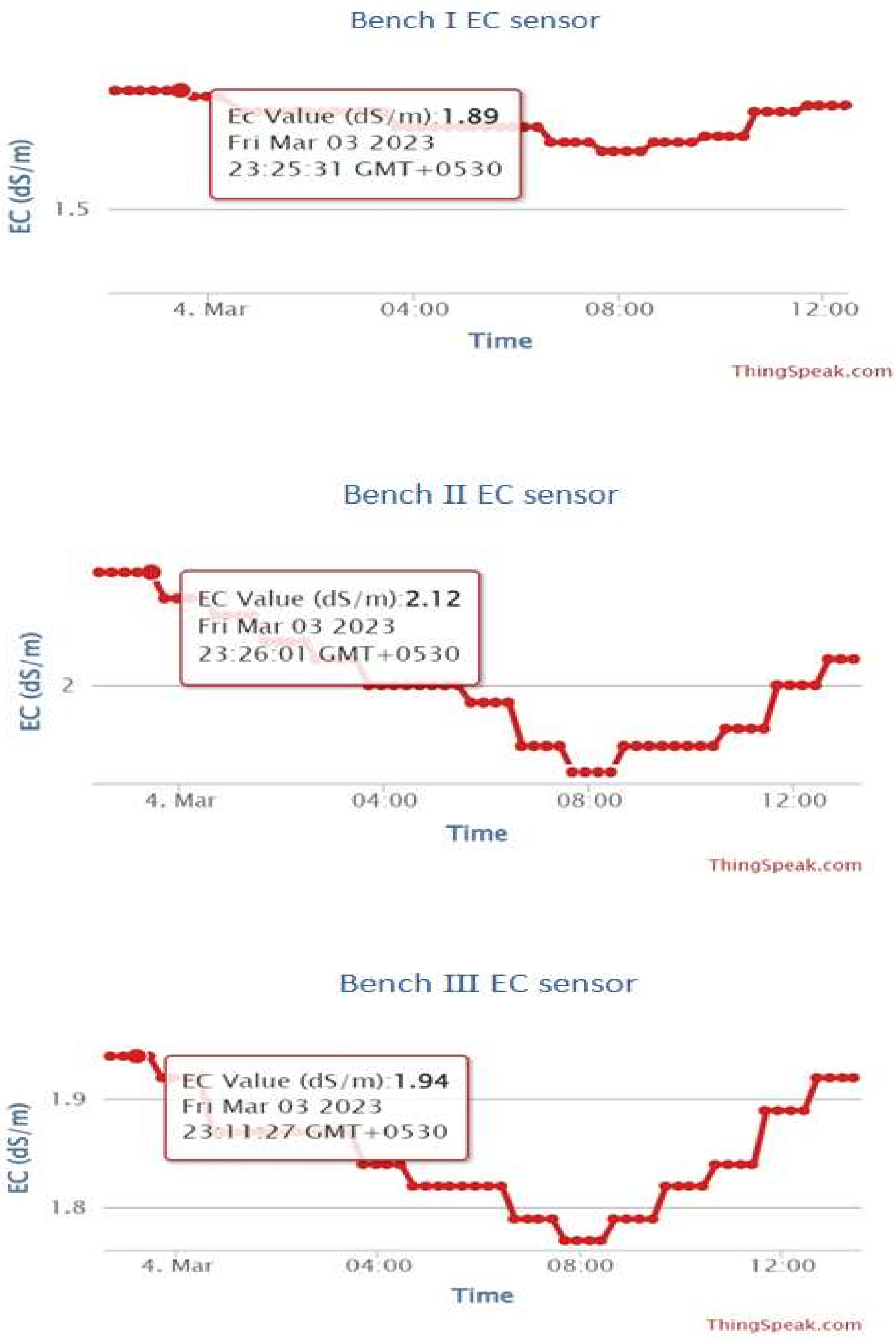


Fig. 4.23 Monitoring of real time EC of nutrient solution in computer from ThingSpeak IoT cloud

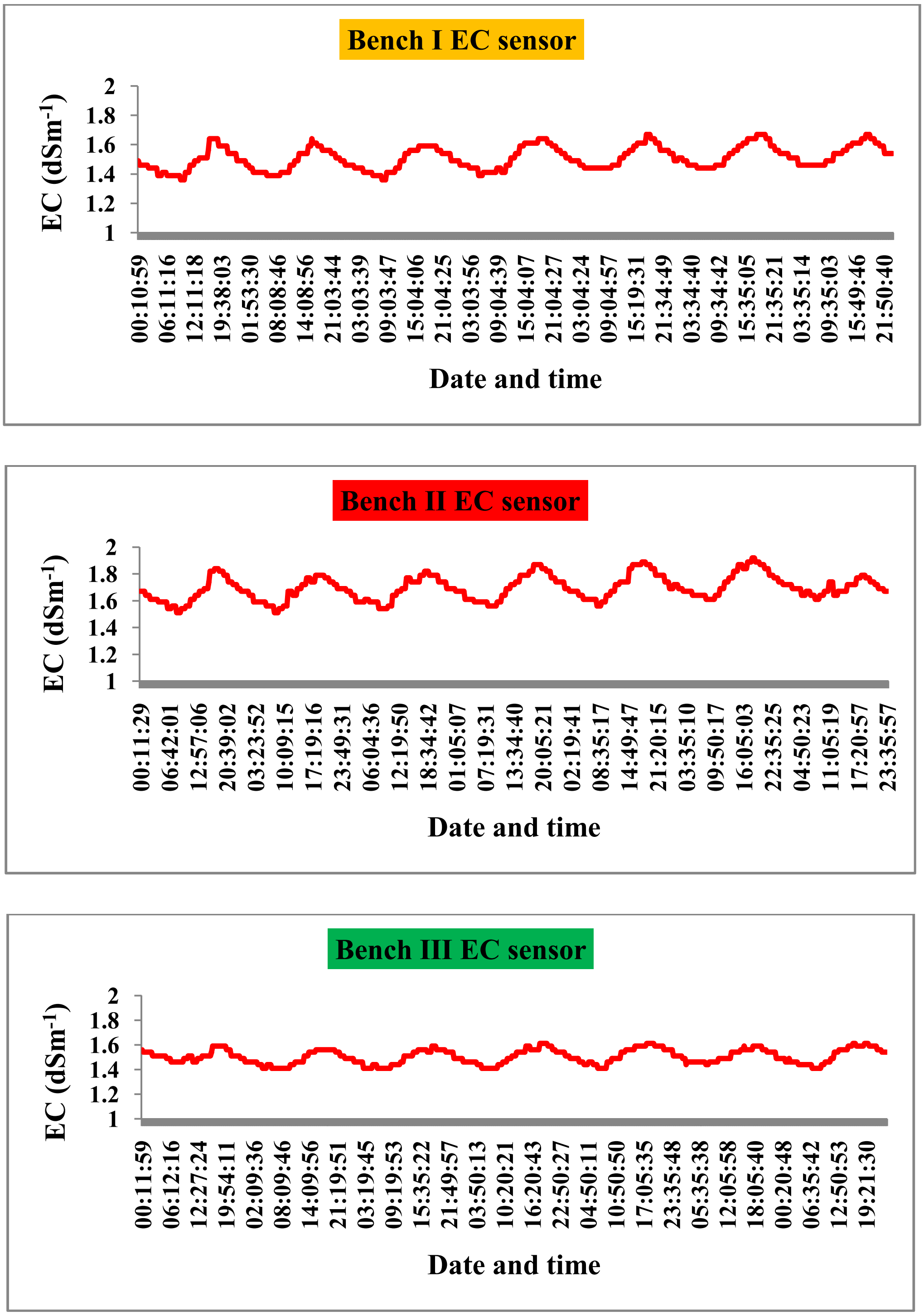


Fig. 4.24 Real time monitoring of EC of nutrient solution for one week (29-12-2022 to 04-1-2023)

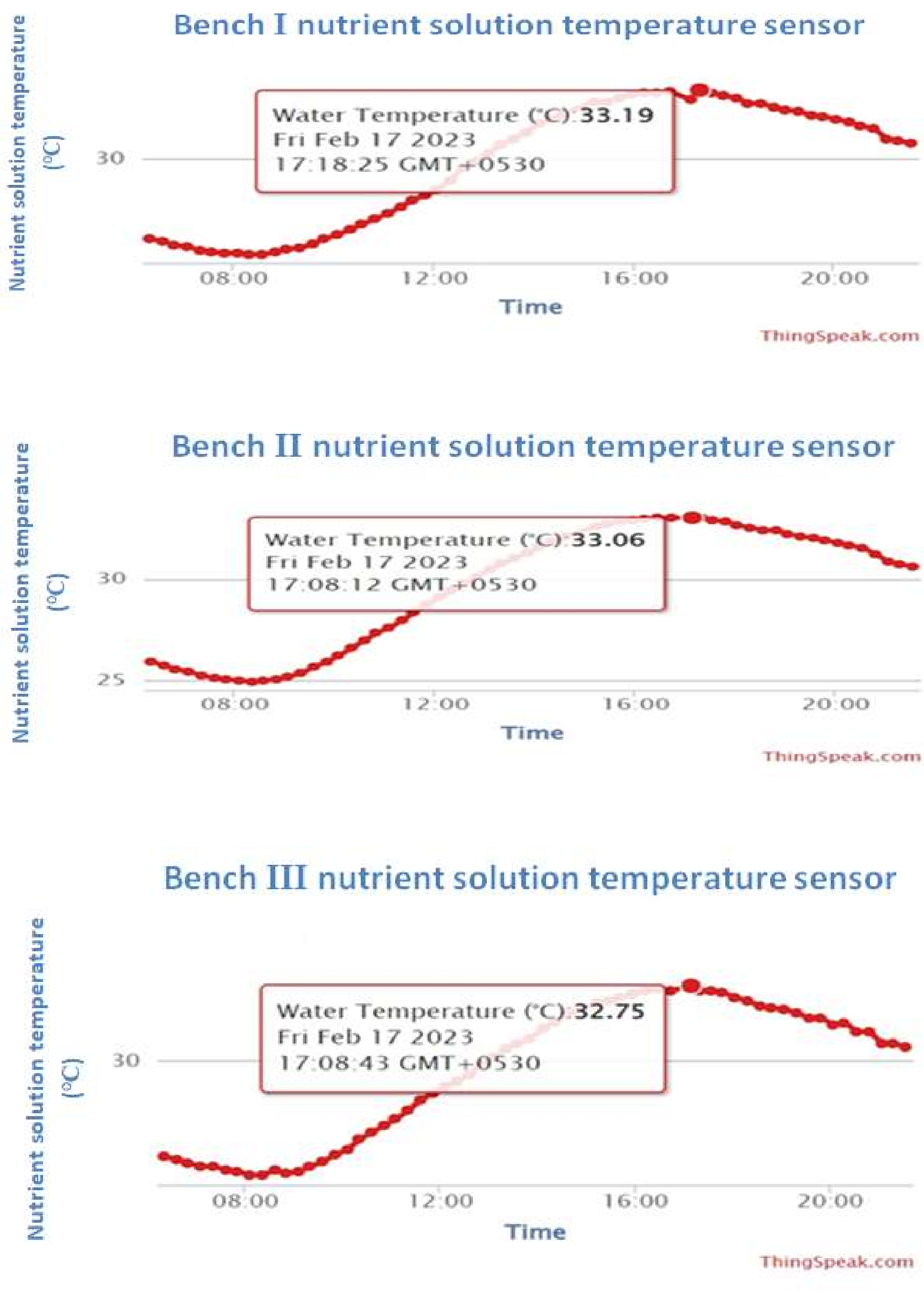


Fig. 4.25 Monitoring of real time temperature of nutrient solution in computer from ThingSpeak IoT cloud

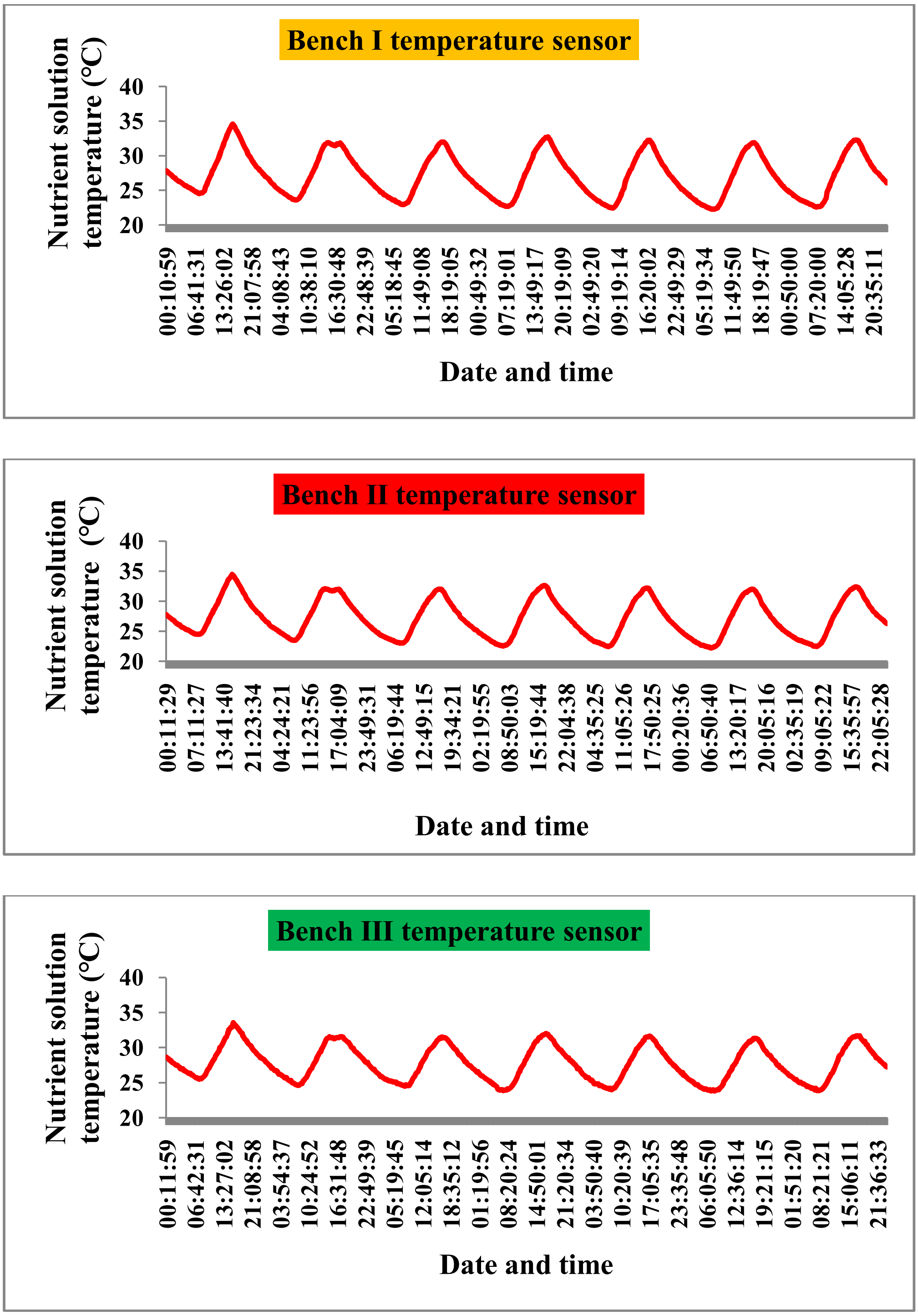


Fig. 4.26 Real time monitoring of nutrient solution temperature for one week (29-12-2022 to 04-1-2023)

4.3.1.4 Depth of nutrient solution in tank

Depths of nutrient solution in the tanks were continuously monitored by using ultrasonic sensors. There is some fluctuation in the depth of solution in the tank as the solution continuously flows back to the tank after recirculating through the channel. Hence there is some fluctuation in the sensor readings also. ThingSpeak keeps the track of the depth of nutrient solution in the tanks of Bench I, II and III, shown in Fig 4.27. Fig 4.28 shows the continuous data acquisition of nutrient solution depth in the tanks of three benches of the hydroponics system for one week during crop period. It shows the fluctuation in the depth due to the continuous flow of nutrient solution to the tanks. Depths of nutrient solution in the tanks were decreased due to uptake of the plants and evaporation. Depths of nutrient solution in the tanks were maintained to keep constant rate of flow of nutrient solution in the channels by adding water and stock solution to the tanks.

4.3.1.5 Depth of nutrient solution in channel

Depth of nutrient solution in the channel was monitored continuously and displayed in ThingSpeak as in Fig 4.29 and it indicates the depth in the channels in different benches at the stage of final harvest. In Bench I nutrient solution shows a depth of 9 mm at the final harvest. Whereas depth of nutrient solution in the channel of Bench II and III were11 and 13 mm respectively. It was found that the sensor has an accurate measurement of depth. Fig 4.30 shows one week continuous data acquisition of depth of nutrient solution in the channel of each bench during crop period. It shows monitoring at initial growth stage of crop and has channel depths of 4, 6 and 8 mm for Bench I, II and III respectively. There is no fluctuation in the depth of nutrient solution in the channel from time to time during the day as the flow rate of nutrient solution was maintained.

