Internet of Things Based Plant Monitoring System for Hydroponics Agriculture

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Abstract: The increased population, rapid suburbanization of forest, industrialization, improper agricultural practice which deteriorated the soil flora and fertility cultivable land is decrementing enormously. This made a quench for new alternative technique. Organic farming, being the desideratum of the hour, is chosen as one of the technique to overcome the existing problem in cultivation. Hydroponics is a method of growing plants using water and mineral nutrients solution, without soil. An efficient hydroponics management system have been developed that monitors sensing parameters like pH, light radiation, and conductivity of the solution. Sensor values are then uploaded over the internet and can be accessed from remote places in the world. The system was designed to monitor environmental parameters and the amount of water supplied to the crops. With the knowledge of all the data set collected over the course of time of the experiment relation between these parameters was established. Also different aspects such as water conservation, plant monitoring, efficiency, etc. were taken into consideration and dealt with. The system has provided flawless real time monitoring of the environmental parameters as well as helped to improve and stabilize the crop yields.

Index Terms - **Hydroponic, organic farming, real time monitoring, IoT.**

I. INTRODUCTION

Food being the basic primary need throughout the world must be abundantly cultivated for leading a salubrious life. This production is carried over by the technique called cultivation. Agriculture provides the most essential requirement for living which is victuals. Variety of vegetables, fruits, and spices are being cultivated through variety of techniques. Each crop is grown in a specific environment requiring a specific wide range of parameters essential for its proper growth, depending upon the crop's genetic organization. Chemical fertilizers that are harmful for mankind are being utilized in the present day traditional farming. To surmount this, an environment amicable approach has been adapted called the organic farming. To cerebrate upon with the perspective of considering human health as the at most consequential factor, organic farming needs to be implemented throughout the world. Incipient techniques and a variety of different approaches are required to be considered in order to achieve this organic cultivation. One such widely used organic farming technique is the Hydroponics. Hydroponics mainly involves the cultivation of crops using mineral nutrient solution without the utilization of soil and chemical fertilizers, which prevents the threat of pest and fungal attacks and other crop diseases [1]. The nutrients required for the plant magnification are in the form a water soluble nutrient that includes minor and major nutrients and trace elements. The system can be developed indoor in a closed controlled environment and the crops grown and cultivated here have the potential to nurture and develop without sunlight by providing an artificial source of light. This in turn obviates the algae formation. In the implemented hydroponic system multiple crops can be grown simultaneously in the controlled environment. Although this amends the performance, it lacks integrity. A technique is adapted to overcome these with logical grouping of resources and prioritizing their requirements and needs [1]. Plant performance can be controlled by controlling the climate, pH range and lighting along with the factors affecting the adaptation of sustainable hydroponic culture.

II. RELATED WORK

The system developed by Saaid *et al.*implements the deep dihydrogen monoxide hydroponic system models. In this system model, roots are submerged in a solution of nutrient and oxygen opulent dihydrogen monoxide. pH sensors are utilized to monitor the nutrient content in dihydrogen monoxide. In this paper, automatic control action through automation is taken to control the pH level with the help of microcontroller which is measured with the help of sensor. In this research the change in the pH level when it is starting to deviate from the ideal specified range as well as the change in the effects of pH adjuster solution to the water solution are determined. This paper also focuses on the ability of the system to self adapt the pH value in water solution for the deep water culture technique. The water solution from the hydroponics container is transferred to the main water tank to measure the pH level and make the adjustment according to the desired range if essential and then it is drain back to the hydroponics container to grow the crop. The result from the experimental test showed that the system decreased the pH level by 0.58 and increased the pH level by 1.15.[2]

The conception of the system proposed by Lenord *et al.* demonstrated a hydroponics system that controls the nutrient solution using genetic algorithm and optimizing the system parameters. A Mamdani fuzzy interference system utilizes a set of environmental system parameters to access the quality of solution utilized as its fitness function. Light is considered to be the main influencing factor for plant magnification and yield rate. To assess the performance of proposed interference system a hydroponic nutrient control system with a nutrient solution monitoring unit was designed. The designed system provided better efficiency and resource utilization as compared to the conventional agriculture system.[3]

