American Academic Scientific Research Journal for Engineering, Technology, and Sciences
ISSN (Print) 2313-4410, ISSN (Online) 2313-4402
http://asrjetsjournal.org/

Automated System that Monitors and Controls the pH and Electrical Conductivity of a Closed-Hydroponic Setup

Ma-Clarissa Mabitazan[a]*, Raul Mabitazan[b]

[a,b]Saint Louis University, A. Bonifacio St., Baguio City 2600, Philippines
[a]Email: mcbmabitazan@gmail.com
[b]Email: rcmabitazan@gmail.com

Abstract

The Automated Closed Hydroponics System relates to a system that monitors the pH and electrical conductivity (EC) of the nutrient solution. It is constructed to modify and optimize the conventional hydroponic system as determined through its specific operational requirements to utilize the system safely and profitably. The modules are electronically integrated into the system that continuously monitors the pH level and the EC level of the nutrient solution and automatically adjusts its content to the proper range suitable for the plant used. The developed system lessens human involvement, and in turn, eliminates human error while keeping expenses at a minimum and ensuring yield at maximum. This article discusses the operation of the system which consists of the reservoirs for the dispensing of acid, base, nutrient solution, and water, with its necessary valves, motors, hose, and flow regulators; level sensors installed to the reservoirs to monitor the refilling requirement and operational conditions; pH monitoring and control; electrical conductivity (EC) monitoring and control; and, the nutrient uptake analysis to illustrate the plant nutritional status verifying that the plants were taking up the nutrient balance they require when the pH and EC are on their respective exact levels. The automation in the hydroponic system results in a more balanced culture, creating healthier and more homogeneous leaves.

Keywords: Automated Closed Hydroponics; potential hydrogen-hydroxyl (pH); electrical conductivity (EC).

1. Introduction

Truly a wonder of modern science, hydroponics is one of the sustainable food production methods that work with the laws of nature and seek to enhance rather than exploit natural living systems. Hydroponics imitates the basic natural environment of plants and delivers essential nutrients right at the tips of the plants' roots. Hydroponics, which originally meant nutrient solution culture, is an alternative plant growing system that does not use soil.

----

* Corresponding author.

There are many studies attesting the advantages of using hydroponics. However, hydroponics requires daily check up on pH (potential hydrogen-hydroxyl) and EC (electrical conductivity) level. It is for this reason why the system discussed in this article integrates current trends in the electronics industry and the emerging automation technologies; to control the operation of the system as well as to monitor the quality of the nutrient solution required by the plant. This will alleviate human involvement, to lessen if not altogether eliminate human error with the least expense possible and with the highest yield.

1.1. Background of the study

Currently, land resources are clearly under stress due to rapid urbanization. The demand for food production in the Philippines puts stress on land use and natural resources. The forestland alone is extremely suffering from degradation, with an estimate of 6.8 hectares of forestlands' net loss of 400,000 hectares every year. The cause of this destruction is attributed to food production [1]. Moreover, the Philippine Statistics Authority (PSA) reports that by 2045, the Philippine population is projected to increase from its 2010 Census Count of 93 million to 142 million (2016). Though CAR region, known as the salad bowl of the Philippines for its vegetable crops, has the smallest population with 2.6 million by year 2045, it is apparent that the influx of tourist arrivals [2] causes the construction of several establishments in the Baguio City and in nearby towns in Benguet. As a result, the space to do farming or gardening is becoming more depleted. The availability of the land as well as the nutrients needed by the plants is becoming scarcer. Traditional systems of land management are either breaking down or are no longer appropriate.