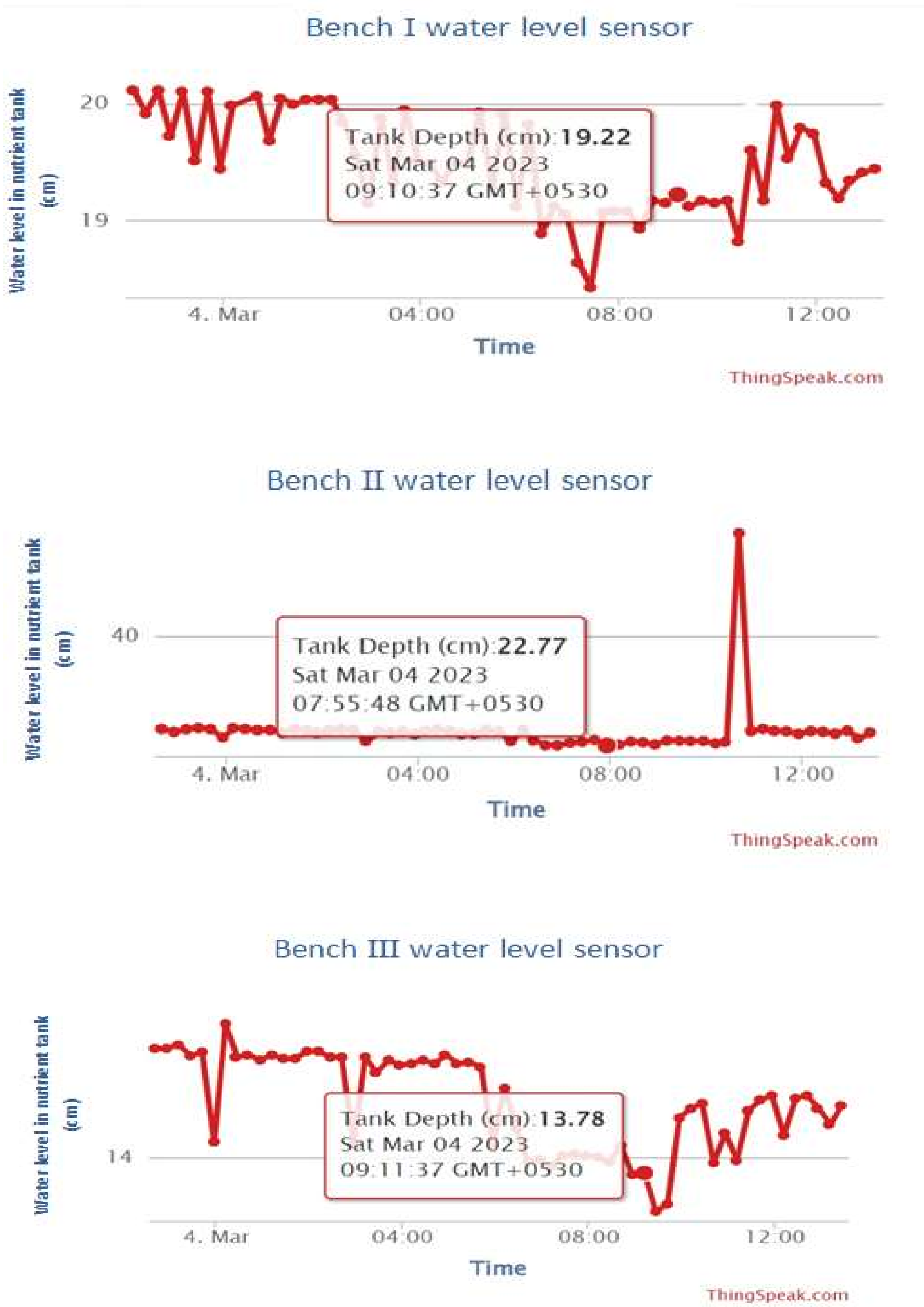


Fig. 4.27 Monitoring of real time depth of nutrient solution in tank in computer from ThingSpeak IoT cloud

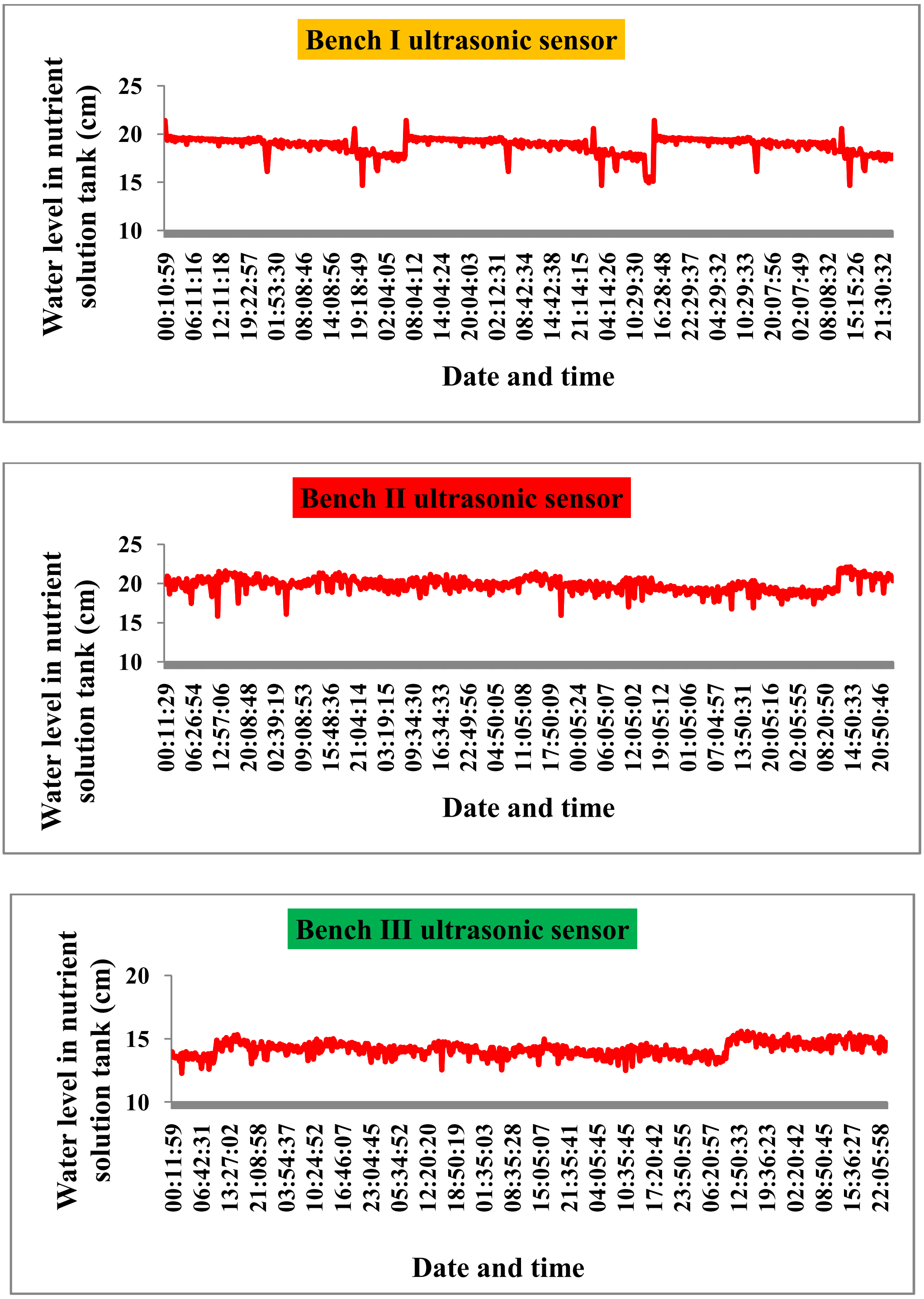


Fig. 4.28 Real time monitoring of depth of nutrient solution in tank for one week (29-12-2022 to 04-1-2023)

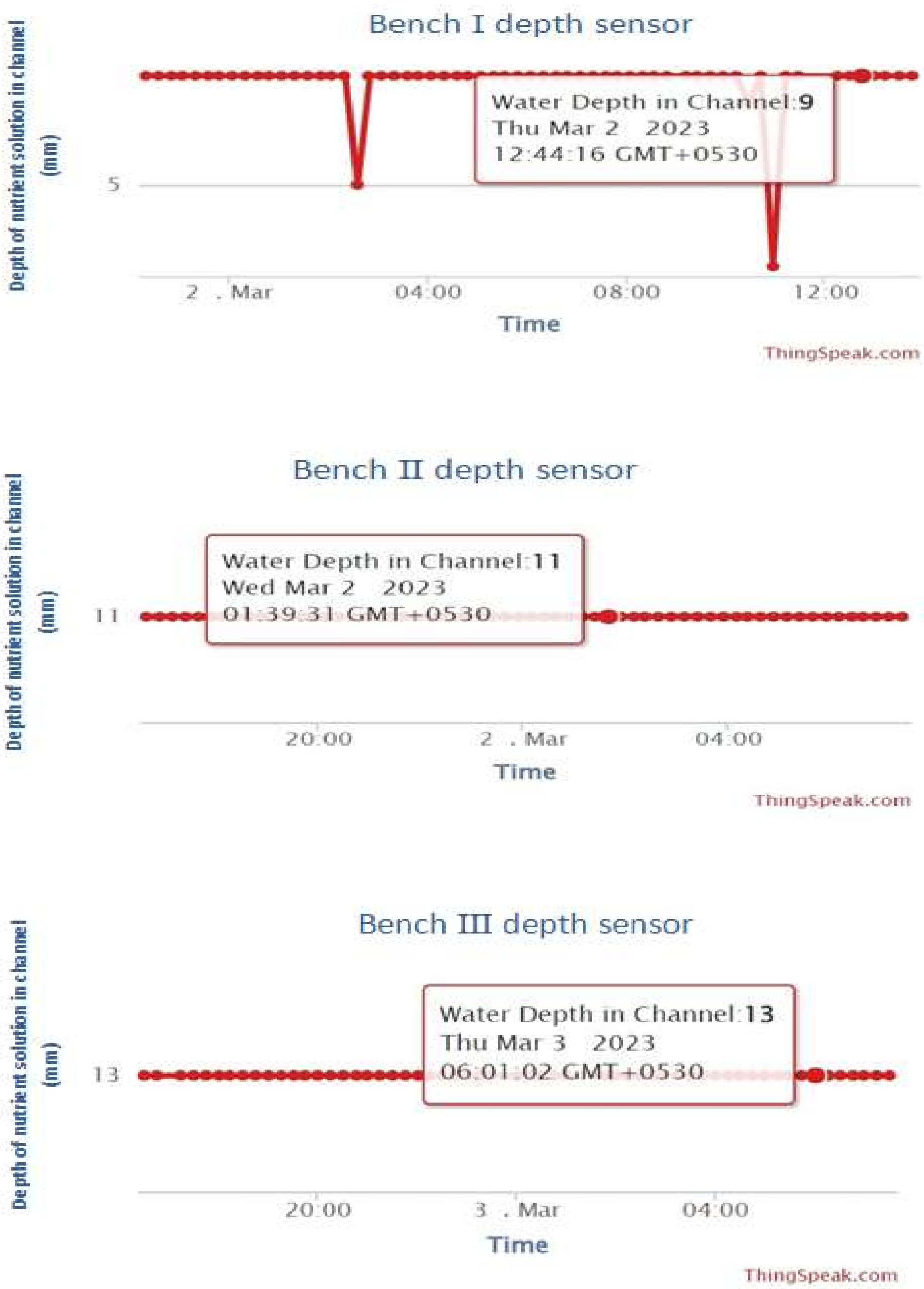


Fig. 4.29 Monitoring of real time depth of nutrient solution in channel in computer from ThingSpeak IoT cloud

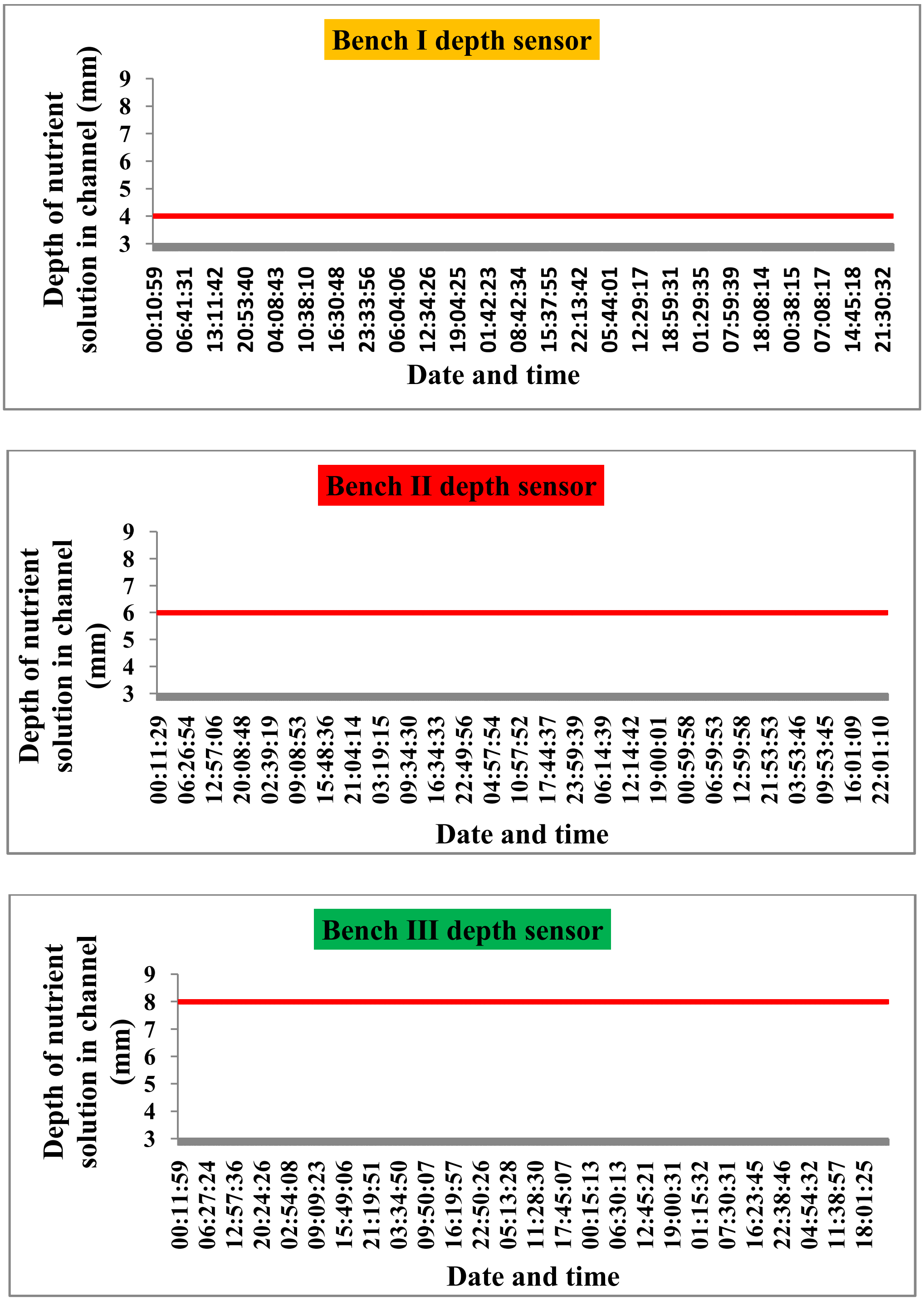


Fig. 4.30 Real time monitoring of depth of nutrient solution in channel for one week (29-12-2022 to 04-1-2023)

4.3.1.6 Air temperature and humidity

Air temperature inside the polyhouse was continuously monitored by the developed system using DHT22 sensor. It is easy to understand the variation of air temperature from the graph provided by the ThingSpeak (Fig 4.31). Fig 4.32 shows the one week continuous data acquisition of air temperature inside the polyhouse during crop period. It shows that air temperature varies from time to time during the day.

RH was continuously monitored and stored in the ThingSpeak. The ThingSpeak display of RH is shown in Fig 4.33. Fig 4.34 shows the one week continuous data acquisition of RH inside the polyhouse. It indicates that RH also varied from time to time during the day.

4.3.1.7 Light intensity

Light intensity sensor (BH1750) monitored the light intensity inside the polyhouse. Light intensity was continuously monitored and displayed in the ThingSpeak platform as shown in Fig 4.35. Fig 4.36 shows the continuous data acquisition of light intensity inside the polyhouse for one week. It shows that light intensity varies from time to time during the day.

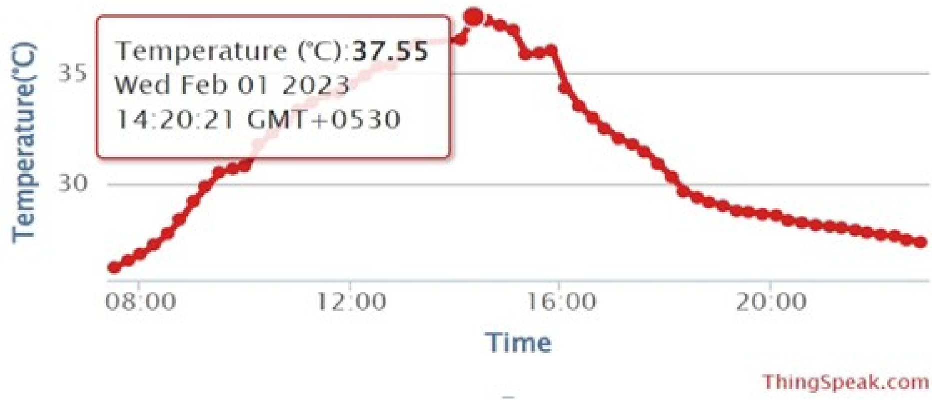


Fig. 4.31 Monitoring of real time air temperature in computer from ThingSpeak IoT cloud

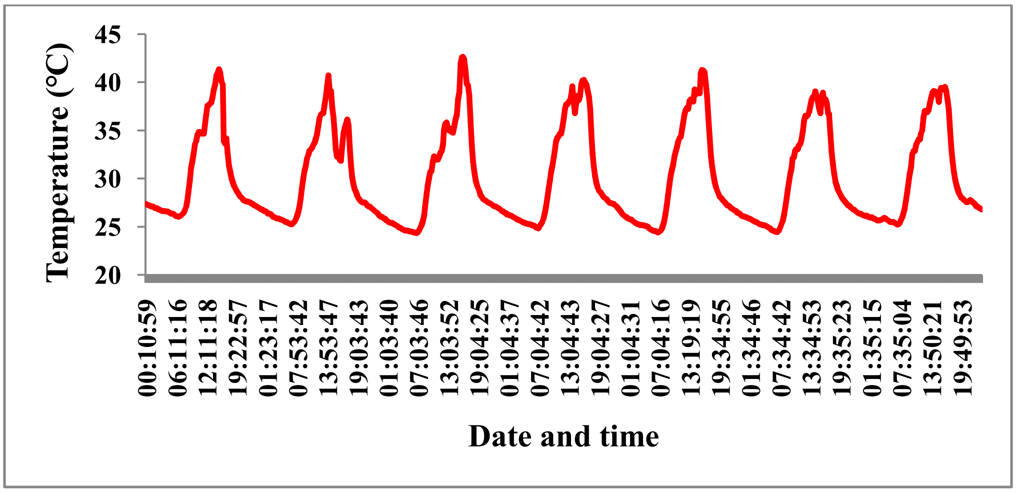


Fig. 4.32 Real time monitoring of air temperature for one week (29-12-2022 to 04-1-2023)

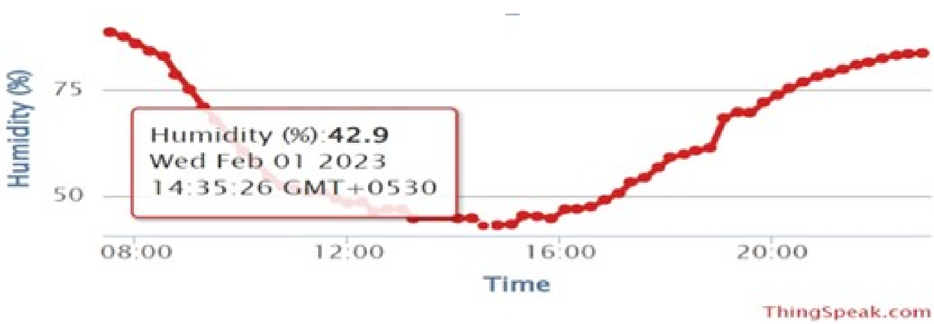


Fig. 4.33 Monitoring of real time RH in computer from ThingSpeak IoT cloud

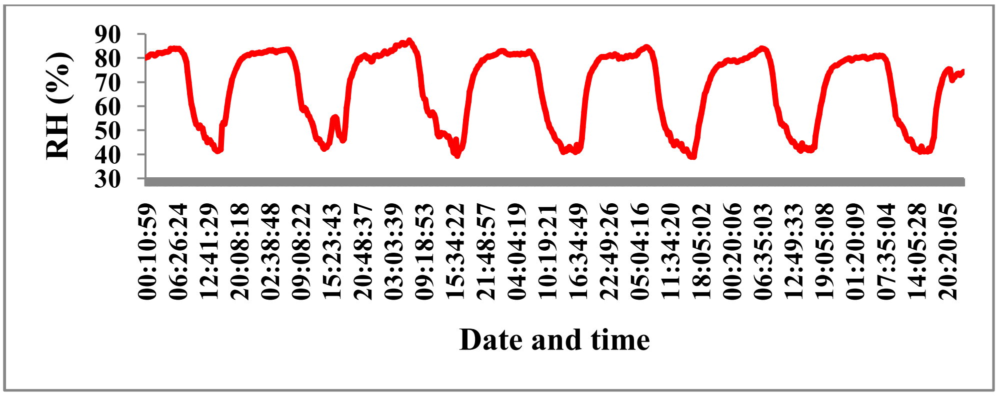


Fig. 4.34 Real time monitoring of RH for one week (29-12-2022 to 04-1-2023)

Fig. 4.35 Monitoring of real time light intensity in computer from ThingSpeak IoT cloud

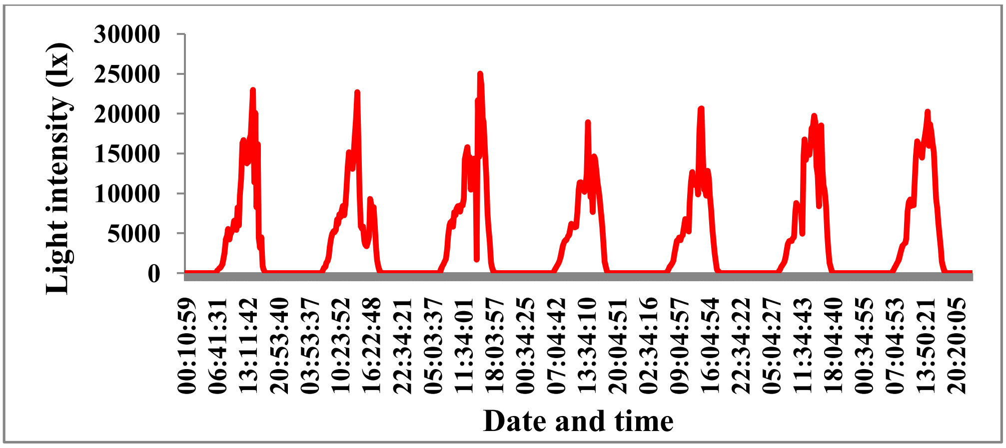


Fig. 4.36 Real time monitoring of light intensity for one week (29-12-2022 to 04-1-2023)

4.3.1.8 Automated control of fan and fogger

Along with the automated monitoring of different nutrient solution parameters and microclimatic parameters the system also controls the operation of fans and foggers automatically. Developed automation system controls the fan and fogger based on the pre-set time and temperature. The temperature set points adopted were 25 °C as lower threshold value and 28 °C as the upper threshold value of operation of fans. Foggers were operated when the air temperature reached 35 °C and lower threshold value was 32°C. As the continuous operation of the fogger led to increased humidity, foggers were operated for one minute and remained off for the next 15 minutes. This process continues until temperature decreases below the lower threshold value of operation of fogger. When the temperature rises above 28 °C, air circulating fan and exhaust fans start working and stop when temperature decreases to 25 °C (Fig 4.37). If air temperature increases above 35 °C, foggers also get operated and it has an ON time of one minute and OFF time of fifteen minutes. Foggers get stopped when temperature decreases to 32 °C (Fig 4.38). Fig 4.37 and 4.38 shows the status of operation of fans and foggers corresponding to the air temperature (Fig 4.39). Automatic control of air temperature and humidity worked well inside the greenhouse. During peak hours of the day, these parameters were controlled by automation system. The working of foggers when air temperature increases above 35°C is shown in Plate 4.7.