Rongsheng Chen *et al.* have described about the magnification and productivity of lettuce and how a specific colour light has affected the plant growth in hydroponic system. Red light was utilized as an fitness parameter to stimulate the magnification of the crop. And it was analyzed that the magnification incremented with a raise in intensity of red light. In the method proposed the lettuces plants were grown and maintained for about 35 days under different light treatments. From the critical analysis it was observed that both the growth and quality of lettuce were significantly affected by light quality treatment where the growth was enhanced by red light and increased even more as the quantity of red light increased. This research concluded that the amount of soluble sugar concentration and vitamin C in lettuce increased under red light and the nitrate concentration has decreased thus concluding that the increased amount of red light is beneficial for the development and quality of lettuce in hydroponic.[4]

The system proposed by Saaid *et al.* predicated on Aquaponics which is nothing but the integration of hydroponics culture and aqua culture. Arduino programming has been utilized to obtain information from the sensors and process the indispensable output. The magnification of goldfish has been discussed. In this research the growth performance of comet goldfish was evaluated against a hydroponic plant Spinacia Oleracea and was analyzed towards the parameters such as temperature, light and fish waste effectiveness. In this system the fish were feed containing 30% crude protein that provides all the nutrient required for the growth of plant. The auto-feeder system were used to maintain the growth and survival rates. Also the set point is calibrated and maintained to control and monitor the temperature in fish tank as well as the temperature surrounding the plant area. These methods can considerably make organic farming an easy and routine process at homes. The above implementations have potential possibilities for finding solutions to meet growing food demand in the near future. A simpler integration and leverage is needed to make these techniques feasible for common people and farmers in the market. [5]

III. THEORETICAL FRAMEWORK

The magnification environment for the hydroponics system differs for each and every crop predicated and based on the morphological and genetic structure of each plant. The proposed work deals with integrating the growing environmental conditions and parameters for individual crops on to a single system. Appropriate water soluble nutrient solution is supplied to the crops, mixing them with the required quantity of water. Various sensing parameters are utilized for monitoring the pH level of the nutrient solution, light intensity, conductivity and the water level. The input obtained from these sensors will enable the controller to regulate the corresponding parameter according to the changes adapted for the growth and maintenance of the crop. The controller is programmed with an efficient algorithm which will systematically regulate the flow. The system once built is tested upon for meeting an individual crop's requisite and then all of which are integrated. This integrated system will improvise the magnification of crops rapidly as compared to the traditional farming. The soul of the implemented hydroponics system is the microcontroller that enables the entire functioning of the environmental parameters required for the maintenance of the crop. pH meter, light intensity measurements and conductivity levels are used for calibrating the appropriate measurements needed for the plant growth.

IV. RESEARCH METHODOLOGY

The implemented hydroponics system deals with integrating all the environmental parameter for the growth of crops on to a single system. Appropriate water soluble nutrient solution is supplied to the crops with the required quantity of water. Various controlling parameters are analyzed for monitoring the pH level, conductivity of the nutrient solution, light intensity and the water level. The input obtained from these sensors will enable the controller to regulate the controlling action in correct proportion. The implemented system block diagram is as shown in the figure below