Aside from the depletion of the land resources in the country, the recent typhoons that consecutively hit the Northern Luzon left the communities devastated, facing serious challenges in their respective livelihood both in the agriculture and in small scale mining. The small-scale mining accounts for 80% of direct source of income for approximately 60,000 individuals who are directly dependent from the earnings of the miners. The federation of the Benguet small scale miners is working hard to bring together short term and long-term solutions to seemingly daunting task of providing either alternative or supplementary livelihood programs. As such, the federation asked the assistance of different sectors of societies and experts for help in the introduction of various livelihood programs for their families. However, the conventional farming may not be applicable to be adapted in the area, as the soil may still need to be treated from contamination of poisonous substances, such as cyanide, used in mining.

Indicators, such as the decline of agricultural production [3] due to the rapid increase in urbanization in the country, the worsening situation of irrigation, and the tragedy inherent to natural calamities, show reasons to drive the agricultural sector to be less dependent on conventional farming practices. If the local government units do not adapt to these realities, the expected boost in urbanization and population growth could further increase the vulnerability of urban dwellers to sudden shocks in agricultural markets [4]. With the increasing global population that was projected by the United Nations (UN) to reach nearly 10 billion people by 2050, demand for food production also increases. [5] While modern industrialized agriculture can supply the necessary food demand, it continually depletes the topsoil and aquifers, and its reliance on pesticides and other agrochemicals pollute the air and water. Moreover, the world faces acute food shortages from climate-related events such as flooding, irregular rains, droughts, and high temperatures. It does not help that the Philippines has long been vulnerable to extreme weather due to its geography, being in the western Pacific Ocean and surrounded by naturally warm waters. Due to this, the country is also identified as the number one most affected by climate change according to the Global Climate Risk Index 2015. This threatens the country's agricultural sector causing significant losses in food production.

In light of aforementioned reasons, there is a need for the adaptation of alternative systems, like hydroponics, that can grow food in a controlled environment, with less water, and in higher yields. The technology to address the problem of future food security is much needed. Studies show the many benefits of using hydroponics over the soil farming. Hydroponics efficiently mimic the vital elements of a plant’s natural environment and delivers precise quantities of nutrients at precise times [6]. However, hydroponics requires daily check up on pH and EC (electrical conductivity) levels.

In the Philippines, current hydroponic technology is being practiced in conventional way. Respective studies leading to better understanding of hydroponic technology were already done, and it is clear that the specialists know the many advantages of growing the plants in hydroponics than in soil.

There were already attempts on using hydroponics system done by the farmers, but either have already been discontinued or have not gained popularity among the local farmers. The control of the EC value is the dilemma of some growers and farmers. They do not anticipate the calculations of the exact amount of nutrients specifically formulated for hydroponic plants. The important aspect to the hydroponic techniques is that the exact formulation should be checked to allow an estimation of the amounts of nutrient solution to be added and the level of EC and the pH values of the resulting nutrient solution should be monitored. Hence, the technical know-how of the farmers and the proper support to sustain the chemicals for the nutrient formulation are the key factors that hinder the stability of the technology. As what have been the concerns of the common farmers, hydroponic technology is more complicated and involved process than dirt farming. Hence, this project was conducted which aims to focus not only on the plant growth but to devise a solution that would lessen human involvement in monitoring and controlling the pH level and EC of the nutrient solution that is suitable for the plants’ living requirements.

The management of the nutrient solution is a key to successful hydroponic growing. The availability of elements to the plants is dependent upon correct pH as well as the concentration and ratios of nutrients in the solution [7,8]. The term pH refers to the potential hydrogen-hydroxyl ion content of a solution. Solutions ionize into positive and negative ions. For example, for lettuce, a particular pH level that will produce optimum results is the use of highly soluble nutrients of maximum purity available for lettuce with pH between 5.6 and 6.0. Nutrients are in the form of salts dissolved in water. An important parameter to determine the amount of salt or salts in solution is the Electrical Conductivity (EC); a factor that influences a plant’s ability to absorb water. At a constant water level, the decrease in salt concentration is related to a decrease in electrical conductivity, which can be used for monitoring the nutrient levels in the solution [9].