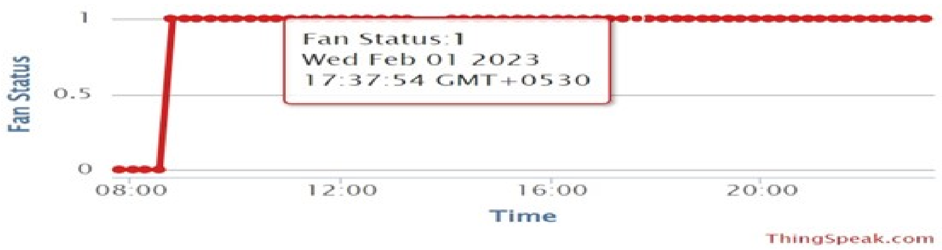


Fig. 4.37 Monitoring of real time operation status of fans in computer from ThingSpeak IoT cloud

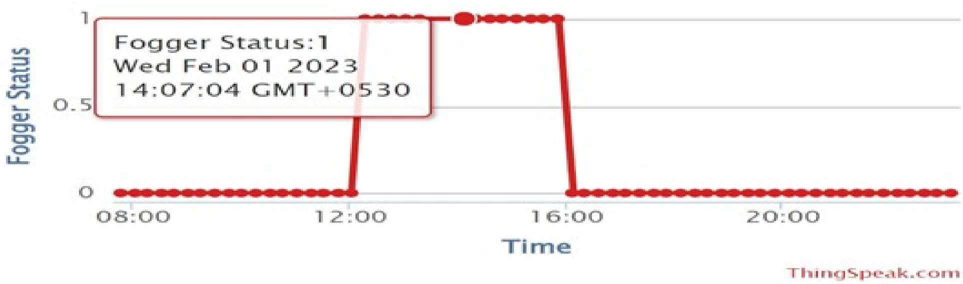


Fig. 4.38 Monitoring of real time operation status of foggers in computer from ThingSpeak IoT cloud

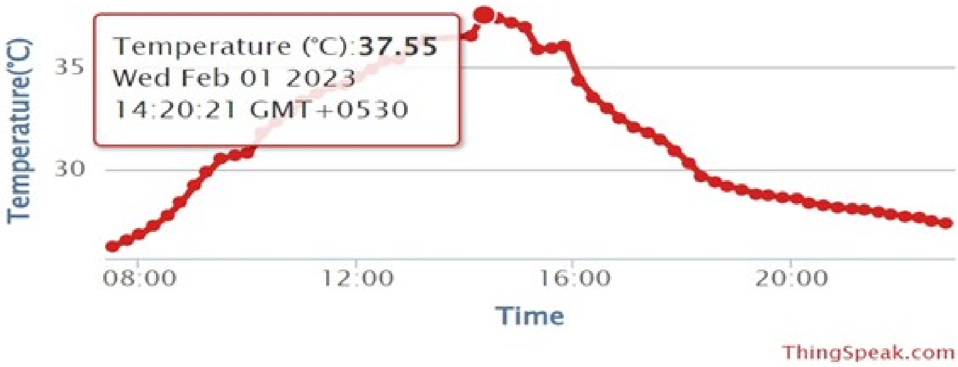


Fig. 4.39 Monitoring of real time air temperature in computer from ThingSpeak IoT cloud

Plate 4.7 Working of foggers inside the polyhouse

4.3.2 Evaluation of NFT hydroponics system for crop performance under different flow rate

The performance of spinach crop at three different flow rates of 60 (T_1), 120 (T_2) and 180 l/h (T_3) were evaluated in the NFT hydroponics system. Various parameters including plant height, number of leaves, root length, dry weight of root and yield were studied. Water consumption and nutrient use were also studied. Data collected was analyzed using WASP software (version 2.0).

4.3.2.1 Plant height

Table 4.2 presents plant height in cm of treatments having different flow rates during different harvests. From the Table, it is observed that in T_1 the average plant height obtained were 24.49, 27.11, 26.49, 27.15, 24.97 and 25.08 cm in first, second, third, fourth, fifth and sixth harvest respectively. For T_2 the average plant heights were 27.10, 26.40, 28.23, 26.52, 23.06 and 24.11 cm. Plant heights of 24.24, 26.23, 23.51, 26.92, 24.57 and 25.07 cm were observed for T_3. From statistical analysis it was found that there was no significant difference in plant height between the flow rates (Table 4.2). For all harvest under different treatments, the plant height was more for T_2 while compared to $T_1$and T_3 (Fig 4.40).Treatment T2 (120 l/h) has the highest plant height of 25.91 cm and T3 (180 l/h) has the lowest plant height of 25.09 cm (Fig 4.41).

In comparison to the rate of 120 l/h, the height of plants grown under the flow rate of 60 l/h and 180 l/h decreased by 0.1 % and 3.2 % respectively.

Table 4.2 Effect of flow rates on plant height of spinach under NFT hydroponics system

Sl. No	Treatments	Plant height (cm)						Av. plant height (cm)
		First harvest	Second harvest	Third harvest	Fourth harvest	Fifth harvest	Sixth harvest	
1	T1	24.49[a]	27.11[a]	26.49[ab]	27.15[a]	24.97[a]	25.08[a]	25.88[a]
2	T2	27.10[a]	26.4[a]	28.23 [a]	26.52[a]	23.06[a]	24.11[a]	25.91[a]
3	T3	24.24[a]	26.23[a]	23.51 [b]	26.92[a]	24.57[a]	25.07[a]	25.09[a]
4	CD (0.05)	NS	NS	3.00	NS	NS	NS	NS

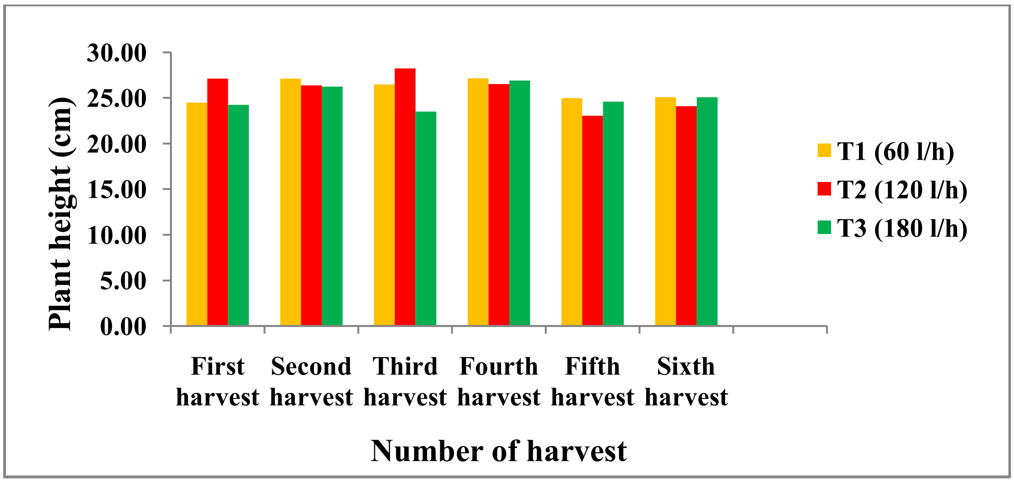


Fig. 4.40 Average plant height in different flow rates during different harvests

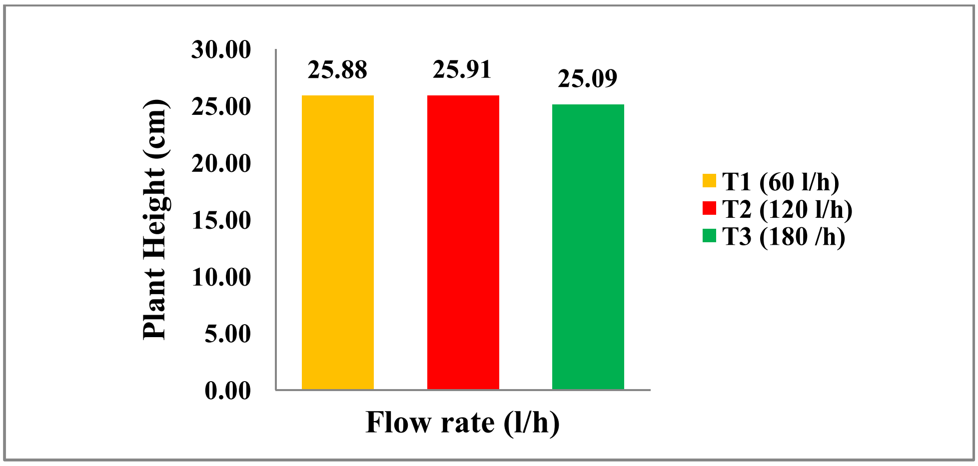


Fig. 4.41 Average plant height in different flow rates during the crop period

4.3.2.2 Number of leaves

Table 4.3 shows that the maximum number of leaves was produced in T_2 with a count of 22.46, 17.26, 19.66, 17.20, 17.00 and 24.60 per pot in each harvest. Leaves count for T_1 was 18.80, 17.13, 14.60, 15.93, 16.73 and 21.46 and in T_3 count was 14.53, 11.06, 10.60, 13.40, 11.73 and 19.06 in each harvest. Statistical analysis shows that there is no significant difference between different flow rates for the number of leaves (Table 4.3). T_2 has the highest number of leaves per pot in all harvest and T_3 has the lowest number of leaves per pot in all harvest (Fig 4.42).

Fig 4.43 shows that the highest average number of leaves per pot was found in T_2 (19.70) and lowest was found in T_3 (13.40). The highest total number of leaves per pot was also achieved in T_2 (118.18 leaves) and lowest in T_3 (80.38).

Table 4.3 Effect of flow rate on number of leaves of spinach under NFT hydroponics system

Sl. No	Treatment	Number of leaves per pot							
		First harvest	Second harvest	Third harvest	Fourth harvest	Fifth harvest	Sixth harvest	Average	Total
1	T1	18.80[ab]	17.13[a]	14.60[ab]	15.93[a]	16.73[a]	21.46[a]	17.44[a]	104.65[a]
2	T2	22.46 [a]	17.26[a]	19.66 [a]	17.20[a]	17.00[a]	24.60[a]	19.70[a]	118.18[a]
3	T3	14.53 [b]	11.06[a]	10.60 [b]	13.40[a]	11.73[a]	19.06[a]	13.40[a]	80.38[a]
4	CD (0.05)	4.71	NS	6.74	NS	NS	NS	NS	NS

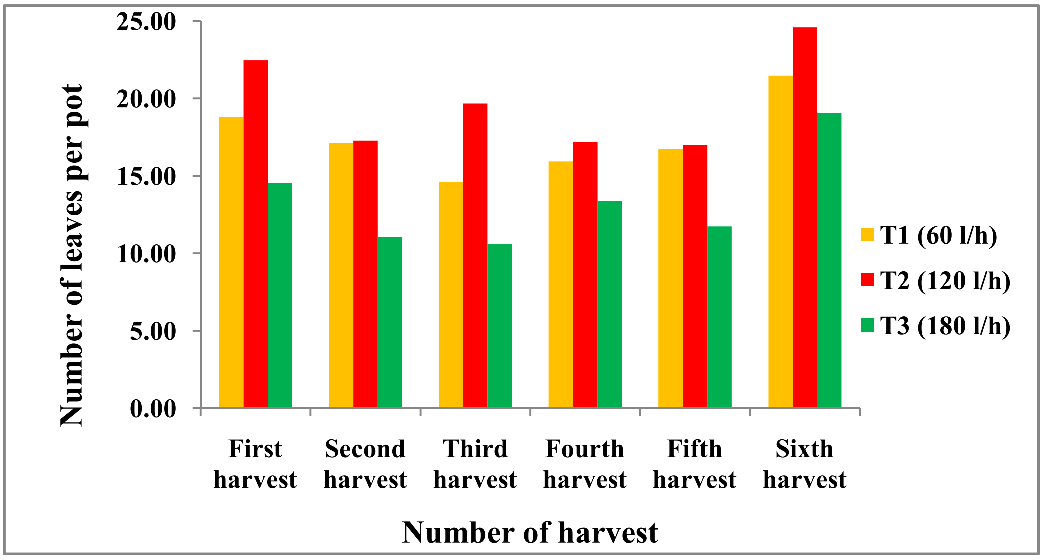


Fig. 4.42 Average number of leaves in different flow rates during different harvests

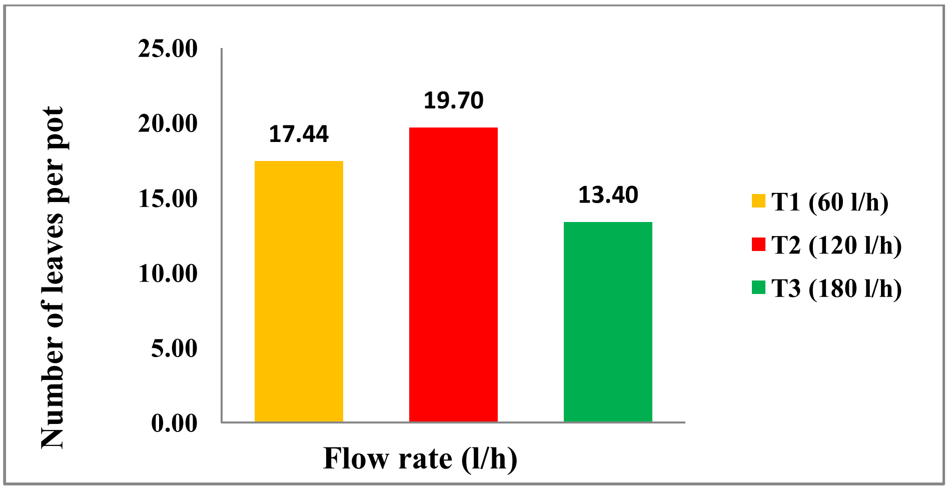


Fig. 4.43 Average number of leaves in different flow rates during crop period

4.3.2.3 Root length

Table 4.4 shows the average root length measured for each treatment during all harvests. T_1 has the lowest root length measured during each harvest. Plants grown in T_1 show an average root length of 19.07, 19.20, 19.40, 22.53, 22.69 and 23.86 cm in first, second, third, fourth, fifth and sixth harvest respectively. Whereas the root lengths of crops in T_2 are 28.53, 29.63, 30.40, 38.26, 39.50 and 41.60 cm in each harvest. In the case of T_3 the average root length in each harvest was found as 27.40, 28.20, 30.33, 37.03, 39.83 and 46.90 cm respectively. Statistical analysis shows T_1 (60 l/h) is significantly different from T_2 (120 l/h) and T_3 (180 l/h) whereas there is no significant difference between the root lengths of T_2 and T_3. T_2 shows the highest root length in the first four harvests and T_3 shows the highest root length in the last two harvests. T_1 shows the lowest root length in all harvests (Fig 4.44).

The highest root length was found in T_3 (34.95 cm) and T_1 has the lowest root length (21.12 cm) (Fig 4.45). Root growth of spinach under different flow rates were shown in Plate 4.8 and it indicates that root length was more for T_2 and T_3 and less for T_1 whereas root density was more for T_1 and T_2 and less for T_3.