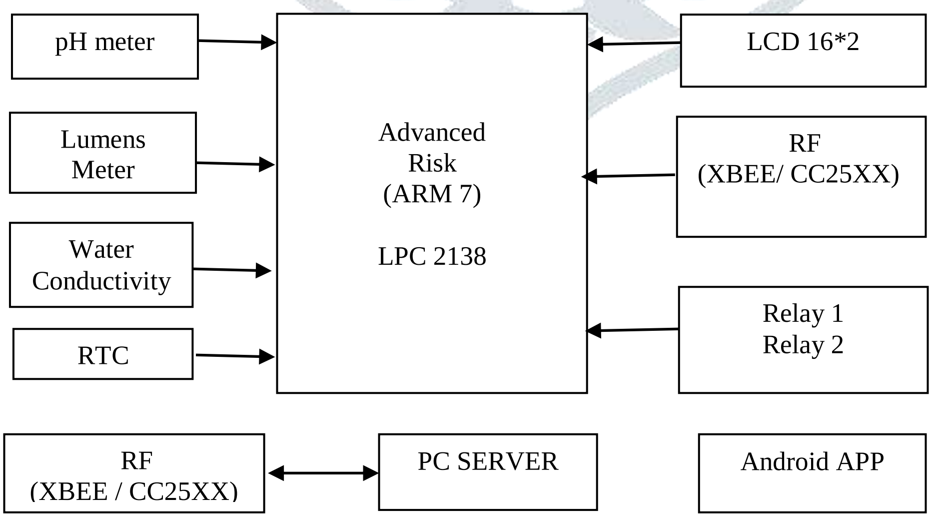

Figure 4.1. System diagram of Hydroponics

The system is formulated by initially building up a setup for a well-organized flow and functioning. This is an important parameter as there are variety of aspects that govern the growth rate and yield of plants. Not only the nutrients would suffice the growth, but a well-constructed controlled environment is essential for the proper growth and nourishment of the plant. As shown in the above figure the brain of this plant health monitoring system for hydroponics agriculture is the microcontroller that enables the overall functioning of various parameters responsible for the plant growth. The microcontroller will continuously monitor several environmental conditions such as pH of the solution, water conductivity and luminosity to achieve the optimal growth of the plants.

In hydroponics the preferred pH range for the plant lies in between 5.8 to 6.8. The tap water does not have suitable constant pH value. The pH value needs to be constantly monitored and control on daily basis. Altering the pH affects the photosynthetic activity of the plant and the maximal growth of the plant can be achieved by increasing its pH. In addition, the unbalance of uptake of various macro and minor nutrient elements by the plants causes unstable pH in root zone. Therefore the best managing range of nutrient and pH nutrient solution is necessary for the maximum growth of the hydroponics plant. The water conductivity is also monitored which affects the absorption rate of nutrients by plants. Proper conductivity level leads to the maximum growth and yield of the plant.

Giving lights to the plants is another major important factor. Each plant light requirement is different than others and varies according to its genetic structure. The ambient light is measured using the luminosity meter which give output in lumens. In hydroponics agriculture system the plants need to be kept under light for 16 hours and in the dark for 8 hours to get maximum yield. For this the inbuilt RTC function of the controller is used through relays that will turn lights ON/OFF every 16 hours and so on.

The android app developed for this system will monitor and control the hydroponics plant growth from remote places throughout the world using Internet of Things. A graphical representation of plant growth will be drawn on the graphical user interface for manipulations and analysis of the plant growth and for effective control of plant growth. In the output window there will be a provision to see all the database growth in the form of a report generated in Excel file to compare the methodology offline and the data can be used at any time in the future whenever necessary for analysis and control of the system. The output readings of the various parameters taken while controlling and monitoring of the plant are displayed on the liquid control display.[6]

4.1 RULE BASE FOR HYDROPONIC SYSTEM

Hydroponic system uses output parameters with combinations and produces input parameters by using more than one data as shown in the Table 4.1

Table 4.1: The relationship that make up output rule table

Sr. No.	Input parameters	Relationship	Related output parameters
1	Oxygen device	~	Water oxygen value, Water pH value, Water conductivity value
2	Food	~	Water conductivity value, Water pH value, Plant growth rate
3	pH balancing	~	Water conductivity value, Water pH value, Plant colour
4	Climate	~	Room temperature, Plant colour
5	Artificial light	~	Light intensity, room temperature, Plant growth rate

V. STATISTICAL MODEL OF HYDROPONIC SYSTEM

The electrical conductivity (EC) and pH of the plant are used to design and collect the data in three experiments as follows

- Experiment 1: Experiment 1 includes adjusting only EC of the water by filling solution A and B in the container or the reservoir where the plant is kept and focussing on the changes in pH value as illustrated in the Figure 5.1.
- Experiment 2: Experiment 2 includes adjusting only pH of the water by adding acetic acid in the reservoir and focussing on the change of EC value as illustrated in the figure 5.2.
- Experiment 3: Experiment 3 includes adjusting EC and pH to the EC and pH of the plant. This process use the EC adjusting equation and pH adjusting equation.