1.2. Review of literature

The fact that practically, no study has been found in the Philippines, describing automated control of pH and electrical conductivity of nutrient solution in the hydroponic systems, it made difficult to compare with the literature. One of the concerns in designing of the automated hydroponics system is the in-depth understanding, not only of its benefits, but to practice flexible growing method that lets the grower have full control over the hydroponics environment, including the active root zone. Alternatively, thorough studies leading to better understanding of absorption and consumption of hydroponic lettuce plants was conducted, recording the amounts in different stages of plant growth in conventional hydroponic environment. These served as the basis of the design of automated hydroponic system.

Primarily automated hydroponic system was carried out by mimicking traditional methods based on production in conventional hydroponic system. These traditional hydroponic procedures proves to yield better quality of produce, which is expected to meet the consumer preferences. However, with the application of the automation in the hydroponics setup, the sensitivity of a system in recognizing values allows better correction of pH and conductivity parameters with speed, precision and efficiency, there is no need to wait until it reaches the extreme limits before the adjustments are made [10].

The methods used by Diego S. Domingues, et. al. [10] was prescribed as the basis in conducting the experiments. The cultivations were done in parallel, in order to compare data obtained using, first, their developed system the new fully automated system; second, using the current widely used system of hydroponic growth, where nutrient solution concentration is adjusted manually; and the third, cultivation in the ground, made in a more conventional way. The experiments lead to only two systems being available for comparison done in parallel, using automated hydroponic system developed and conventional cultivation in soil, taken as reference of quality. The conventional hydroponics was discontinued due to lack of technical care. The experiments resulted to similar behavior regarding the agronomic characteristics evaluated, by the comparison of the two setups. Unlike with the experiments done by D. S. Domingues and his colleagues where their developed system was compared with the soil crop, the developed system being discussed in this article was tested and compared in parallel cultivation with identical environment between the automated hydroponic system and the conventional hydroponic system.

Series of activities were done to show the ways on how to build and operate various hydroponic techniques used for construction in this study [5,6]. The intent was to help the researchers in familiarization of the different methods where the control system would be integrated. The information within, certainly affected the decisions of what, where and how to grow the lettuce which ultimately improved the chance of a successful production. How electrical conductivity [9] and pH levels affect the availability of nutrients and the growth of the plants [7,8] were the key parameters taken into considerations in implementing automation to the manual procedures of controlling both open and closed hydroponics systems. The Closed irrigation system was adopted in the developed hydroponics system, as it increases the water-use efficiency and reduce the environmental impact of greenhouses and nurseries. These systems, can increase the efficiency of water-usage while maintaining its quality, as well as support eco-agriculture when intensively implemented [11].

1.3. Scope and Limitations of the Study

The developed automated hydroponics system is suitable to any kind of hydroponics technique. Variations (or combinations) of Wick system, Deep Water Culture, and NFT hydroponics were applied during experimental stage of the study. This shows that the control system is adapted to any hydroponic techniques. Also, there are two fundamental types of soilless systems, namely open and closed. Though in the current hydroponic setup, the closed system was used, the monitoring and controlling of the pH and EC level may be integrated to either system. However, aspects on managing these systems are not covered in the study; likewise, the study did not deal with the relative differences of each technique that relates to the effects in monitoring and controlling the pH and EC level to each system.

The researchers focused on growing of lettuce only as it is best suited for the study because of its sensitivity to the climate, nutrient uptake, pH and EC levels and yet the length of production, from the germination up to the harvest time is enough to conduct several trials and experiments. The research did not deal with the comparative study of the lettuce from the hydroponics garden and that of the traditional garden which uses soil as growing medium. Likewise, the system does not determine the maturity and the right harvesting time. The growth was predetermined through experiments and researches. The plantation site is assumed to have adequate room temperature, ventilation and natural sunlight, that was utilized for the growth of lettuce, such as the preferred location of the study, Benguet, Philippines. Hence, other environmental factors of growing lettuce were not part of the research that would be monitored by the system.