Table 4.4 Effect of flow rate on root length of spinach under NFT hydroponics system

Sl. No	Treatments	Root length (cm)						Av. root length (cm)
		First harvest	Second harvest	Third harvest	Fourth harvest	Fifth harvest	Sixth harvest	
1	T1	19.07 [b]	19.20 [b]	19.40 [b]	22.53 [b]	22.69 [b]	23.86 [b]	21.12 [b]
2	T2	28.53 [a]	29.63 [a]	30.40 [a]	38.26 [a]	39.50 [a]	41.60 [a]	34.65 [a]
3	T3	27.40 [a]	28.20 [a]	30.33 [a]	37.03 [a]	39.83 [a]	46.90 [a]	34.95 [a]
4	CD (0.05)	4.55	5.10	5.50	9.66	11.86	16.81	7.48

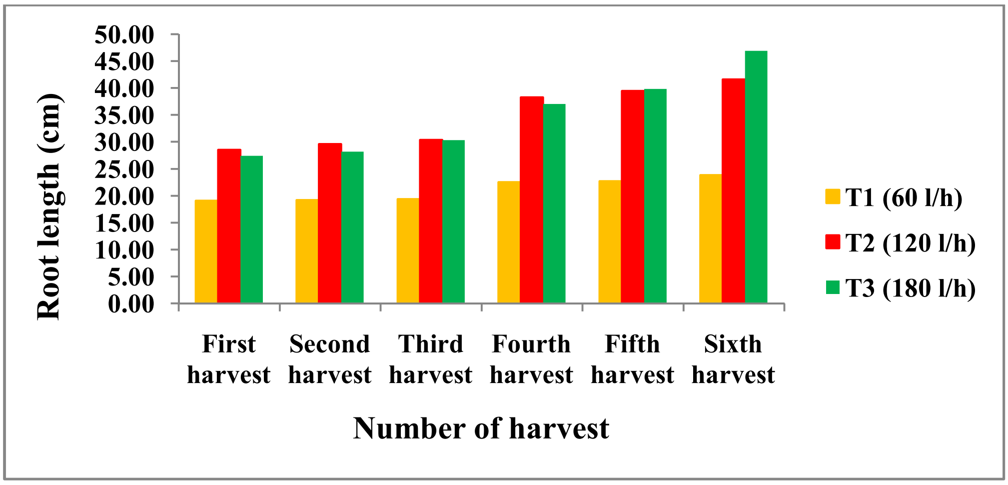


Fig. 4.44 Average root length in different flow rates during different harvests

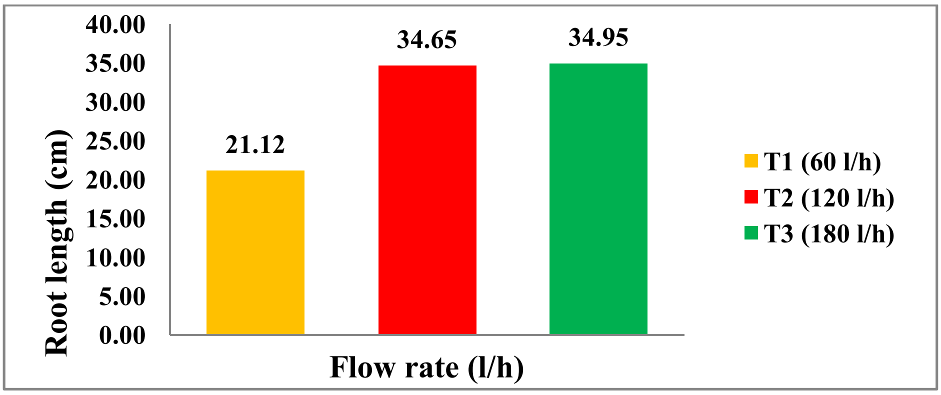


Fig. 4.45 Average root length in different flow rates during crop period

a. b. c.

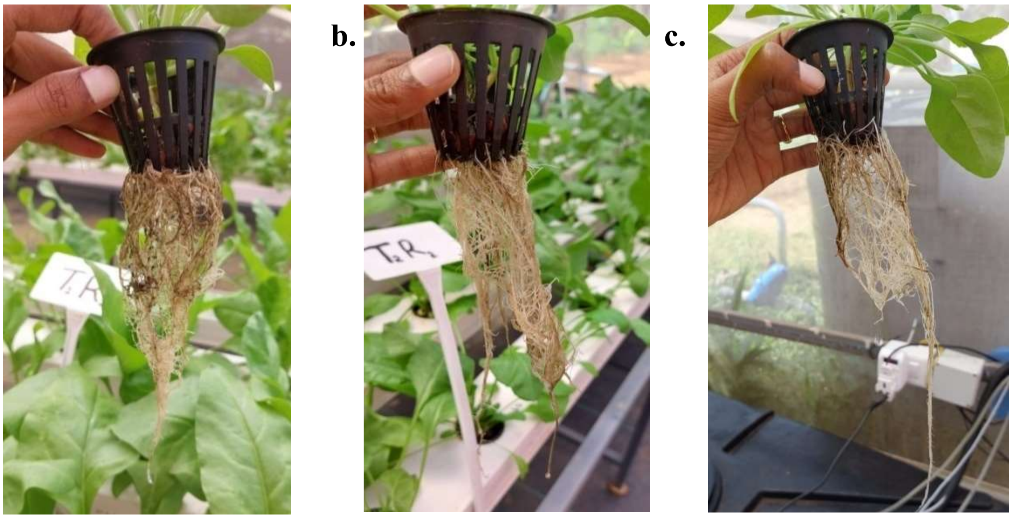


Plate 4.8 Growth of root under different flow rates: (a) T_1 (60 l/h), (b) T_2 (120l/h), (c) T_3 (180 l/h)

4.3.2.4 Dry weight of root

Table 4.5 shows the average dry weight of the root at the end of the final harvest under different flow rates. Plants grown in $T_{1,}$ T_2 and T_3 had an average dry weight of 5.56 g, 5.44 g and 1.65 g respectively. Statistical analysis shows that dry weight of root has a significant difference between the different flow rates (Table 4.5). Average dry weight of root was more in T_2 (5.44 g) and was less in T_3 (1.65 g) (Fig 4.46).

Table 4.5 Effect of flow rate on dry weight of root of spinach under NFT hydroponics system

Sl. No	Treatment	Dry weight of root (g)					Average dry weight of root (g)
		R_1	R_2	R_3	R_4	R_5	
1	T_1	4.96	4.87	4.75	7.35	3.87	5.16^{a}
2	T_2	6.75	2.54	4.17	8.70	5.05	5.44^{a}
3	T_3	4.28	2.02	0.33	1.02	0.59	1.65^{b}
4	CD (0.05)						2.50

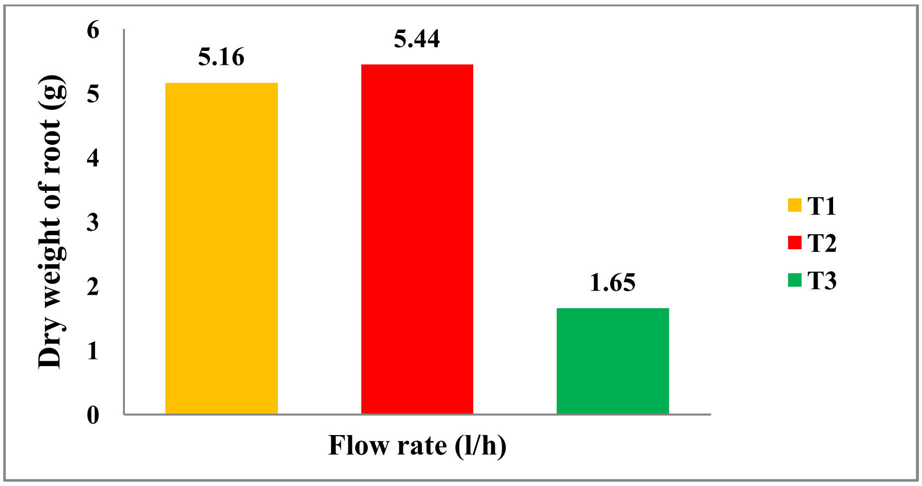


Fig. 4.46 Average dry weight of root in different flow rates at the end of final harvest

4.3.2.5 Yield

Yield was varied among different treatments. Table 4.6 indicates T_1 gives yields of 22.85, 18.59, 19.19, 22.59, 18.39 and 27.59 g/pot from each harvest. T_2 yields of 29.39, 19.66, 21.25, 23.72, 18.66 and 29.86 g/pot and 18.65, 13.99, 9.85, 18.18, 13.25 and 22.05 g/pot were obtained from T_3. Highest yield per pot was obtained from T_2 in all six harvests and lowest yield per pot was obtained from T_3 in all six harvests (Fig 4.47). Fig 4.48 indicates that T_2 has the highest yield and it was found that a total yield of 10.83 kg from all six harvests and lowest yield was obtained from T_3 (7.29 kg). The analysis of the data revealed that there is a difference between the yields from various treatments. But it is significantly visible between T_1 and T_3 and also between T_2 and T_3. T_1 and T_2 did not show a significant difference. Analysis of result presented in Table 4.6.

Plate 4.9, 4.10 and 4.11 shows the spinach crop at harvesting stage in Bench I, II and III respectively and Plate 4.12 presents all the three benches of NFT hydroponics systems with the crop.

Table 4.6 Effect of flow rate on yield of spinach under NFT hydroponics system

Sl. No	Treatment	Yield per pot (g)							Total yield (kg)
		First harvest	Second harvest	Third harvest	Fourth harvest	Fifth harvest	Sixth harvest	Average yield	
1	T1	22.85[ab]	18.59 [a]	19.19 [a]	22.59[a]	18.39 [a]	27.59[a]	21.53[a]	9.82[a]
2	T2	29.39 [a]	19.66 [a]	21.25 [a]	23.72[a]	18.66 [a]	29.86[a]	23.76[a]	10.83[a]
3	T3	18.65 [b]	13.99 [b]	9.85 [b]	18.18[a]	13.25 [b]	22.05[a]	16.00[b]	7.29 [b]
4	CD (0.05)	7.53	3.97	3.88	NS	3.53	NS	4.07	1.85

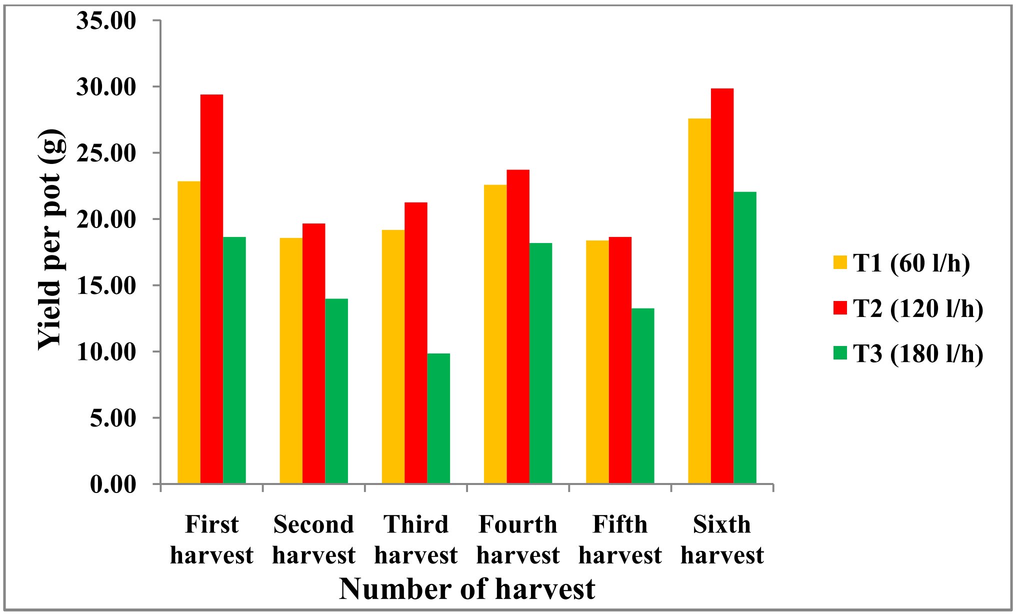


Fig. 4.47 Average yield in different flow rates during different harvests

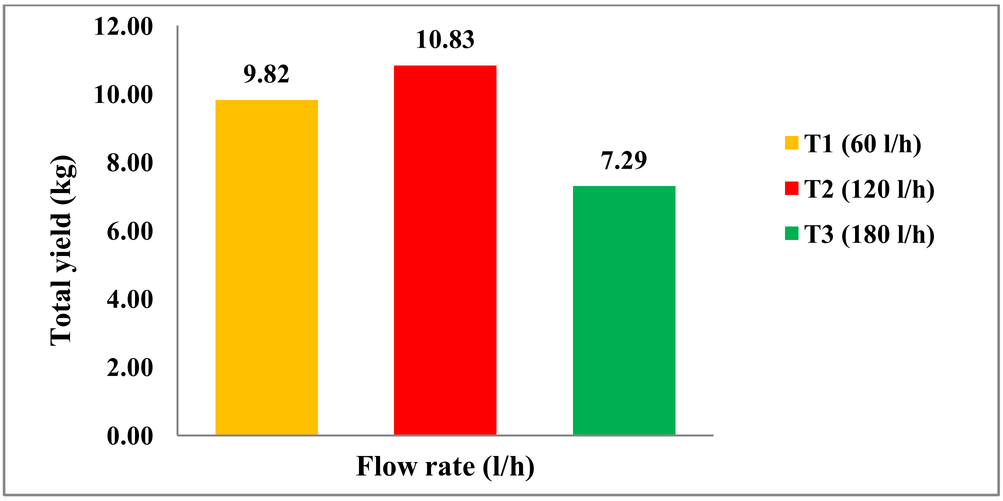


Fig. 4.48 Total yield in different flow rates during crop period

Plate 4.9 Bench I crops at harvesting stage

Plate 4.10 Bench II crops at harvesting stage

Plate 4.11 Bench III crops at harvesting stage

Plate 4.12 Crops grown in NFT hydroponics systems with different flow rates

4.3.2.6 Number of survival plants

All the plants transplanted were found survived. Two seedlings were transplanted in each net cup. Hence a total of 152 plants were transplanted in each bench and all these plants were survived.

4.3.2.7 Water consumption

The comparison between the water consumption of the three treatments to produce yield was presented in Fig 4.49. To compare the water use efficiency of the growing systems having different flow rate, water consumption was normalized by yield, which gave the average estimate of water consumption in units of L kg^{-1}. The Bench III having 180 l/h flow rate (T_3) consumed the maximum water to produce a kilogram of fresh weight yield, which was 54.46 L kg^{-1}. Bench I having flow rate of 60 l/h has the lowest water consumption of 29.19 L $kg^{-1}$and that of 120 l/h was 32.57 L kg^{-1}. Water savings of around 46.41 % and 40.20 % were obtained from T_1 and T_2 respectively compared to T_3. Hence it can be concluded that the system having the lowest flow rate has higher water use efficiency.

4.3.2.8 Nutrient use efficiency

Amount of nutrient stock solution used to produce one kilogram of yield was shown in Fig 4.50. It was found that the amount of nutrient solution used to produce one kilogram fresh weight of spinach was less in case of growing crops with 60 l/h (T_1) flow rate of nutrient solution; it was 0.3 L kg^{-1} only. Bench II with flow rate of 120 l/h (T_2) has nutrient usage of 0.32 L kg^{-1} and Bench III with flow rate of 180 l/h (T_3) has the highest nutrient usage which is 0.42 L kg^{-1}. Comparing to T_1, T_2 has an increased use of 6.66 percent and T_3 has 40 per cent increased use of stock solution.

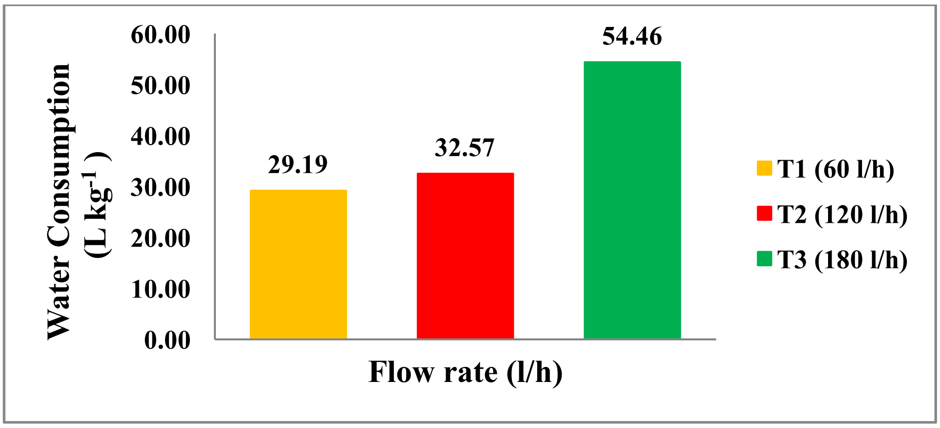


Fig. 4.49 Water consumption in different flow rates

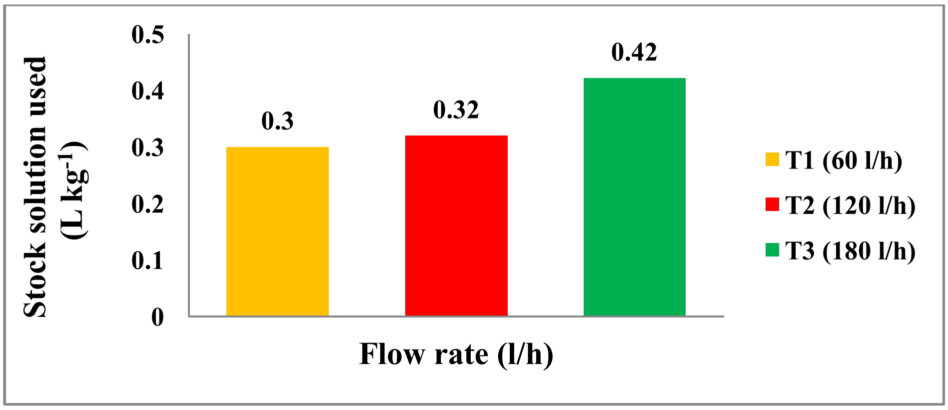


Fig. 4.50 Stock solution used per kilogram of fresh weight in different flow rates

4.4 STUDY OF NUTRIENT SOLUTION STATUS AND MICRO CLIMATE

In hydroponics, plants get nutrients through nutrient solution. Different parameters of nutrient solution affect the uptake of nutrients by plants. Hence all the parameters should be in the optimum level to get sufficient amounts of nutrients to the crop. Climate is the most important factor which influences the suitability of a crop to a particular region. The growth and development of a crop is largely dependent on the environmental factors which play a dominant role in crop production. Change in the optimum level of environmental conditions may cause deterioration of crop growth and development.

4.4.1 pH of the nutrient solution

It is important to maintain the pH of the nutrient solution as it affects the solubility, availability, and uptake of many essential nutrient ions. Hence it was continuously monitored through the automated data acquisition system and adjusted frequently to the optimum value. pH of the nutrient solution of Bench I, II and III for the entire crop period were shown in Fig. 4.51. It indicated that pH of nutrient solution was maintained between 5.5 and 6.5 throughout the growing period, which is the optimum range of pH at which the maximum number of necessary elements are highly available to plants. The fluctuation in the pH value of the nutrient solution is due to uptake of nutrients and pH was maintained by adding pH up or pH down solution. As the nutrients were absorbed by the plants the pH of the nutrient solution decreased over time, which was countered by adding pH up solution to the nutrient solution tank.

4.4.2 Electrical conductivity of nutrient solution

Growth, development and production of plants are determined by total ionic concentration of a nutrient solution which is indirectly measured by electrical conductivity of the nutrient solution. The conductivity values of the nutrient solution throughout the growing period of Bench I, II and III were presented graphically in Fig. 4.52. It is clear from the graphs that electrical conductivity of the nutrient solution was maintained at low level (0.3 dS m^{-1}) during the early growth stage of crop, i.e. for one week after transplantation. It is increased to 1.2 dS m^{-1} in the 2^{nd} week after transplantation then increased to 1.8 dS m^{-1} in the third week. Finally, EC of the nutrient solution was maintained at 2.1 dS m^{-1} from the fourth week onwards. As the nutrients were taken up by the plants, the conductivity value was lowered since there were lesser salts in the solution.

Alternatively, there was an increase in the conductivity value when the removal of water from the solution took place either through evaporation or transpiration. Nutrient solution was added to maintain the electrical conductivity as it decreased. Water is added to decrease the value of electrical conductivity when it is increased beyond the limit. Sudden increase in the EC shows that the addition of nutrient stock solution and sudden decrease in the EC shows the addition of water to the tank.