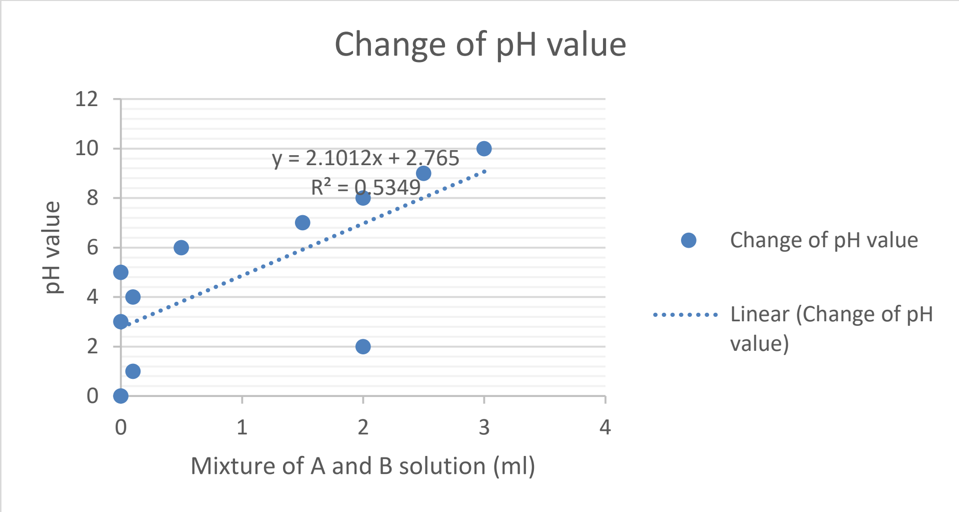

Figure 5.1: pH change after the addition of increasing volume of mixed A and B solution

5.1 LINEAR REGRESSION IMPLEMENTATION

The purpose of the study was to find the relation between the Electrical Conductivity (EC) and the pH of the hydroponics nutrient solution and to calculate the Electrical Conductivity (EC) and the pH adjusting equation by using linear regression analysis to generate the mathematical equation. The result that will be obtained using this experiment will demonstrate that the Electrical Conductivity (EC) and the pH adjusting equation can estimate the amount to fill A and B solution in Electrical Conductivity adjusting process and the amount of acetic acid in pH adjusting process.

General linear regression equation is given by

$$y = \beta_0 + \beta_1 x \quad (1)$$

where, y is the linear regression equation output,
x is the linear regression equation input,
β_0 is the y- intercept and β_1 is the gradient

β_0 is calculated from the equation 2 as shown below

$$\beta_0 = \frac{(\sum x^2)(\sum y)-(\sum x)(\sum xy)}{n(\sum x^2)-(\sum x)^2} \quad (2)$$

where, n is the number of data

β_1 is be obtained from equation 3 as shown below

$$\beta_1 = \frac{n(\sum xy)-(\sum x)(\sum y)}{n(\sum x^2)-(\sum x)^2} \quad (3)$$

The correlation coefficient (r) is used for measuring the strength and the direction of a linear relationship between x and y on a relative scale ranging from -1 to +1. r can be obtained from equation 4 as follows

$$r = \frac{(\sum xy)-(\sum x)(\sum y)/n}{(S_x)(S_y)(n-1)} \quad (4)$$

where,

S is the standard error of the regression that can be calculated from the equation 5 and equation 6 as follows

$$S_x = \frac{(\sum x^2)-(\sum x)^2/n}{n-1} \quad (5)$$

$$S_y = \frac{(\sum y^2)-(\sum y)^2/n}{n-1} \quad (6)$$

Using the linear regression equations EC adjusting equation and pH adjusting equations are obtained. From the linear regression equation EC adjusting equation is calculated as

$$\text{Amount of A and B} = \beta_0 + \beta_1 EC_{error} \quad (7)$$

where, Amount of A and B is the amount of A and B solutions (in ml.) used for adjusting EC in the water tank or reservoir, β_0 and β_1 are calculated from equation 2 and equation 3 by using data from the experiment