The solution tank has sensors that continuously measure the current EC and pH levels of the solution, the measured EC and pH levels is the basis of the automated system in adjusting the values to the appropriate levels for the plant used in the system. The calibration of these sensors were done using standard buffer solutions and verified using standard pH and EC meters commercially available in the market. To evaluate the performance of the developed hydroponics system, two analyses were done: nutrient uptake analysis and virtual or physiological analysis. These two analyses provided information on potential response of lettuce to nutrient solution being monitored and adjusted to proper pH and EC levels.

2. Materials and Methods

This study commenced with an extensive research, done to promote improved understanding on conventional hydroponic procedures, and to be able to translate this understanding to the concepts of automated hydroponics techniques. The main concern was to determine the technological and environmental aspects essential to the hydroponics technique through possible experiments, observational studies, field experiments along with logical consequences and plans about the project structure and the location where the prototype would be suitably built, including the environmental factors identified and maintained for the whole crops' time. Then, by the use of these conventional method translated into automated hydroponic environment, the research was integrated into practice of constructing the modules for monitoring and automatically controlling the pH and electrical conductivity (EC) of nutrient solution ideal for the vegetable production. Parameters of the nutrient solution such as the pH and EC, significant to the growth of a plant were measured, monitored and automatically controlled to specified levels which reduced human intervention, thus, limiting human error in using the instrumentation of the automated closed hydroponics system. The next phase was the implementation of the design algorithms/ procedures integrated into system of automating the hydroponic system resulting from the present practices and settings of the conventional farming. Nutrient solution was formulated, followed by the evaluation of the produce through nutrient uptake analysis and physiological analysis. Parallel cultivations were done in order to compare how much nutrients were taken up by the plants and to compare the physiological data of the produce at the same harvest period. Both systems used identical closed hydroponic systems and differed only in nutrient solution management. The first cultivation was a Deep Water conventional hydroponics where the pH and EC were analyzed on laboratory, and the nutrient solution concentration was adjusted manually as needed. The second was also Deep Water hydroponics setup with automatic control of pH and EC. By means of spectrophotometry and titrimetric methods, the plants' assimilation of calcium, phosphate, nitrate, ammonium, and nitrogen were monitored weekly for three trials and analyzed. The amount of the concentration diminished from the remaining solution taken from the root zone of plants represents the actual amount of uptake by the plants. Upon completion of the growth cycle, the plants were harvested to compare the yield of the conventional and automated hydroponic setup conducted for lettuce plant, with regards to the color of the leaves, the average diameter of the leaves, the height of the plant, the diameter of the main stalk, and the average weight of one (1) plant head.

The pH and the EC are the two main parameters that were taken into account in the research project. These served as the basis of the design of the automated hydroponic system. The sensitivity of a system in recognizing values allows the correction of pH and electrical conductivity (EC) parameters with speed, precision and efficiency; hence there is no need to wait until it reaches the extreme limits before the adjustments are made.

2.1. Monitoring and controlling of pH and EC level

In this system, the controller continuously monitors pH and EC and automatically injects acid (phosphoric acid, H_3PO_4) or base (potassium hydroxide, KOH) into the nutrient solution, to maintain the pH and EC values at which the controller/processor has been set to specified levels which reduces human intervention, thus, limiting human error in the instrumentation of the automated closed hydroponics system. The pH and EC probes are placed into the nutrient solution tank which output voltage values. The probe outputs are then connected to signal conditioning circuits which translate these voltages into levels appropriate as inputs to the analog inputs of the microcontroller. The microcontroller converts the analog inputs to digital which are displayed on a liquid crystal display (LCD) in the control panel. Calibration of the pH meter is done by using standard solutions with known pH values. Likewise, the calibration is verified by comparing the measured pH and EC values with that of a standard/ commercially available pH and EC meters. The nutrient solution is placed on a tank whose size will depend on the number of plants considered in the setup. It is on this tank where the nutrient solution is kept and where measurement of EC and pH are made, monitored and controlled. Regardless of the type of the setup of the hydroponic system, the components or parts in automating the system are basically the same. These basic parts are (1) the pH meter, (2) EC meter, (3) the processor or the controller. Solution level sensors are installed to monitor the levels of the different solutions used in the system. This is shown in figure 1.