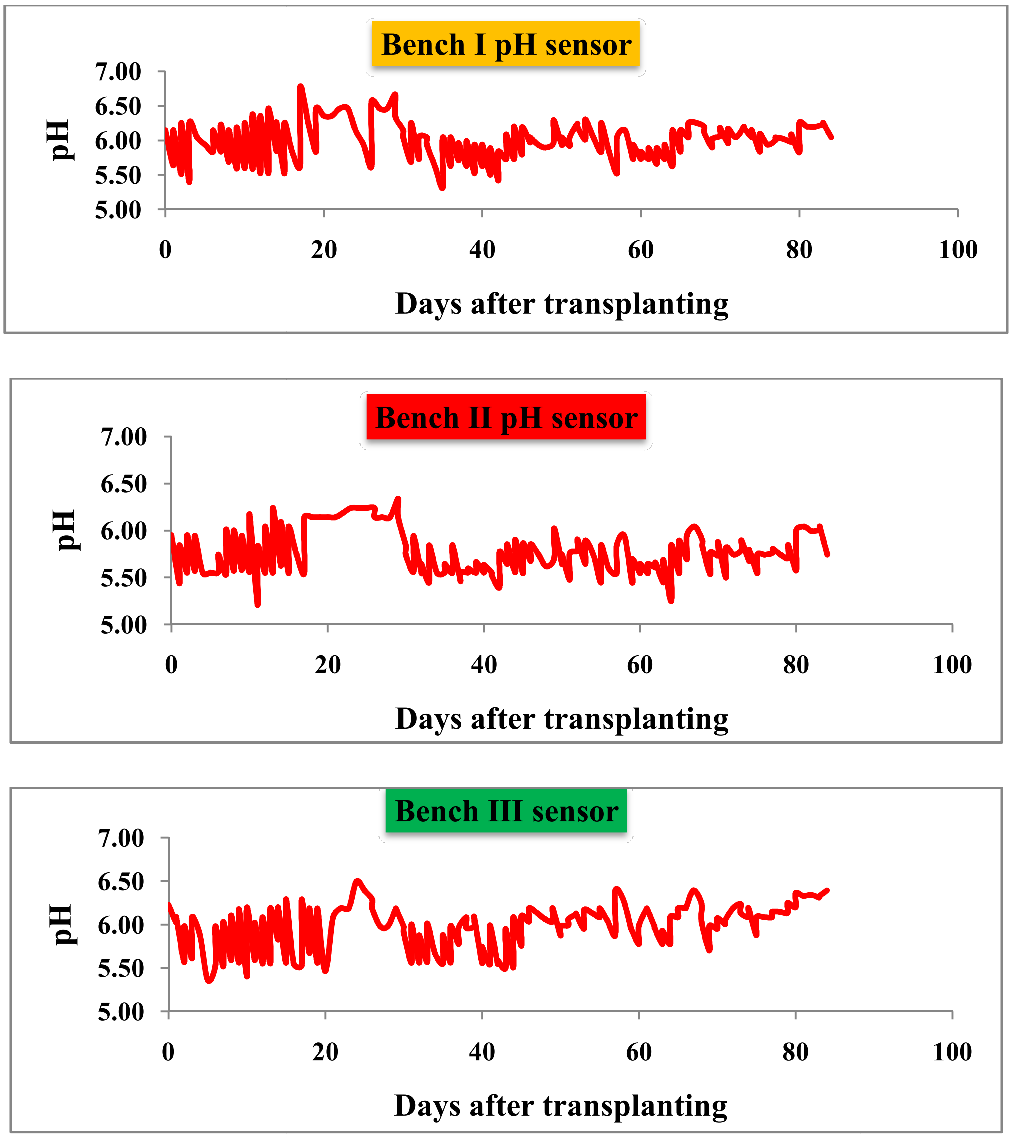


Fig. 4.51 pH of the nutrient solution during crop period monitored by continuous data acquisition system

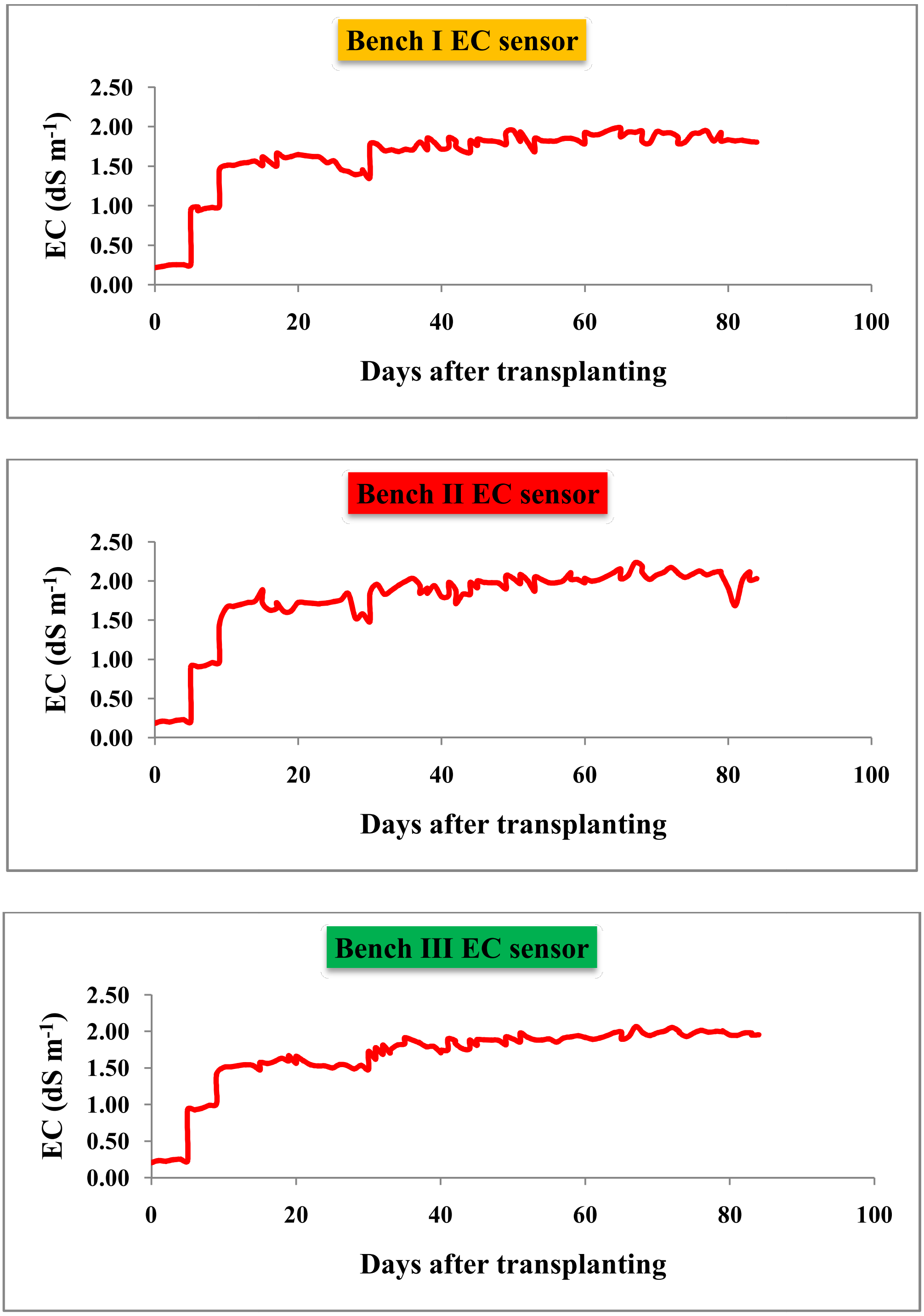


Fig. 4.52 EC of the nutrient solution during the crop period monitored by continuous data acquisition system

4.4.3 Temperature of nutrient solution

Nutrient solution temperature affects the solubility of oxygen in the solution. The optimum nutrient solution temperature in hydroponics was found at 28 °C (Nxawe *et al.*, 2010). Table 4.7, 4.8 and 4.9 gives the hourly average nutrient solution temperature of Bench I, II and III respectively for each week.

It was observed that (Table 4.7) nutrient solution temperature of Bench I increased above 28 °C from 12 pm to 9 pm in the 1st and 2nd weeks, 1 pm to 8 pm in the 3rd and 4th weeks, 12 pm to 11 pm in 5th and 6th weeks, 12 pm to 1 am in the 7th and 8th weeks, 11 am to 3 am in the 9th and 10th and 10 am to 5 am in the 11th and 12th weeks. During day time (6 am to 6 pm) nutrient solution temperature varied between 23.52 °C to 31.75 °C in the first two weeks, whereas in the last two weeks nutrient solution temperature was varied between 27.42 °C to 33.12 °C during day time in Bench I.

Nutrient solution temperature of Bench II (Table 4.8) increased above 28 °C from 12 pm to 9 pm in the 1st and 2nd weeks and 3rd and 4th weeks also. Nutrient solution temperature increased above 28 °C in the 5th and 6th weeks during 1 pm to 10 pm, in 7th and 8th weeks from 12 pm to 2 am, in 9th and 10th weeks from 11 am to 2 am and 11th and 12th weeks 10 am to 5 am. During day time (6 am to 6 pm) nutrient solution temperature of Bench II was varied between 23.47 °C to 31.93 °C in the first two weeks and was increased to 27.55 °C to 33.63 °C in the last two weeks.

In Bench III nutrient solution temperature was increased above 28 °C during the hours of 12 pm to 10 pm in the first two weeks, 1 pm to 10 pm in 3rd and 4th weeks, 1 pm to 11 pm in 5th and 6th weeks, 11 am to 2 am in 7th and 8th weeks, 11 am to 3 am in 9th and 10th weeks and 10 am to 5 am in the last two weeks. During day time (6 am to 6 pm) the nutrient solution temperature was varied between 24.55 °C to 31.60 °C in the first two weeks, whereas 27.98 to 33.70 °C in the last two weeks in Bench III.

So, it was observed that for Benches I, II and III the temperature of the nutrient solution increased above 28 °C almost during the same hours of the day across the crop period. Also, the variation of the nutrient solution temperature was not considerable during day time for all the three benches.

Fig 4.53 shows the variation of nutrient solution temperature during the entire crop period. Higher temperature of nutrient solution was found during the last two weeks of the crop period. Highest nutrient solution temperature of Bench I was 33.93 °C, Bench II was 34.23 °C and Bench III was 34.17 °C. Minimum hourly average nutrient solution temperature was found at 8 am in all weeks for all the three benches. Maximum hourly average nutrient solution temperature was found at 4 pm, except for first 2 weeks (maximum at 5 pm) for Bench I and Bench II. In Bench III maximum hourly average nutrient solution temperature was at 5 pm during first 6 weeks and at 4 pm during next 6 weeks.

Table 4.7 Hourly average nutrient solution temperature of Bench I for each two week

Sl. No	Time	Av. nutrient soln temp of week 1 and 2	Av. nutrient soln temp of week 3 and 4	Av. nutrient soln temp of week 5 and 6	Av. nutrient soln temp of week 7 and 8	Av. nutrient soln temp of week 9 and 10	Av. nutrient soln temp of week 11 and 12
1	00:00	26.62	25.60	27.61	28.59	29.54	30.02
2	01:00	25.90	25.08	27.30	28.26	29.15	29.69
3	02:00	25.31	24.61	26.97	27.87	28.80	29.35
4	03:00	24.79	24.19	26.28	27.57	28.09	28.63
5	04:00	24.29	23.80	26.04	27.50	27.75	28.40
6	05:00	23.90	23.42	25.77	26.75	27.41	28.11
7	06:00	23.52	23.05	25.12	26.22	26.79	27.42
8	07:00	23.19	22.72	24.42	25.61	26.03	26.66
9	08:00	23.12	22.68	24.11	25.29	25.63	26.34
10	09:00	23.40	23.26	24.40	25.48	25.86	26.86
11	10:00	25.34	24.68	25.63	26.39	26.98	28.01
12	11:00	26.71	26.30	26.92	27.69	28.39	29.36
13	12:00	28.01	27.93	28.28	29.17	29.58	30.47
14	13:00	29.42	29.34	29.54	30.32	30.76	31.53
15	14:00	31.01	30.59	30.75	31.39	31.97	32.45
16	15:00	32.05	31.59	31.48	32.10	33.08	33.35
17	16:00	32.25	32.15	31.85	32.49	33.86	33.93
18	17:00	32.73	32.05	31.70	32.35	33.75	33.93
19	18:00	31.75	31.10	30.97	31.79	33.22	33.12
20	19:00	30.56	29.96	30.58	31.31	32.68	32.50
21	20:00	29.46	28.85	30.09	30.83	32.18	32.09
22	21:00	28.55	27.88	29.24	30.11	31.42	31.59
23	22:00	27.75	27.10	28.82	29.62	30.87	31.08
24	23:00	27.02	26.36	28.49	29.20	29.89	30.83

Table 4.8 Hourly average nutrient solution temperature of Bench II for each two week

Sl. No	Time	Av. nutrient soln temp of week 1 and 2	Av. nutrient soln temp of week 3 and 4	Av. nutrient soln temp of week 5 and 6	Av. nutrient soln temp of week 7 and 8	Av. nutrient soln temp of week 9 and 10	Av. nutrient soln temp of week 11 and 12
1	00:00	26.45	25.66	27.11	28.74	29.34	30.20
2	01:00	25.83	25.15	26.61	28.41	28.89	29.86
3	02:00	25.21	24.69	26.28	28.12	28.67	28.21
4	03:00	24.66	24.26	25.82	27.42	27.83	28.80
5	04:00	24.21	23.86	25.26	27.17	27.54	28.52
6	05:00	23.80	23.48	25.16	26.88	27.22	28.20
7	06:00	23.47	23.13	24.77	26.29	26.55	27.55
8	07:00	23.18	22.82	24.30	25.61	25.68	26.68
9	08:00	23.12	22.79	24.06	25.27	25.28	26.33
10	09:00	23.71	23.33	24.19	25.51	25.61	26.47
11	10:00	25.52	24.75	25.24	26.48	26.73	28.16
12	11:00	27.06	26.49	26.64	27.77	28.21	29.53
13	12:00	28.34	28.01	27.89	29.06	29.48	30.69
14	13:00	29.68	29.43	29.18	30.32	30.77	31.81
15	14:00	31.10	30.69	30.39	31.36	31.91	32.85
16	15:00	32.04	31.67	31.33	32.12	33.05	33.68
17	16:00	32.40	32.13	31.76	32.51	33.83	34.23
18	17:00	32.73	32.10	31.81	32.47	33.81	34.18
19	18:00	31.93	31.23	31.23	31.85	33.12	33.63
20	19:00	30.65	30.02	30.42	31.50	32.67	33.03
21	20:00	29.56	28.89	29.68	31.07	32.20	32.64
22	21:00	28.63	28.01	28.95	30.22	31.31	31.93
23	22:00	27.74	27.21	28.32	29.80	30.79	31.43
24	23:00	27.03	26.52	27.80	29.45	30.41	31.12

Table 4.9 Hourly average nutrient solution temperature of Bench III for each two week

Sl. No	Time	Av. nutrient soln temp of week 1 and 2	Av. nutrient soln temp of week 3 and 4	Av. nutrient soln temp of week 5 and 6	Av. nutrient soln temp of week 7 and 8	Av. nutrient soln temp of week 9 and 10	Av. nutrient soln temp of week 11 and 12
1	00:00	27.48	26.93	27.58	28.99	29.48	30.51
2	01:00	26.92	26.43	27.23	28.48	29.10	30.09
3	02:00	26.37	26.05	26.96	28.35	28.81	29.76
4	03:00	25.94	25.70	26.54	27.79	28.18	29.15
5	04:00	25.49	25.34	26.20	27.59	27.91	28.83
6	05:00	25.17	25.01	26.01	27.31	27.60	28.58
7	06:00	24.55	24.72	25.65	26.81	27.06	27.98
8	07:00	24.54	24.92	25.30	26.29	26.40	27.33
9	08:00	24.46	24.29	25.11	26.11	26.14	27.09
10	09:00	24.80	24.52	25.28	26.25	26.41	27.53
11	10:00	26.10	25.33	26.00	26.96	27.22	28.40
12	11:00	27.21	26.72	26.93	28.04	28.43	29.49
13	12:00	28.27	27.64	27.84	29.06	29.47	30.59
14	13:00	29.24	28.57	28.98	30.14	30.58	31.69
15	14:00	30.40	29.64	30.10	31.10	31.71	32.75
16	15:00	31.35	30.60	30.89	31.82	32.78	33.65
17	16:00	31.75	31.19	31.35	32.21	33.53	34.17
18	17:00	32.12	31.36	31.43	32.17	33.37	34.14
19	18:00	31.60	31.00	30.99	31.72	32.83	33.70
20	19:00	30.76	30.34	30.50	31.41	32.45	33.31
21	20:00	29.97	29.41	29.90	30.96	31.94	32.63
22	21:00	29.25	28.85	29.31	30.31	31.08	32.10
23	22:00	28.59	28.16	28.84	29.87	30.71	31.71
24	23:00	27.91	27.64	28.26	29.53	30.34	31.25

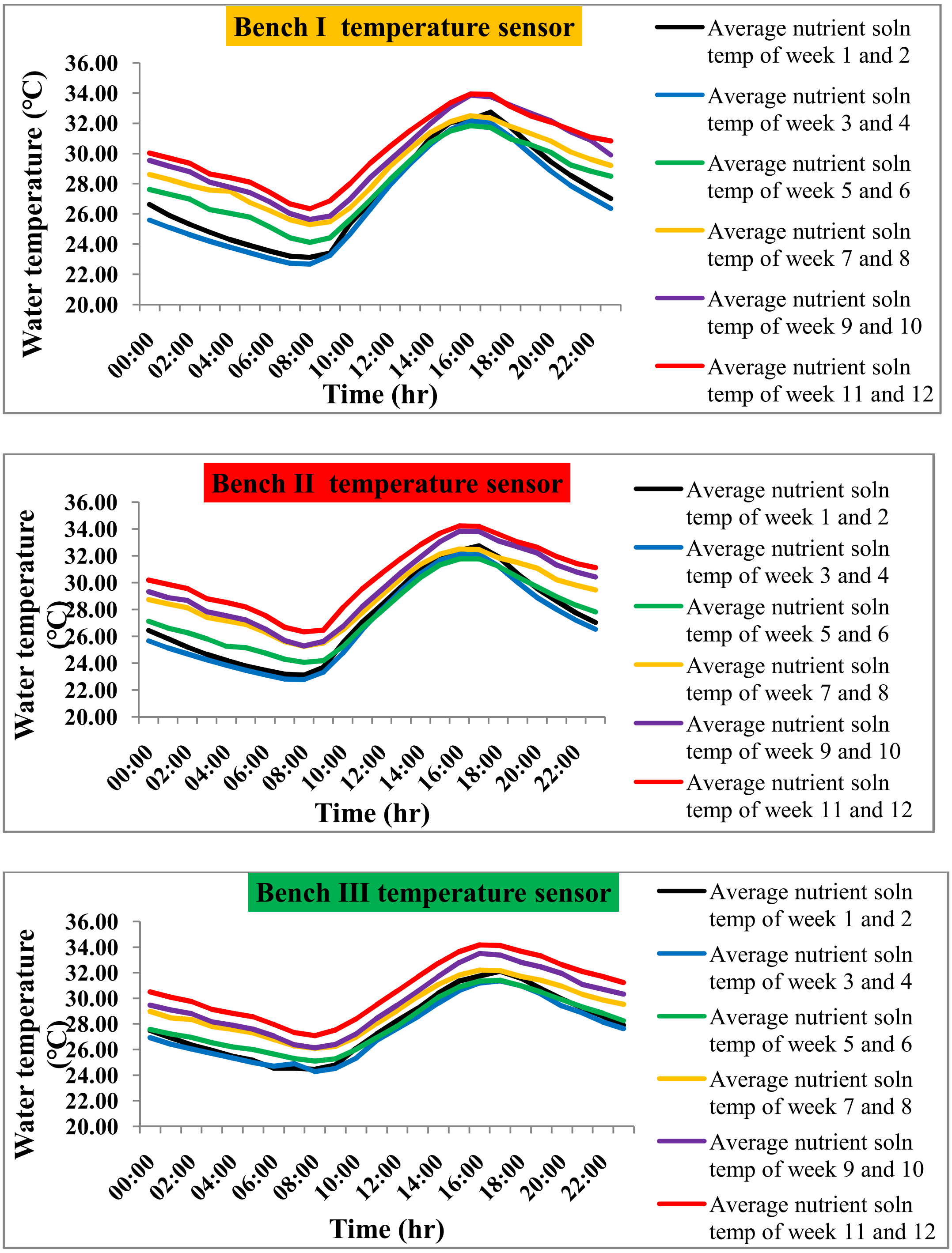


Fig. 4.53 Temperature of nutrient solution during the crop period monitored by continuous data acquisition system

4.4.4 Depth of nutrient solution in tank

Nutrient solution level is decreased as the water used by the crop. Levels of nutrient solution in the tanks were maintained by adding water to it to keep the constant flow rate of 60 L h^{-1}, 120 L h^{-1} and 180 L h^{-1}in Benches I, II and III respectively. Daily average depths of nutrient solution in the tanks are presented in the Fig 4.54. Depth of nutrient solution in the tank of Bench I was maintained between 15 and 20 cm, Bench II between 15 and 25 cm and Bench III was maintained around 15 cm. Increase in the depth of nutrient solution was due to addition of water to the tank.