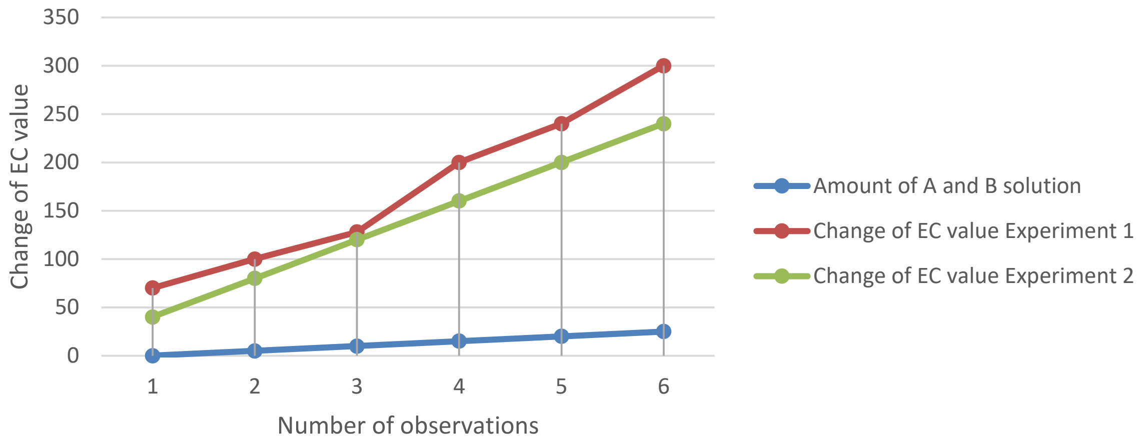

Figure 5.2: Data from adjusting EC experiment

Figure 5.2 represent the relation between EC value and the amount of A and B solution with the line increasing to linear.

Table 5.1: Data to apply EC adjusting equation

N	$\sum x$	$\sum y$	$\sum xy$	$\sum x^2$	$\sum y^2$
10	23,714	450	87,167	4,796,772	1,650

Thus from equation 2, β_0 = 0.58 and from equation 3, β_1 = 0.02. Substituting β_0 and β_1 values to get EC adjusting equation

Amount of A and B = 0.58+0.02 EC_{error} (8)

From equation (4) the correlation coefficient r can be obtained. Thus r = 0.9. Calculating S_x and S_y from equation (5) and (6) respectively gives S_x = 83.86 and S_y = 1.42

pH adjusting equation can be calculated from linear regression equation as follows

Amount of acetic acid = $\beta_0 + \beta_1$ pH_{target} (9)

where, amount of acetic acid is the amount of acetic acid (in ml) used to adjust the pH in reservoir, β_0 and β_1 are calculated from equation (4) and equation (5) using data from the experiment

Table 5.2: Data to apply pH adjusting equation

N	$\sum x$	$\sum y$	$\sum xy$	$\sum x^2$	$\sum y^2$
10	72.2	250	218	63.76	750

From equation (2), β_0 = 0.17 and from equation (3), β_1 = 3.22

Substituting values of β_0 and β_1 in equation (9),

Amount of acetic acid = 0.17 + 3.22 pH_{target} (10)

Finding correlation coefficient r from equation (4), we have r = 0.99 where S_x and S_y is obtained from equation (5) and equation (6) respectively as S_x = 0.34 and S_y = 1.12.

5.2 TESTING OF ELEECTRICAL CONDUCTIVITY ADJUSTING EQUATION

In the above demonstrated experiment, the equation is tested by manually filling the A and B solutions in the water tank. The Electrical Conductivity adjusting process need to adjust before pH adjusting process because in the pH adjusting process that uses acetic acid have effect to increase the number of Electrical Conductivity value as indicated in the table below

Table 5.3: Electrical Conductivity adjusting test equation

Amount of A and B solution (ml)	EC_{error} (μS/cm)	EC_{real} (μS/cm)	EC_{real} - EC_{error} (μS/cm)
4	171	176	5
5	221	230	9
7	321	331	10
9	421	427	6
11	521	532	11

From Electrical Conductivity adjusting test equation, the precision of estimate of standard Electrical Conductivity error can be calculated by using

$$S = [(\sum \text{Error of Electrical conductivity equation})^2 / n-2]^{1/2} \quad (11)$$

The Electrical Conductivity adjusting equation have standard error estimate S= 1.98 that means the range of Electrical Conductivity after adjusting in this process will increase and decrease in the range of 1.98 from $EC_{error.}$

5.3 TESTING OF pH ADJUSTING EQUATION

The results obtained testing of pH adjusting equation is illustrated in the table below