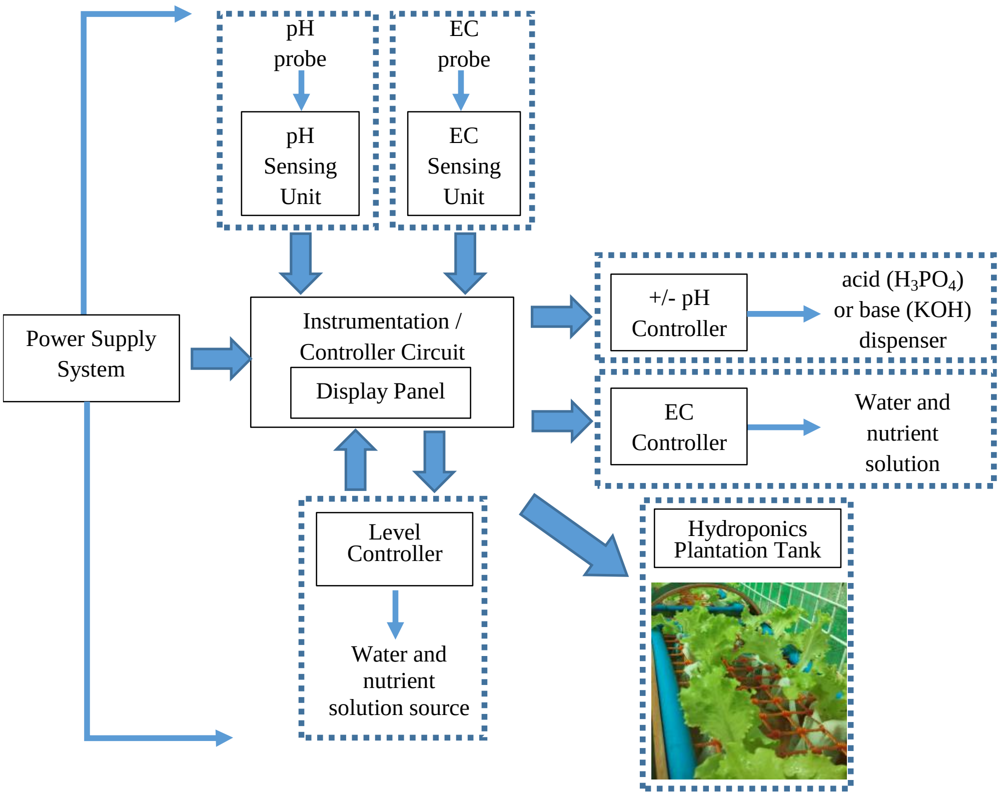


Figure 1: Basic Parts of the Electronic Controller

Low (L) level sensors are installed on the nutrient solution source, phosphoric acid (H_3PO_4), and the potassium hydroxide (KOH) reservoirs to monitor the refilling / critical conditions of these solutions during the operation of the system. Low (L), high (H) and overflow (OV) level sensors are installed on the plantation nutrient solution tank. The low (L) level sensor monitors the level of the nutrient liquid solution which requires addition of nutrient solution on the plantation tank. The high (H) level sensor monitors the level of the nutrient liquid solution which commands the addition of nutrient solution on the plantation tank to stop refilling. The overflow (OV) level sensor monitors the level of the nutrient liquid solution which requires flushing partly or entirely the volume of nutrient solution on the plantation tank into the nutrient solution drain tank depending on what system operation may require. An OV sensor is also installed on the drain tank to monitor the overflow level condition which requires replacement of the container for the used-up nutrient solution. All outputs of these level sensors are entered into the digital inputs of the microcontroller. The process of monitoring and controlling of the level of the nutrient solution in the plantation tank is shown in figure 2. Based on the states of these level sensors, the microcontroller will output appropriate control signals to the nutrient solution dispensing unit, to the nutrient solution mixer, to the phosphoric acid dispensing unit, to the potassium hydroxide dispensing unit, to the plant tank drain system, to the aerator, to the LCD and to the alarm system.