4.4.5 Depth of nutrient solution in channel

Depth of nutrient solution in the channel during the crop period is shown in Fig 4.55. Initial depth of solution in the channel for 60 l/h flow rates was 4 mm, that of 120 l/h flow rate was 6 mm and for 180 l/h flow rate was 8 mm. As the crop grows root length and density also increased and the depth of flow increased due to the restriction of flow of solution through the channel. It was found that depth of solution in the channel at the time final harvest was 9 mm, 11 mm and 13 mm for Bench I, Bench II and Bench III respectively.

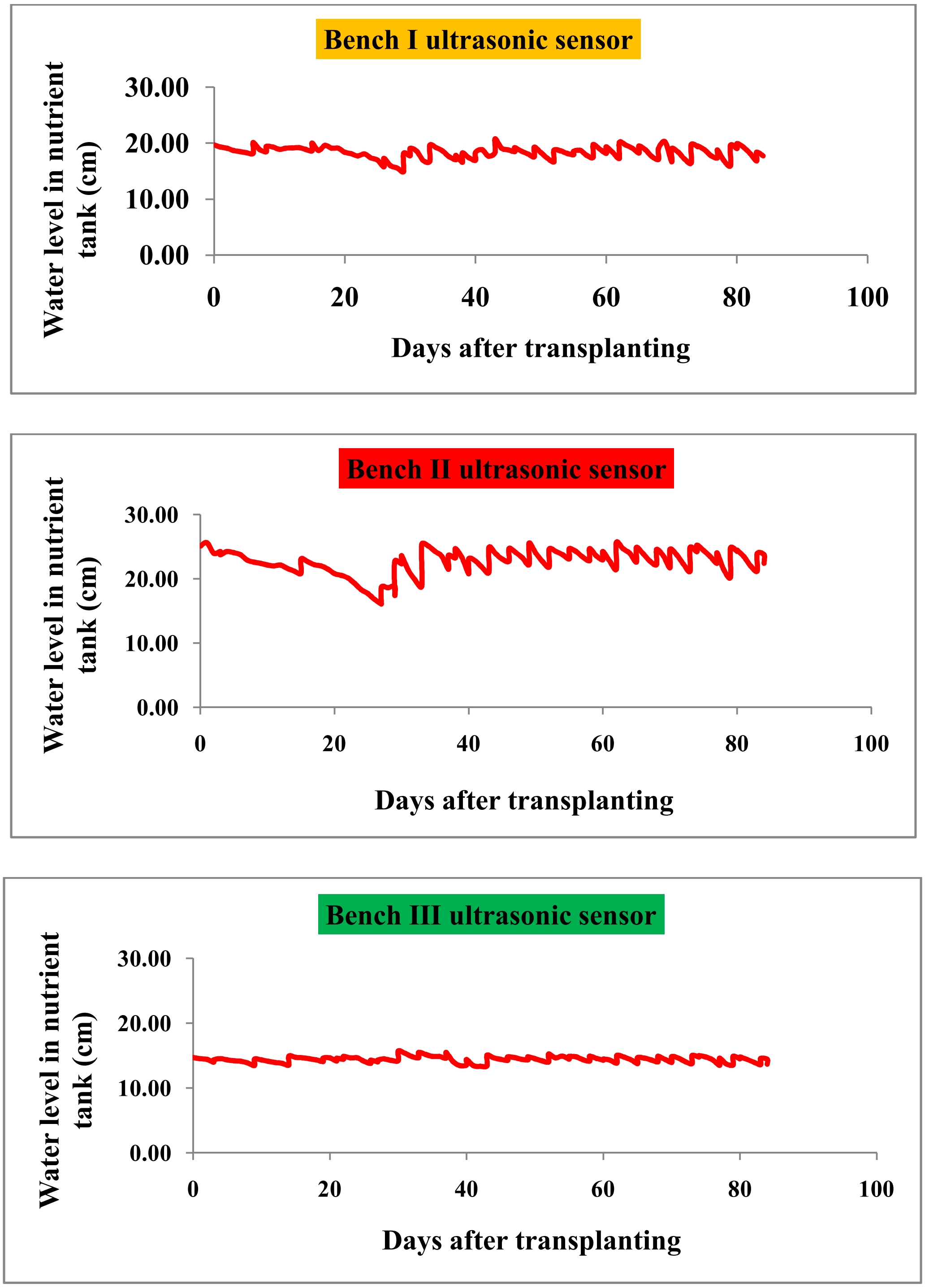
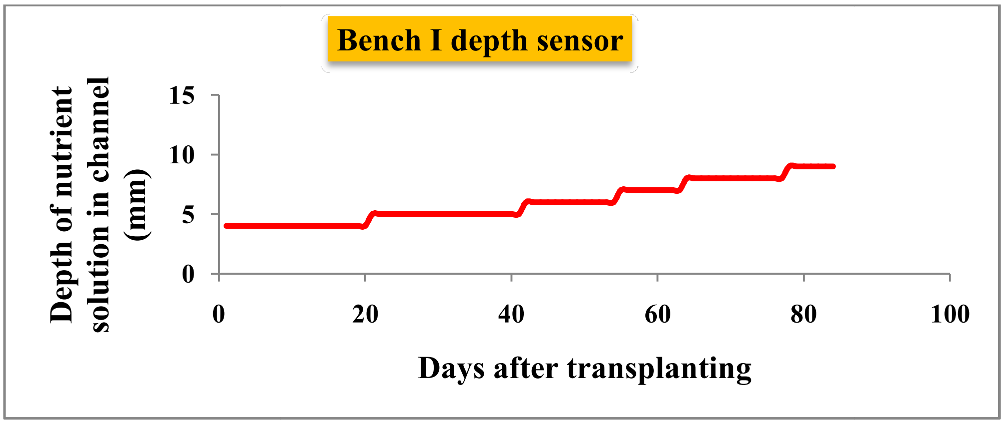
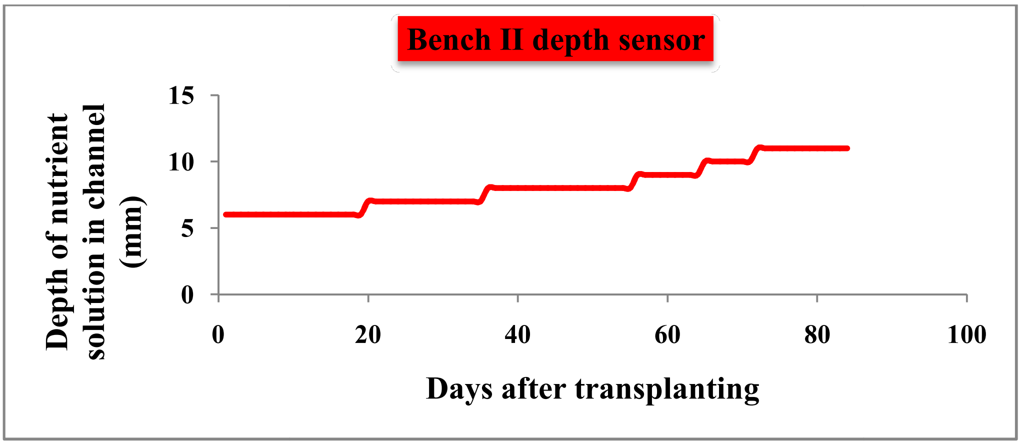


Fig. 4.54 Depth of nutrient solution in the tank during the crop period monitored by continuous data acquisition system





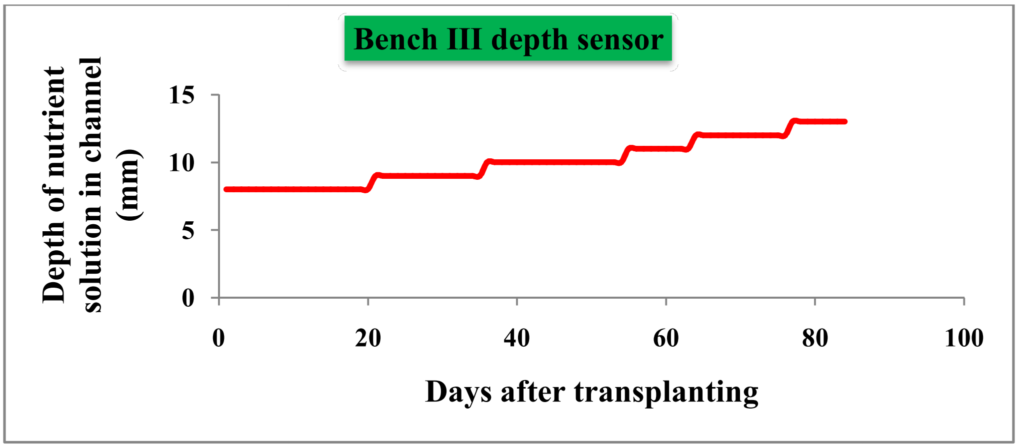


Fig. 4.55 Depth of nutrient solution in the channel during the crop period monitored by continuous data acquisition system

4.4.6 Air temperature and Relative humidity

Plant growth is significantly affected by the air temperature and moisture content in the atmosphere. Hence the air temperature and relative humidity should be within the permissible limit. Developed automated system continuously monitored and controlled the temperature and relative humidity inside the polyhouse. The hourly average temperature for each two weeks in the whole crop period is shown in Table 4.10 and Fig 4.56. Similar trend was observed in hourly variation of temperature in all weeks. There is an increase and then decrease in the temperature, which denotes the daily change in air temperature. Optimum temperature for spinach growth is 15 to 35 ℃. Air temperature increased above 35℃ during 1 pm to 4 pm in most weeks. Air temperature was more in the last two weeks compared to other weeks.

During the first two weeks maximum temperature inside the polyhouse was 38.18 ℃ and minimum was 25.22 ℃. During 3rd and 4th weeks the maximum temperature was 36.93 ℃ and minimum was 24.48 ℃. Maximum and minimum temperatures of 5th and 6th weeks were 35.88 ℃ and 24.90 ℃ respectively. The 7th and 8th weeks have a maximum temperature of 35.49 ℃ and minimum temperature of 25.43 ℃. Whereas in 9th and 10th weeks maximum temperature was 37.86 ℃ and minimum temperature was 25.28 ℃. During the last two weeks the maximum temperature was 38.22 ℃ and minimum was 25.92 ℃.

Temperature inside the polyhouse ranges between 24.48 ℃ and 38.22 ℃ during the crop period. The peak temperature was usually found between 1 pm to 3 pm (35.49 to 38.22℃) and minimum temperature was found between 6 to 7 am (24.48 to 25.92 ℃). Hourly average temperature of the entire crop period was calculated and given in Table 4.11. The mean temperature of the whole growing period was 29.62℃. The minimum and maximum hourly average temperature for the entire crop period was 25.22℃ and 36.91℃ respectively.

Table 4.12 and Fig. 4.57 show the hourly variation in relative humidity of each two weeks for the entire crop period. Normally, relative humidity varies depending on the time of the day. When the air temperature is the same as the dew point temperature, relative humidity is 100%. Optimum RH was 50- 70 % for the better growth of spinach (Brechner and Villiers, 2013).

RH decreased below 50 % during 1 to 4 pm in most weeks. Lowest relative humidity was found in the last two weeks. During the first two weeks maximum and minimum relative humidity was 83.30 % and 44.87 %. During the 3rd and 4th week maximum relative humidity was higher than the first two weeks (86.60 %) and minimum relative humidity was 44.89 %. Maximum and minimum relative humidity during 5th and 6th weeks was 86.16 % and 46.92 % respectively. 7th and 8th weeks have maximum relative humidity of 85.54 % and minimum of 48.55 %. During 9th and 10th weeks maximum relative humidity was 86.91 % and minimum relative humidity was 43.17 %. Last two weeks have the lowest minimum relative humidity (42.97 %) and maximum relative humidity was 84.90 %. Hence hourly average RH inside the polyhouse ranges between 42.97% and 86.91% during the crop period.

Relative humidity also followed a similar trend in the variation with respect to time in all weeks. As the temperature increases relative humidity is decreased and temperature decreases relative humidity is increased. Higher values of relative humidity were usually found between 5 am and 7 am (83.30 to 86.91 %). Less values of relative humidity were observed between 1 pm and 3 pm (42.97 to 48.55 %).

Table 4.11 showed hourly variation of seasonal average relative humidity. Mean relative humidity of the entire growing period was 69.38 %. Maximum relative humidity was observed at 6 am and minimum relative humidity was found at 2 pm. Maximum and minimum values of relative humidity were 85.4 % and 45.67 % respectively.

Table 4.10 Hourly average air temperature inside the polyhouse for each two week during the crop period

Sl. No	Time	Av. air temp of week 1 and 2	Av. air temp of week 3 and 4	Av. air temp of week 5 and 6	Av. air temp of week 7 and 8	Av. air temp of week 9 and 10	Av. air temp of week 11 and 12
1	00:00	26.67	25.99	26.32	26.75	26.72	27.48
2	01:00	26.36	25.77	26.06	26.48	26.48	27.16
3	02:00	26.13	25.49	25.82	26.17	26.21	26.89
4	03:00	25.88	25.23	25.54	26.01	26.05	26.75
5	04:00	25.64	25.00	25.30	25.72	25.71	26.45
6	05:00	25.45	24.77	25.10	25.52	25.49	26.16
7	06:00	25.22	24.57	24.94	25.43	25.28	25.92
8	07:00	25.22	24.48	24.90	25.47	25.93	26.01
9	08:00	26.36	25.77	25.97	26.59	26.54	27.57
10	09:00	29.90	28.57	28.58	29.27	29.21	31.62
11	10:00	32.42	31.00	30.93	30.98	31.98	33.79
12	11:00	33.62	32.80	32.45	32.90	33.48	34.85
13	12:00	35.00	34.25	34.14	34.12	35.14	36.38
14	13:00	36.49	35.84	35.19	35.49	35.98	37.47
15	14:00	38.18	36.93	35.88	34.91	36.43	37.55
16	15:00	38.02	36.80	35.22	35.35	37.86	38.22
17	16:00	37.80	36.77	34.48	33.96	36.18	36.54
18	17:00	36.35	34.50	32.87	32.16	33.49	34.62
19	18:00	31.05	29.92	29.65	29.69	30.31	31.53
20	19:00	28.91	28.17	28.07	28.44	28.81	29.43
21	20:00	28.10	27.44	27.44	27.73	28.13	28.94
22	21:00	27.64	26.95	27.14	27.40	27.77	28.59
23	22:00	27.34	26.60	26.91	27.04	27.40	28.12
24	23:00	26.95	26.28	26.65	26.77	27.13	27.78

Table 4.11 Hourly average air temperature and relative humidity inside the polyhouse during the crop period

Sl. No	Time	Average temperature (°C)	Average RH (%)
1	00:00	26.65	81.77
2	01:00	26.38	82.55
3	02:00	26.12	83.26
4	03:00	25.91	83.65
5	04:00	25.64	84.37
6	05:00	25.41	85.09
7	06:00	25.22	85.40
8	07:00	25.33	84.01
9	08:00	26.47	79.95
10	09:00	29.52	67.33
11	10:00	31.85	58.94
12	11:00	33.35	53.63
13	12:00	34.84	49.77
14	13:00	36.08	46.42
15	14:00	36.65	45.67
16	15:00	36.91	45.73
17	16:00	35.95	48.26
18	17:00	34.00	52.26
19	18:00	30.36	62.12
20	19:00	28.64	70.63
21	20:00	27.96	75.25
22	21:00	27.58	78.18
23	22:00	27.23	79.40
24	23:00	26.93	80.98

Table 4.12 Hourly average RH inside the polyhouse for each two week during the crop period

Sl. No	Time	Av. RH of week 1 and 2	Av. RH of week 3 and 4	Av. RH of week 5 and 6	Av. RH of week 7 and 8	Av. RH of week 9 and 10	Av. RH of week 11 and 12
1	00:00	80.31	81.43	80.73	83.24	84.71	80.17
2	01:00	80.42	81.96	82.34	83.33	85.82	81.46
3	02:00	80.36	83.03	83.44	83.69	86.65	82.38
4	03:00	81.06	83.79	83.86	83.67	86.37	83.15
5	04:00	81.87	84.66	85.00	84.47	86.23	84.01
6	05:00	82.71	85.43	86.16	85.16	86.71	84.37
7	06:00	83.30	85.97	85.80	85.54	86.91	84.90
8	07:00	83.23	86.06	86.09	84.48	79.99	84.21
9	08:00	79.30	81.22	81.84	79.61	80.82	76.88
10	09:00	67.34	69.42	71.94	70.32	64.90	60.08
11	10:00	58.46	60.26	61.57	62.75	58.35	52.25
12	11:00	53.83	54.41	55.58	56.57	52.62	48.80
13	12:00	49.98	50.56	51.12	52.76	48.35	45.89
14	13:00	47.80	43.53	49.15	48.55	45.77	43.72
15	14:00	44.94	45.06	46.92	49.25	44.18	43.68
16	15:00	44.87	44.89	48.41	50.08	43.17	42.97
17	16:00	46.03	45.66	50.83	53.17	47.79	46.07
18	17:00	46.24	49.80	55.42	58.15	54.07	49.92
19	18:00	60.13	60.78	63.21	66.92	64.74	56.92
20	19:00	70.21	69.63	70.37	73.84	72.88	66.86
21	20:00	75.58	74.44	73.72	78.31	77.38	72.06
22	21:00	78.37	77.95	76.89	80.93	80.06	74.85
23	22:00	79.49	79.64	78.19	82.64	82.02	74.39
24	23:00	79.87	80.87	79.79	83.54	82.97	78.83