Table 5.4: Test of pH adjusting equation

Amount of acetic acid (ml)	pH_{error}	pH_{real}	pH_{error} - pH_{real}
2.36	7.30	7.0	0.3
2.52	7.80	7.3	0.5
2.46	7.60	7.2	0.4
2.30	7.10	7.6	0.4
2.30	7.12	7.10	0.2

From pH adjusting test equation, the precision of estimate of standard error can be calculated by using

$$S = [(\sum \text{Error of pH equation})^2 / n-2]^{1/2} \quad (12)$$

The pH adjusting equation have standard error estimate S= 3.03 that means the range of pH after adjusting in this process will increase and decrease in the range of 0.32 from $pH_{error.}$

Thus from the experiment of Electrical Conductivity and pH adjusting process, the amount of A and B solutions and the amount of acetic acid have direct relation with the Electrical Conductivity value and pH value given by the correlation coefficient value r= 0.9 and r= 0.99 respectively. That means the amount of A and B solutions have strong relation with Electrical Conductivity and pH value in positive direction.

VI. RESULT AND DISCUSSION

The pH constitutes the important parameters essential for the plant growth. It needs to be maintained within a specific range of 5.8 to 6.8. If the pH is not within the specific range for the respective crop the plant will not be able to absorb the essential mineral nutrient elements required for the growth. If the pH reaches above a level of 7 then by adding pH down solution the pH level is reduced at the desired level as shown in the Figure 6.1. over a course of time when the pH value does not deviates even above the specified pH range the water is made to drain out of the system.

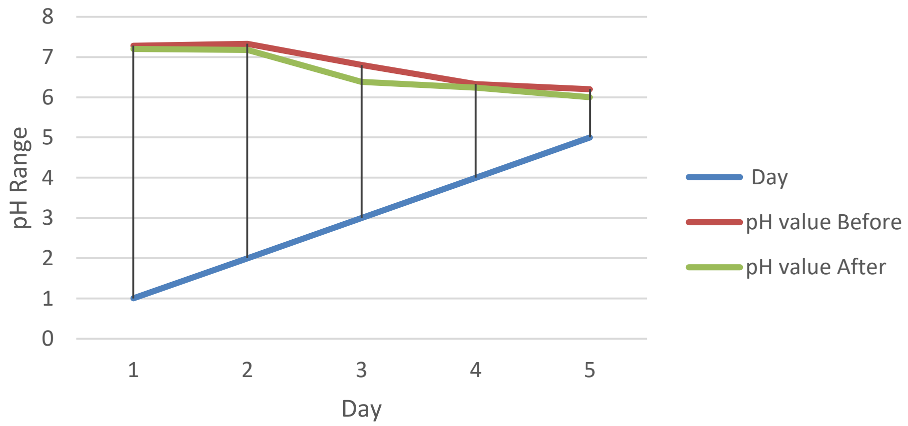

Figure 6.1: Measurement of pH value by applied pH down solution

Hydroponics calls for less water since the required water is supplied in fixed proportions and a controlled environment. This is the greatest merit over conventional irrigation system where much water is wasted without recycling. This also reduces the farmers water cost hence lowering the production costs. On an average the hydroponic crop requires only 1 or 2 liters of water per week whereas the soil cultivation requires approximately 10 liters of water a week. Figure 6.2 illustrates the analysis of water consumed by the plant in soil and soilless cultivation

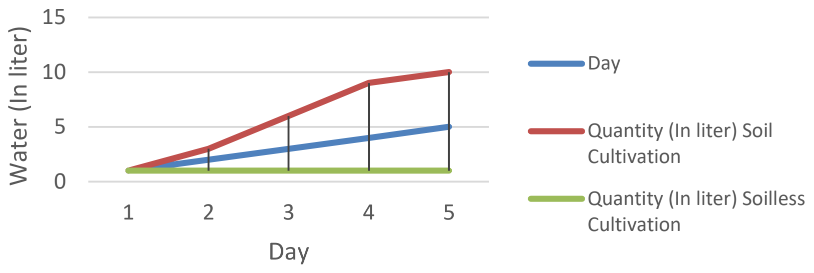

Figure 6.2: Quantity of water consumed by the plant at the end of respective day

The growth rate of plants in hydroponics is about 50% times faster since the hydroponic plants do not need to expand their roots to search for nutrients intake. The faster growth is due to the highly controlled environment with the availability of specific range of environmental parameters such as pH, light, water and nourishing substances for the plants. As shown in the Figure 6.3 hydroponic plants growth rate is larger. There is a significant improvement in the height of the hydroponics plant developed in a favorable environment that ranges upto 75cm. the observations were carried out for about three months.