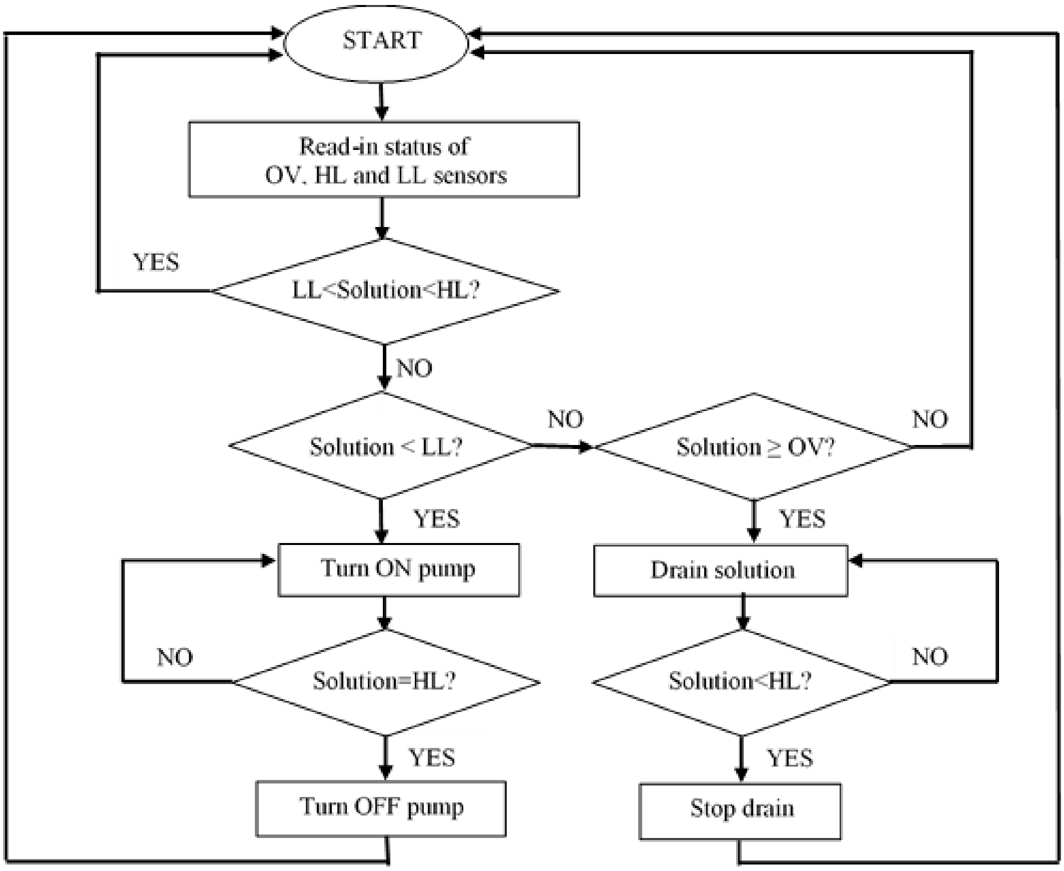


Figure 2: The process of monitoring and adjusting the nutrient solution in the hydroponics plantation tube.