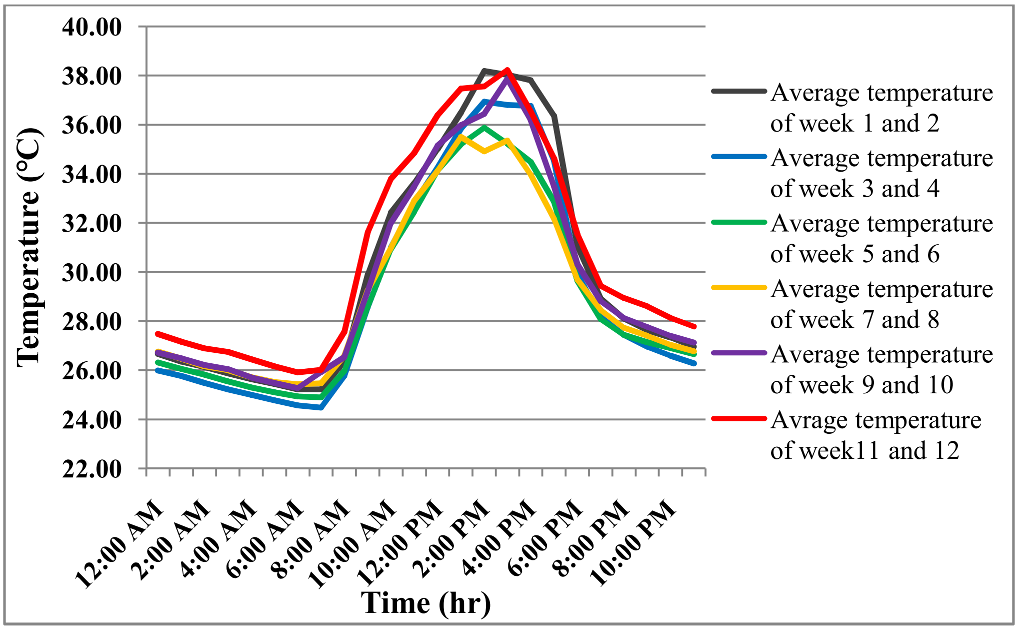


Fig. 4.56 Hourly average temperature variation of each two week during the crop period

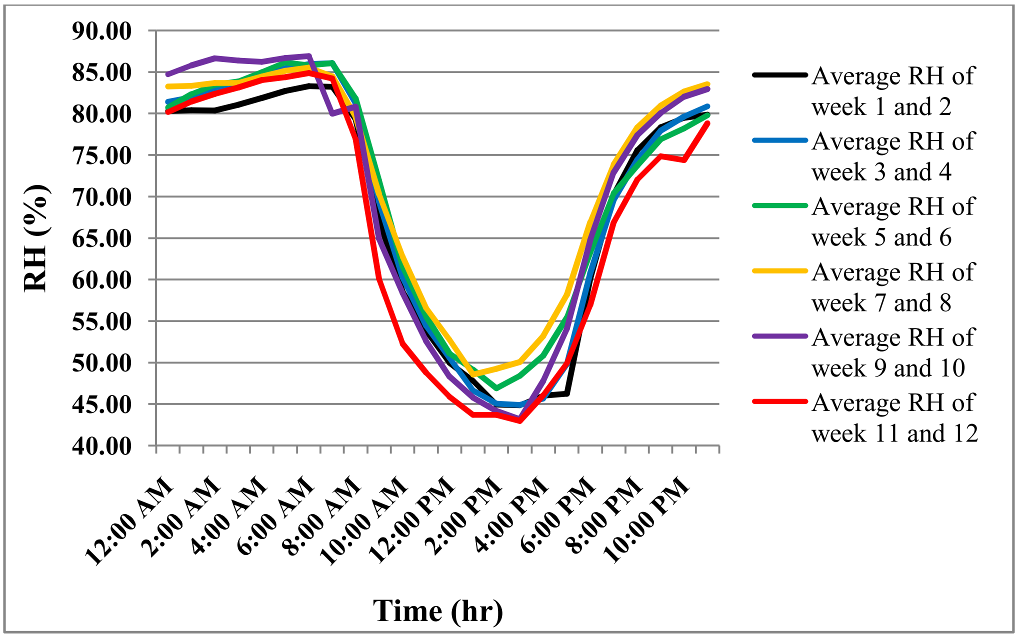


Fig. 4.57 Hourly average RH variation of each two week during the crop period

4.4.7 Light intensity

Sunlight is the ultimate source of energy for plants. Plant growth is significantly dependent on the rate of photosynthesis which mainly depends on the light intensity level. Table 13 shows the hourly average light intensity of each two weeks for the entire crop period inside the polyhouse. Corresponding data were given in Table 4.12. Optimum light intensity was found in the range of 10000 to 16000 lx. Most of the weeks light intensity increased beyond 16000 lx during 12-3 pm (Fig 4.58). Maximum light intensity was observed usually in the range between 1 pm and 3 pm. During the first two weeks after transplanting the light intensity increased to a maximum of 23576.56 lx. Whereas in the next two weeks maximum light intensity (21009.62 lx) is less than that of the first two weeks.

The 5th and 6th weeks had maximum light intensity of 20232.78 lx. Maximum light intensity during 7th and 8th weeks was (19978.36 lx). Highest maximum light intensity was found during 9th and 10thweeks (25612.33 lx). During the last two weeks light intensity reached 23668.45 lx. Hourly variation of seasonal average light intensity was calculated and shown in Table 4.14. Maximum average light intensity observed during the crop period was 21174.90 lx at 1 pm.

Table 4.13 Hourly average light intensity inside the polyhouse for each two week during the crop period

Sl. No	Time	Av. light intensity of week 1 and 2	Av. light intensity of week 3 and 4	Av. light intensity of week 5 and 6	Av. light intensity of week 7 and 8	Av. light intensity of week 9 and 10	Av. light intensity of week 11 and 12
1	00:00	0.00	0.00	0.00	0.00	0.00	0.00
2	01:00	0.00	0.00	0.00	0.00	0.00	0.00
3	02:00	0.00	0.00	0.00	0.00	0.00	0.00
4	03:00	0.00	0.00	0.00	0.00	0.00	0.00
5	04:00	0.00	0.00	0.00	0.00	0.00	0.00
6	05:00	0.00	0.00	0.00	0.00	0.00	0.00
7	06:00	0.00	0.00	0.00	0.00	0.00	0.00
8	07:00	782.63	770.45	485.61	410.46	700.66	779.84
9	08:00	2960.31	2450.7	2216.02	2413.94	2696.11	3161.79
10	09:00	10042.36	9300.65	6943.41	6588.67	9083.70	10098.09
11	10:00	13045.611	10036.95	8759.35	7179.66	8889.14	14772.03
12	11:00	15430.62	15004.23	19227.90	12898.56	14361.25	14502.07
13	12:00	23572.36	20613.22	18041.10	17725.87	20521.87	23345.04
14	13:00	22543.62	20916.23	19894.49	19978.36	20892.13	22824.58
15	14:00	23576.56	21009.62	20232.78	17213.46	18075.55	20356.30
16	15:00	23453.96	18651.78	15418.45	18139.86	25612.33	23668.45
17	16:00	17643.23	13452.3	11192.85	15145.44	16902.40	16811.87
18	17:00	6975.61	6453.32	4913.03	5685.57	7259.53	7347.95
19	18:00	986.32	854.63	770.84	824.30	937.39	1171.96
20	19:00	0.00	0.00	0.00	0.00	0.00	0.00
21	20:00	0.00	0.00	0.00	0.00	0.00	0.00
22	21:00	0.00	0.00	0.00	0.00	0.00	0.00
23	22:00	0.00	0.00	0.00	0.00	0.00	0.00
24	23:00	0.00	0.00	0.00	0.00	0.00	0.00

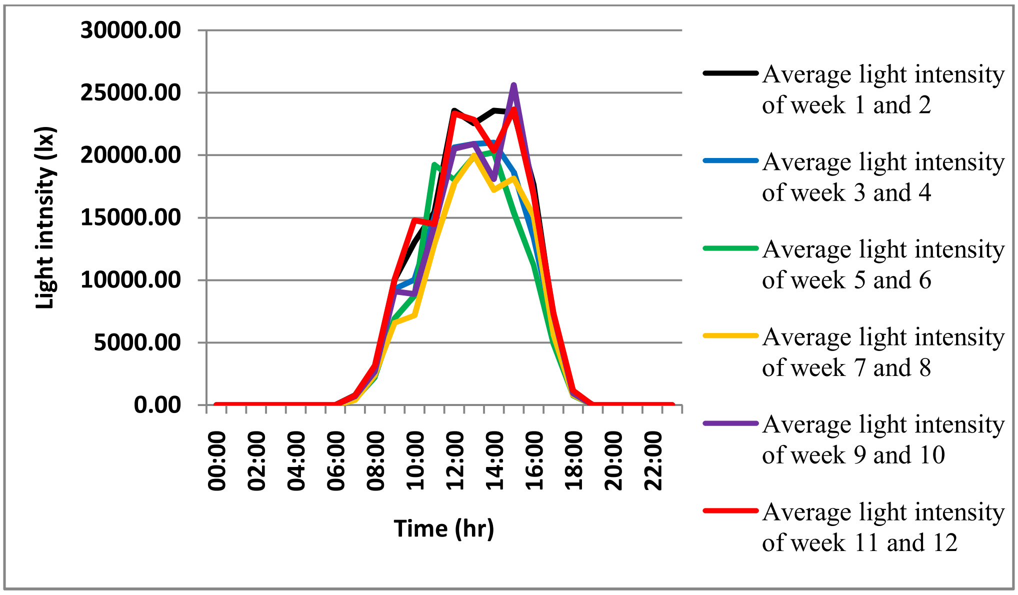


Fig. 4.58 Hourly average light intensity of each two week during the crop period

Table 4.14 Hourly variation of seasonal average light intensity during the crop period

Sl. No	Time	Average light intensity (lx)	Sl. No	Time	Average light intensity (lx)
1	07:00 AM	0.00	7	01:00 PM	20636.58
2	08:00 AM	654.94	8	02:00 PM	21174.90
3	09:00 AM	2649.81	9	03:00 PM	20077.38
4	10:00 AM	8676.15	10	04:00 PM	20824.14
5	11:00 AM	10447.12	11	05:00 PM	15191.35
6	12:00 PM	15237.44	12	06:00 PM	6439.17

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

The study to develop and evaluate automated data acquisition NFT hydroponics was conducted in a naturally ventilated polyhouse, at ARS Chalakudy, Kerala during the period from December 2022- to March 2023. Three benches of an IoT-based automated data acquisition NFT hydroponics system was developed and installed inside the polyhouse. The developed system was able to continuously monitor various nutrient solution parameters like pH, electrical conductivity, nutrient solution temperature and depth of nutrient solution in the tank and in the channel and climatic parameters including air temperature, relative humidity and light intensity in real time as graphical insights and tables in Microsoft Excel file format. These graphs made it simple to observe system trends and instantly spot any issues or potential improvement areas. The system also controlled the operation of fans and foggers inside the polyhouse. It was found that whenever the temperature inside the polyhouse increased above 28°C, the system switched on the air circulating and exhaust fans and switched off when the temperature decreased below 25°C. It was found that the air temperature was less and RH was high inside the polyhouse than outside during peak hours. Hence, the developed system can be considered as accurate and reliable. It was capable of frequently calibrating the pH and EC sensors and inputting the temperature limits of automated operation of fans and foggers and ON-OFF time periods of foggers.

The performance of the developed automated data acquisition NFT hydroponics system was evaluated for different flow rates (60 l/h, 120 l/h and 180 l/h) using the test crop spinach. Analysis of various crop parameters revealed that the crops grown under the flow rates of 60 l/h (T_1) and 120 l/h (T_2) have more yield (9.82 kg and 10.83 kg compared to the yield of 7.29 kg from 180 l/h (T_3) flow rate). Even though there is a significant difference between T_1 and T_2, there is not much difference in the yield. Root length was more for T_2 and T_3 compared to T_1. Whereas the dry weight of the root was more for T_1 and T_2 compared to T_3.

There was no significant difference observed for plant height and number of leaves between the different flow rates, but the highest average plant height and total number of leaves were found in T_2. T_1 has less water and nutrient usage. Water savings of around 46.41 percent and 40.20 percent resulted from the T_1 and T_2 respectively compared to the T_3. Compared to T_3, T_1 has nutrient savings of 28.57 percent and T_2 has 23.81 percent.

Nutrient solution and microclimate parameters were observed continuously during the crop period using the automated data acquisition system. The optimum level of pH between 5.5- 6.5 for the nutrient solution was maintained. EC of the nutrient solution was maintained at 0.3 dS m^{-1}, 1.2 dS m^{-1} and 1.8 dS m^{-1} for the first week, 2nd week, and 3rd week respectively after transplanting. From 4th week onwards EC was maintained at 2.1 dS m^{-1}.

Hourly average nutrient solution temperature for the entire crop period ranged between 22.68 and 33.93 °C for Bench I, 22.79 and 34.23 °C for Bench II and 24.29 and 34.17 °C for Bench III hydroponics system. The depth of the nutrient solution in the tank was also maintained to keep the constant flow rate of the nutrient solution. The initial depth of nutrient solution in the channel was 4 mm, 6 mm, and 8 mm in Bench I, Bench II and Bench III respectively. As the root length and density were increased, the depth of nutrient solution in the channel also increased. Depth at the time of final harvest was found as 9 mm, 11 mm and 13 mm in Bench I, Bench II and Bench III respectively. The gathered microclimatic data revealed that the hourly average air temperature inside the polyhouse ranges between 24.48 °C and 38.22 °C during the crop period. The maximum temperature was usually found between 1 pm to 3 pm (35.49 to 38.22 °C). Minimum temperature was found between 6 to 7 am (24.48 to 25.92 °C). During day time air temperature varied between 24.48 to 38.22 °C during the crop period. Hourly average RH inside the polyhouse ranges between 42.97 percent and 86.91 percent during the crop period. Maximum relative humidity was found between 5 am to 7 am (83.30 to 86.91 percent). Minimum relative humidity was observed between 1 pm to 3 pm (42.97 to 48.55 percent). During day time RH varied between 42.97 to 86.91 percent in the crop period. Light intensity measurements showed that maximum light intensity was observed between 1 pm and 3 pm (19978.4 to 25612.3 lx).

From the study it can be concluded that;

- The developed automated data acquisition NFT hydroponics system was able to provide various climatic and nutrient solution parameters in real time and also it controlled the operation of fans and foggers.
- With the automatic control of the operation of the fan and foggers, it was able to make better conditions of temperature and humidity inside the polyhouse than outside.
- This study also showed that a flow rate of 60-120 l/h provided better yield for spinach cultivation in NFT hydroponics system.
- The success of hydroponics farming highly depends on maintaining various nutrient and climatic parameters at optimum levels.
- Hence, the automated data acquisition system makes it simple to observe these parameters and manage the system accordingly. Such an automated data monitoring system will be highly beneficial for commercial cultivation using hydroponics.