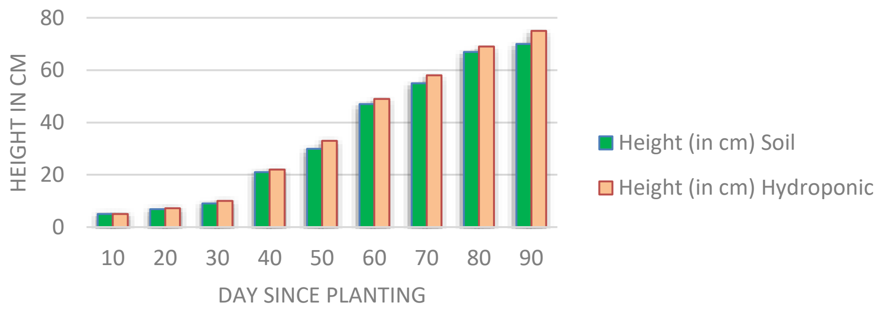

Figure 6.3: Plant height analysis in Hydroponic and Soil system

Figure 6.4 indicates the yield/ productivity of the crop for a period of five months. As compared with the traditional soil culture the yield obtained from hydroponics culture is about three times larger. As indicated from the figure the productivity per crop in the hydroponics system for the first month was 7 chilies per crop which was increased to 38 during the observation period of five months whereas in the soil culture the productivity for the first month was 3 that was increased upto 28 in the last month. This shows the significant improvement in the productivity in the hydroponics environment.

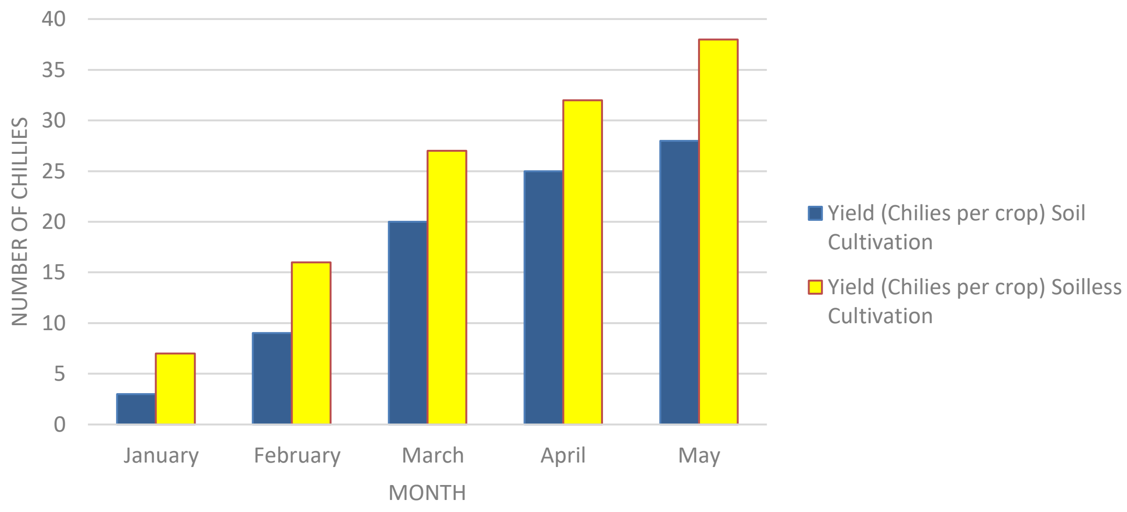

Figure 6.4: Productivity per crop over a period of five months

Thus the methodological approach has been formulated to regulate the system working with the integration of different types of sensors controlled through automation for the maximal plant growth along with its effect on various environmental parameters such as conductivity, light intensity, pH, etc. The plant growth under the soil and hydroponics system has been analyzed demonstrating the efficiency of the hydroponics system. From its characteristics the hydroponics system is a strong candidate for space application as well as for the cleaner nutritive yield having the prominent and potency to feed the whole world.

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