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Appendices

APPENDIX-I

Program code for major automation unit

```
extern volatile unsigned long timer0_millis;

unsigned long currentTime;

unsigned long previousTime = 0;

unsigned long Ph_Ec_prevTime = 0;

unsigned long Ph_prevTime = 0;

unsigned long Ec_prevTime = 0;

unsigned long S_prevTime = 0;

unsigned long P_prevTime = 0;

unsigned long Gsm_prevTime = 0;

unsigned long DataSend_prevTime = 0;

unsigned long Fogger_prevTime = 0;

unsigned long ly=0;

float Ty=0,Hy=0;

const unsigned int Display_Interval = 5000;

const unsigned long Ph_Ec_Interval = 3600000;

const unsigned long DataSend_Interval = 900000;


#include <SoftwareSerial.h>

#include <BH1750.h>

#include <OneWire.h>

#include <DallasTemperature.h>

#include <Wire.h>

#include <LiquidCrystal_I2C.h>

#include <RTClib.h>

#include <EEPROM.h>

#include "DFRobot_EC.h"

#include "DHT.h"


#define ONE_WIRE_BUS 29

#define DHTPIN 9

#define DHTTYPE DHT22

#define DN digitalRead(41)

#define OK digitalRead(43)

#define UP digitalRead(45)

#define PH_Enable digitalWrite(14,LOW)

#define EC_Enable digitalWrite(15,LOW)

#define PH_Disable digitalWrite(14,HIGH)

#define EC_Disable digitalWrite(15,HIGH)

#define P1_Enable digitalWrite(49,HIGH);

#define P2_Enable digitalWrite(47,HIGH);

#define P3_Enable digitalWrite(51,HIGH);

#define P1_Disable digitalWrite(49,LOW);
```

```
#define P2_Disable digitalWrite(47,LOW);
#define P3_Disable digitalWrite(51,LOW);
#define S1_Enable digitalWrite(39,HIGH);
#define S2_Enable digitalWrite(37,HIGH);
#define S3_Enable digitalWrite(35,HIGH);
#define S1_Disable digitalWrite(39,LOW);
#define S2_Disable digitalWrite(37,LOW);
#define S3_Disable digitalWrite(35,LOW);

#define PHSEN1 A0
#define PHSEN2 A1
#define PHSEN3 A2

#define ECSEN1 A3
#define ECSEN2 A4
#define ECSEN3 A5

// #define WDS1 A6
// #define WDS2 A7
// #define WDS3 A8

#define TRIG1 2
#define ECHO1 3
#define TRIG2 4
#define ECHO2 5
#define TRIG3 6
#define ECHO3 7

#define FOGGER 23
#define AIRCIR 27
#define EXHAUST 25
#define FOGGER_Enable digitalWrite(23,HIGH);
#define FOGGER_Disable digitalWrite(23,LOW);
#define AIRCIR_Enable digitalWrite(27,HIGH);
#define AIRCIR_Disable digitalWrite(27,LOW);
#define EXHAUST_Enable digitalWrite(25,HIGH);
#define EXHAUST_Disable digitalWrite(25,LOW);

byte settings_flag=0;
byte Ph_flag=0;
byte Ec_flag=0;
byte UL_flag=0;
byte HM_flag=0;
byte PS_flag=0;
byte P_flag=1;
```

```
byte S_flag=0;
byte Ph_Start_flag=0;
byte EC_Start_flag=0;
byte Data_send_flag=1;
byte Fogger_Start_flag=0;
byte Fogger_Finish_flag =1;
byte Fogger_Status = 0;
byte Fanstatus=0;
byte Pt=0;
byte St=0;
byte F_on=0;
byte F_off=0;
byte F_tem=0;
byte T_hg=0;
byte T_lw=0;
byte On_count;
byte Off_count;

unsigned long P_Time=0;
unsigned long S_Time=0;

float H_value=0;
float T_value=0;
double lux=0;
float P1_value=0.00;
float P2_value=0.00;
float P3_value=0.00;

float E1_value=0.00;
float E2_value=0.00;
float E3_value=0.00;

float tempC1=0.00;
float tempC2=0.00;
float tempC3=0.00;

float UL1=0;
float UL2=0;
float UL3=0;

byte Disp_counter=1;
byte P_counter=1;
byte E_counter=1;
byte S_counter=1;
byte Ph_count=0;
byte Ec_count=0;

OneWire
oneWire(ONE_WIRE_BUS);
RTC_DS3231 rtc;
DFRobot_EC ec1,ec2,ec3;
```

```
DHT dht(DHTPIN, DHTTYPE);
DallasTemperature
sensors(&oneWire);
BH1750 lightMeter;
SoftwareSerial Gsm(11,10);

LiquidCrystal_I2C lcd1(0x26,20,4);
LiquidCrystal_I2C lcd2(0x25,20,4);
LiquidCrystal_I2C lcd3(0x27,20,4);

#define DEPTH3_01 0X24
#define DEPTH3_02 0X23
#define DEPTH2_01 0X21
#define DEPTH2_02 0X22
#define DEPTH1_01 0X20

int Depth_Val1=0;
int Depth_Val2=0;
int Depth_Val3=0;
int Depth_Temp2=0;
int Depth_Temp3=0;

void setup()
{
  pinMode(FOGGER,OUTPUT);
pinMode(AIRCIR,OUTPUT);
pinMode(EXHAUST,OUTPUT);
pinMode(TRIG1,OUTPUT);
pinMode(ECHO1,INPUT);
pinMode(TRIG2,OUTPUT);
pinMode(ECHO2,INPUT);
pinMode(TRIG3,OUTPUT);
pinMode(ECHO3,INPUT);
pinMode(35,OUTPUT);
pinMode(37,OUTPUT);
pinMode(39,OUTPUT);
pinMode(47,OUTPUT);
pinMode(49,OUTPUT);
pinMode(51,OUTPUT);
pinMode(14,OUTPUT);
pinMode(15,OUTPUT);

FOGGER_Disable;
AIRCIR_Disable
EXHAUST_Disable;
PH_Disable;
EC_Disable;
P1_Disable;
P2_Disable;
P3_Disable;
S1_Disable;
S2_Disable;
```

```
S3_Disable;

 Serial.begin(9600);
 Gsm.begin(9600);
 Wire.begin();
 rtc.begin();
 dht.begin();
 ec1.begin();
 ec2.begin();
 ec3.begin();
 lcd1.init();
 lcd2.init();
 lcd3.init();
 Add_Custom_Symbols();
 sensors.begin();
 lightMeter.begin(0X10,0X5C);

 delay(1000);

 EEPROM.get(35,Pt);
 EEPROM.get(36,St);

 P_Time = (long)Pt*1000;
 S_Time = (long)St*1000;

 lcd1.backlight();
 lcd1.setCursor(6,0);
 lcd1.print("BENCH 1");

 lcd2.backlight();
 lcd2.setCursor(6,0);
 lcd2.print("BENCH 2");

 lcd3.backlight();
 lcd3.setCursor(6,0);
 lcd3.print("BENCH 3");
 lcd3.setCursor(0,0);
 lcd3.print(char(0x00));
 delay(3000);
}

void loop()
{
  DateTime now = rtc.now();
 SetCursor_All(6,0);
 lcd1.print("BENCH 1");
 lcd2.print("BENCH 2");
 lcd3.print("BENCH 3");
 currentTime = millis();
 if(currentTime>4000000000)
 {
```

```
  resetMillis();
 }

 if(currentTime-previousTime>Display_Interval)
 {
   clearLine(1);
   clearLine(2);
   clearLine(3);
   switch(Disp_counter)
   {
    case 1:Display_Time();
          Disp_counter++;
          break;
    case 2: //SetCursor_All(1,1);
    //          DisplayAll_Str("PH Value:");
    //      lcd1.print(P1_value);
    //      lcd2.print(P2_value);
    //      lcd3.print(P3_value);
          SetCursor_All(1,1);
          DisplayAll_Str("EC Value:");
          lcd1.print(E1_value);
          lcd2.print(E2_value);
          lcd3.print(E3_value);
          Disp_counter++;
          break;
    case 3:Hy  = dht.readHumidity();
          H_value = (0.693*Hy)+19.27;
          Ty = dht.readTemperature();
          T_value =(0.546*Ty)+13.53;
 Check_Fogger_Air_Exhaust();
          SetCursor_All(1,1);
 DisplayAll_Str("Humidity:");
          lcd1.print(H_value);
          lcd1.print("%");
          lcd2.print(H_value);
          lcd2.print("%");
          lcd3.print(H_value);
          lcd3.print("%");
          SetCursor_All(1,2);
 DisplayAll_Str("Temperature:");
          lcd1.print(T_value);
          lcd1.print((char)0xDF);
          lcd1.print("C");
          lcd2.print(T_value);
          lcd2.print((char)0xDF);
          lcd2.print("C");
          lcd3.print(T_value);
          lcd3.print((char)0xDF);
          lcd3.print("C");
```

```
ly= lightMeter.readLightLevel();
lux=(1.059*ly)-4.442;
SetCursor_All(1,3);
DisplayAll_Str("Light :");
DisplayAll_Data(lux);
DisplayAll_Str("lx");
Disp_counter++;
break;
case 4:Display_WaterTemp();
Depth_Val1 = MeasureDepth(0x20);
lcd1.setCursor(0,2);
lcd1.print("WT Depth: ");
lcd1.print(Depth_Val1);
lcd1.print("mm ");
Depth_Temp2 = MeasureDepth(0x21);
Depth_Val2 = MeasureDepth(0x22);
Depth_Val2 += Depth_Temp2;
// Depth_Val2 += 9;
lcd2.setCursor(0,2);
lcd2.print("WT Depth: ");
lcd2.print(Depth_Val2);
lcd2.print("mm ");
// Wire.endTransmission();
Depth_Temp3 = MeasureDepth(0x23);
Depth_Val3 = MeasureDepth(0x24);
Depth_Val3 += Depth_Temp3;
// Depth_Val3 += 9;
lcd3.setCursor(0,2);
lcd3.print("WT Depth: ");
lcd3.print(Depth_Val3);
lcd3.print("mm ");
SetCursor_All(1,3);
DisplayAll_Str("Tank Level:");
UL1 = UL_percentage(TRIG1,ECHO1);
UL2 = UL_percentage(TRIG2,ECHO2);
UL3 = UL_percentage(TRIG3,ECHO3);
lcd1.print(UL1);
lcd1.print("Cm  ");
lcd2.print(UL2);
lcd2.print("Cm  ");
lcd3.print(UL3);
lcd3.print("Cm  ");
Disp_counter=1;
break;
}
```

```
    previousTime = currentTime;

  }

  if(currentTime-
Ph_Ec_prevTime>Ph_Ec_Interval)

  {

//      Serial.println("PH EC ready to
start");

if(P_flag==0&&Ph_Start_flag==0&
&EC_Start_flag==0&&S_flag==0)

    {

      P_flag = 1;

//       Serial.println("PH EC ready to
start");

    }

    Ph_Ec_prevTime = currentTime;

  }


    EEPROM.get(35,Pt);

    EEPROM.get(36,St);


    P_Time = (long)Pt*1000;

    S_Time = (long)St*1000;


  if(currentTime-
P_prevTime>P_Time)

  {

    if(P_flag==1)

    {

     switch(P_counter)

     {

      case 1:P1_Enable;

          P_counter++;

//                Serial.println("pump1
started");

          break;

      case 2:P1_Disable;

          P2_Enable;

          P_counter++;

//                Serial.println("pump2
started");

          break;

      case 3:P2_Disable;

          P3_Enable;

          P_counter++;

//                Serial.println("pump3
started");

          break;

      case 4:P3_Disable;

          P_counter=1;

          P_flag=0;

          Ph_Start_flag=1;

          break;

     }


    }

    P_prevTime=currentTime;
```

```
 }

 if(currentTime-Ph_prevTime>6000)
 {
   if(Ph_Start_flag==1)
   {
     PH_Enable;
     EC_Disable;
     lcd3.setCursor(15,0);
     lcd3.print("P");
     Ph_count++;
     P1_value= PH_Measure(PHSEN1,0,4);
     P2_value= PH_Measure(PHSEN2,8,12);
     P3_value= PH_Measure(PHSEN3,16,20);
//     Serial.println("PH measured");
     if(Ph_count>10)
     {
       Ph_count = 0;
       Ph_Start_flag = 0;
       PH_Disable;
       lcd3.setCursor(15,0);
       lcd3.print(" ");
       EC_Start_flag = 1;
     }
   }
   Ph_prevTime = currentTime;
 }
 if(currentTime-Ec_prevTime>6000)
 {
   if(EC_Start_flag==1)
   {

     EC_Enable;
     PH_Disable;
     lcd3.setCursor(15,0);
     lcd3.print("E");
     Ec_count++;
     E1_value = Measure_EC(ECSEN1);
     E2_value = Measure_EC(ECSEN2);
     E3_value = Measure_EC(ECSEN3);
//     Serial.println("EC measured");
     if(Ec_count>10)
     {
       Ec_count=0;
       EC_Start_flag=0;
       EC_Disable;
       S_flag = 1;
       lcd3.setCursor(15,0);
       lcd3.print(" ");
     }
```

```
    Ec_prevTime = currentTime;
   }
  }

  if(currentTime-
S_prevTime>S_Time)
  {
   if(S_flag==1)
   {
    switch(S_counter)
    {
     case 1:S1_Enable;
           Serial.println("Discharging
1 Started");
           S_counter++;
           break;
     case 2:S1_Disable;
           S2_Enable;
           Serial.println("Discharging
2 Started");
           S_counter++;
           break;
     case 3:S2_Disable;
           S3_Enable;
           Serial.println("Discharging
3 Started");
           S_counter++;
           break;
     case 4:S3_Disable;
           S_counter=1;
           S_flag=0;
           break;
    }
    S_prevTime = currentTime;
   }
  }
  if(currentTime-
DataSend_prevTime>DataSend_Inte
rval)
  {
   if(Data_send_flag==0)
   {
   Data_send_flag=1;
   }
   DataSend_prevTime =
currentTime;
  }
   if(currentTime-
Gsm_prevTime>6000)
  {
   SendData();
   Gsm_prevTime = currentTime;
  }
  if(currentTime-
Fogger_prevTime>60000)
  {
   Check_Fogger_Air_Exhaust();
```

```
  if(Fogger_Start_flag==1 && Fogger_Finish_flag ==1)
  {
   On_count++;
   FOGGER_Enable;
   Fogger_Status = 1;
   lcd3.setCursor(17,0);
   lcd3.print(char(0x03));
   if(On_count>F_on)
   {
    On_count=0;
    Fogger_Finish_flag=0;
   }
  }
  if(Fogger_Start_flag==1 && Fogger_Finish_flag ==0)
  {
   Off_count++;
   FOGGER_Disable;
   lcd3.setCursor(17,0);
   lcd3.print(" ");
   if(Off_count>F_off)
   {
    Off_count=0;
    Fogger_Finish_flag=1;
   }
  }
  Fogger_prevTime = currentTime;
 }
 if(settings_flag==0 && OK==1)
 {
  Clear_AllDisplay();
  delay(500);
  if(settings_flag==0 && OK==1)
  {
  delay(500);
  settings_flag=1;
  P1_Disable;
  P2_Disable;
  P3_Disable;
  FOGGER_Disable;
  PH_Disable;
  EC_Disable;
  S1_Disable;
  S2_Disable;
  S3_Disable;
  }
 }
 while(settings_flag==1)
 {
  main_menu();
 }

}
```

```
}

void Clear_AllDisplay()
{
   lcd1.clear();
   lcd2.clear();
   lcd3.clear();
}

void SetCursor_All(byte c1,byte c2)
{
 lcd1.setCursor(c1,c2);
 lcd2.setCursor(c1,c2);
 lcd3.setCursor(c1,c2);
}

void DisplayAll_Data(float data)
{
 lcd1.print(data);
 lcd2.print(data);
 lcd3.print(data);
}
void DisplayAll_Str(String str)
{
 lcd1.print(str);
 lcd2.print(str);
 lcd3.print(str);
```

```
void clearLine(byte line)
{
 lcd1.setCursor(0,line);
 lcd1.print("                ");
 lcd2.setCursor(0,line);
 lcd2.print("                ");
 lcd3.setCursor(0,line);
 lcd3.print("                ");
}

void Check_Fogger_Air_Exhaust()
{
  EEPROM.get(31,F_on);
  EEPROM.get(32,F_off);
  EEPROM.get(33,T_hg);
  EEPROM.get(34,T_lw);
  EEPROM.get(40,F_tem);
  if(T_value>F_tem && Fogger_Finish_flag==1)
  {
    Fogger_Start_flag = 1;
  }
  if(T_value<(F_tem-3) && Fogger_Finish_flag==1)
  {
    Fogger_Start_flag = 0;
```

```
  FOGGER_Disable;
}
if(T_value>T_hg)
{
  AIRCIR_Enable;
  EXHAUST_Enable;
  Fanstatus =1;
  lcd3.setCursor(18,0);
  lcd3.print(char(0x02));
  lcd3.setCursor(19,0);
  lcd3.print(char(0x04));
}
if(T_value<T_lw)
{
  AIRCIR_Disable;
  EXHAUST_Disable;
  Fanstatus=0;
  lcd3.setCursor(18,0);
  lcd3.print(" ");
  lcd3.setCursor(19,0);
   lcd3.print(" ");
  }
}
void resetMillis()
{
  noInterrupts();
  timer0_millis=0;
  previousTime = 0;
  Ph_Ec_prevTime = 0;
  Ph_prevTime = 0;
  Ec_prevTime = 0;
  S_prevTime = 0;
  P_prevTime = 0;
  Gsm_prevTime = 0;
  DataSend_prevTime = 0;
  interrupts();
  currentTime=millis();
}
```

APPENDIX-II

Program code for pH measurement unit

```
extern volatile unsigned long timer0_millis;

unsigned long currentTime= 0;

unsigned long previousTime = 0;

unsigned long Gsm_prevTime = 0;

unsigned long Cmd_prevTime = 0;

unsigned long DataSend_prevTime = 0;


const unsigned int Display_Interval = 5000;

const unsigned long DataSend_Interval = 60000;

const unsigned int Cmd_Interval = 1500;


byte Data_send_flag=0;

byte Calib_flag = 0;


byte Cal_count=0;


float P1_value=0.00;

float P2_value=0.00;

float P3_value=0.00;


float X1=0.00,X2=0.00;

float m =0.00,C=0.00;

byte addr1,addr2;

String Calib_Cmd=" ";


#include <SoftwareSerial.h>

#include <EEPROM.h>


String tempSerial=" ";


#define PHSEN1 A0

#define PHSEN2 A1

#define PHSEN3 A2


int SENSOR;


SoftwareSerial Sim800(2, 3);


void setup()

{

  pinMode(PHSEN1,INPUT);

  pinMode(PHSEN2,INPUT);

  pinMode(PHSEN3,INPUT);


   Serial.begin(9600);
```

```
  Sim800.begin(9600);


}


void loop()
{
 currentTime = millis();
 if(currentTime>4000000000)
 {
  resetMillis();
 }
 if(Calib_flag == 0)
 {
  if(currentTime-previousTime>Display_Interval)
   {
    P1_value = PH_Measure(PHSEN1,0,6);
    Serial.print("PH Sensor1 Value:");
    Serial.print(P1_value);
    Serial.print("\t");
    Serial.print("\t");
    P2_value = PH_Measure(PHSEN2,12,18);
    Serial.print("PH Sensor2 Value:");
    Serial.print(P2_value);
    Serial.print("\t");
    Serial.print("\t");
    P3_value = PH_Measure(PHSEN3,24,30);
    Serial.print("PH Sensor3 Value:");
    Serial.println(P3_value);
        previousTime = currentTime;
   }


   if(currentTime-DataSend_prevTime>DataSend_Interval)
   {
    if(Data_send_flag==0)
    {
     Data_send_flag=1;
    }
    DataSend_prevTime = currentTime;
   }
  if(currentTime-Gsm_prevTime>5000)
   {
    SendData();
    Gsm_prevTime = currentTime;
   }


 }
 if(Calib_flag == 1)
```

```
 {
  if(Cal_count==1)
  {
   X1= Ph_Calib(SENSOR);
   Serial.print("Value @ PH7 buffer: ");
   Serial.println(X1);
   delay(1000);
  }
  if(Cal_count==2)
  {
   X2= Ph_Calib(SENSOR);
   Serial.print("Value @ PH4 buffer: ");
   Serial.println(X2);
   delay(1000);
  }
  if(Cal_count==3)
  {
   m = (4-7)/(X2-X1);
   C = 7-(m*X1);
   EEPROM.put(addr1,m);
   delay(10);
   EEPROM.put(addr2,C);
   delay(10);

Serial.println("**************************");
   Serial.print("value of m= ");
   Serial.println(m);
   Serial.print("value of C= ");
   Serial.println(C);
   delay(3000);

Serial.println("**************************");
   Cal_count=0;
   Calib_flag=0;
  }
 }
 GetCommand();
}



void GetCommand()
{
 while(Serial.available()!=0)
 {


  Calib_Cmd  = Serial.readString();  //Read from Serial Monitor and store it in this variable.
  Calib_Cmd.trim();
  Serial.println(Calib_Cmd);
  if(Calib_Cmd == "CALIB PH1" && Calib_flag==0)
    {
     Calib_flag =1;
```

```
        addr1 = 0;
      addr2 = 6;
      SENSOR = PHSEN1;
Serial.println(">>>>>>>>>>>>>>>>>>>>>>>>Calibration mode PH Sensor 1<<<<<<<<<<<<<<<<<<<<<<");
      delay(2000);
      Calib_Cmd =" ";
    }
    if(Calib_Cmd == "CALIB PH2" && Calib_flag==0)
    {
      Calib_flag =1;
      addr1 = 12;
      addr2 = 18;
      SENSOR = PHSEN2;
Serial.println(">>>>>>>>>>>>>>>>>>>>>>>>Calibration mode PH Sensor 2<<<<<<<<<<<<<<<<<<<<<<");
      delay(2000);
      Calib_Cmd =" ";
    }
    if(Calib_Cmd == "CALIB PH3" && Calib_flag==0)
    {
      Calib_flag =1;
      addr1 = 24;
      addr2 = 30;
      SENSOR = PHSEN3;
Serial.println(">>>>>>>>>>>>>>>>>>>>>>>>Calibration mode PH Sensor 3<<<<<<<<<<<<<<<<<<<<<<");
      delay(2000);
      Calib_Cmd =" ";
    }
    if(Calib_flag == 1 && Calib_Cmd == "PH7"&& Cal_count == 0)
    {
      Cal_count = 1;
      Serial.println("Dip PH Sensor in PH7 buffer solution");
      delay(4000);
      Calib_Cmd =" ";
    }
    if(Calib_flag == 1 && Calib_Cmd == "PH4" && Cal_count == 1)
    {
      Cal_count = 2;
      Serial.println("Dip PH Sensor in PH4 buffer solution");
      delay(4000);
      Calib_Cmd =" ";
    }
    if(Calib_flag == 1 && Calib_Cmd == "END CALIB" && Cal_count == 2)
```

```
{
    Cal_count = 3;
    Serial.println("Calibration is finished!!!");
    delay(2000);
    Calib_Cmd =" ";
  }
 }
}
void resetMillis()
{
  noInterrupts();
  currentTime= 0;
  previousTime = 0;
  Gsm_prevTime = 0;
  Cmd_prevTime = 0;
  DataSend_prevTime = 0;
  interrupts();
  currentTime=millis();
```

DEVELOPMENT AND EVALUATION OF AUTOMATED DATA ACQUISITION NFT HYDROPONICS SYSTEM

by

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ABSTRACT OF THESIS

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ABSTRACT

A study was conducted to develop an automated data acquisition NFT hydroponics system, to evaluate the performance of the developed system for different flow rates and to study the microclimate and nutrient solution status. Three independent units of NFT hydroponics systems were installed in the naturally ventilated polyhouse, ARS Chalakudy during the period December 2022- March 2023. An automated data acquisition system was developed by interfacing various sensors, actuators and IoT cloud platform to a microcontroller. The performance of the developed automated data acquisition NFT hydroponics system was evaluated for different flow rates (60 l/h, 120 l/h and 180 l/h) by cultivating the crop spinach. The developed automation system continuously measured the real-time nutrient solution and microclimatic parameters. These data were uploaded to an IoT cloud platform called ThingSpeak every 15 minutes and displayed on a laptop and mobile phone. The automated system also controlled the operation of the fans and foggers in the polyhouse. The result indicated that the developed automated data acquisition system reduced the air temperature and increased RH inside the polyhouse than outside during peak hours. The evaluation of NFT hydroponics system for different flow rates resulted that 60 and 120 l/h provided a better yield, higher water savings and nutrient savings for spinach cultivation. The study of different nutrient solution and microclimatic parameters showed that EC, pH and depth of nutrient solution in tank were maintained at its respective range and depth of nutrient solution in the channel was found to vary as the crop grows. Hourly average nutrient solution temperature, air temperature, RH and light intensity were varying from time to time during the crop period. Hence it can be concluded that the developed automated data acquisition NFT hydroponics system makes it simple and quick to observe these parameters and manage the system accordingly. Such an automated data monitoring system will be highly beneficial for the commercial cultivation of hydroponics.