2.2. The pH Monitoring and Controlling

A pH meter is basically a high impedance voltmeter that measures the generated voltage by the pH probe. It is the same as measuring the voltage with a standard digital voltmeter (DVM) with its probes immersed into water and with a pre-amplifier that provide the high impedance interface with the gain that matches the pH-voltage conversion factor. The pH meter measures the voltage generated by the pH electrodes / sensors showing the hydrogen concentration in the nutrient solution in the pH scale. Based from the datasheet of the pH electrodes used, at 25 degrees Celsius, its voltage change is -59.16 mV/pH. The output of the electrode will swing from -7pH x -59.16 mV/pH = +414.12 mV (pH 0 strong acid) to +7pH x -59.16 mV/pH = -414.12 mV (pH 14 strong caustic/base). The pH probe's output is connected to a signal-conditioning circuit which translates the voltage into 0 to 5 V DC a voltage level appropriate as input to the analog input of the microcontroller. The signal conditioning circuit should output around 2.5V DC when the pH probes is immersed in pure water (neutral). The microcontroller will then convert the analog input to digital and the measured value displayed on a liquid crystal display (LCD) panel. The calibration of the pH meter designed and constructed by the researchers in this study was done by measuring the pH of a known standard buffer solutions with known pH values, then verified by comparing the pH values using a commercial-grade pH meter available in the market.

In this automated closed hydroponics system, the range for the needed pH may be programmed. For example, for lettuce, which was the experimental vegetable used in the project, the pH was maintained to approximately

5.8. Hence, the pH between 5.6 and 6.0 was established as the range to control for the parameter. It was demonstrated that while the monitoring circuit acquires data through the pH probe and compares it from pH range which has been pre-programmed, one of the pumps responsible for controlling the pH is triggered, dispensing acid (H_3PO_4) or base (KOH) in the nutrient solution container, causing the pH of the solution to go back to the pre-established value. When the pH measured is above 6.0, the pump responsible for dispensing phosphoric acid (H_3PO_4) is switched ON for a specific amount of time, dispensing drops of acid solution. The system would stand for mixing, allowing time for the pH reading of the nutrient solution to stabilize. Depending on the reading of the pH monitoring circuit, more acid is added again. The process of adding and mixing the acid continued until the nutrient solution attained the desired pH value. When the system detected a pH value below the 5.6, the pump responsible for base solution (such as KOH) is switched ON, dispensing drops of base solution. After allowing it to stand for mixing, more base solution is added as needed. The process of adding and mixing the base solution continued until the desired pH value of the nutrient solution is attained.

2.3. The EC controller

The EC meter probe's output is connected to a signal conditioning circuit which translates this voltage into a level appropriate as input to the analog input of the microcontroller. The microcontroller will then convert the analog input to digital which is shown on the display panel. The EC level of the nutrient solution is measured and maintained throughout the duration of the growth of the plant. The range of the electrical conductivity of the nutrient solution to be maintained in the system ranges from at 1.0 mS per cm. to 1.5 mS per cm. If the EC increases to above 1.5 mS per cm, water from the reservoir is added onto the plant nutrient solution tank through the water valve. If the EC is lower than 1.0 mS per cm. fresh mixture of nutrient solution from the reservoir is added onto the tank. This process continues as the EC is measured and the specified EC is maintained. It must be noted that if EC level cannot be attained after adding water and the level on the tank has reached the overflow (OV) level, the nutrient solution on the plant tank will be drained to equal the high level (HL) as fresh nutrient solution will be added onto the plant nutrient solution tank.

The calibration of the EC meter designed and constructed by the researchers in this study was limited to meter testing by measuring the electrical conductivity (EC) of a standard solution/mixture. The calibration of this EC meter was then verified by comparing the ECs taken with a commercial-grade EC meter available in the market.

3. Results and Discussion

In the developed system, the real time monitoring of pH and EC to acquire updated data was made possible through the sensors immersed in the nutrient solution throughout the 24 hour per day period and to compare these with the pre-programmed range of standard values set to the system, making the immediate control of these parameters. Figure 3 shows an illustration of the actual set up of the automated system.

Figure 3: The actual setup of the automated hydroponic system

To verify the performance of the designed system, a parallel cultivation was performed comparing some parameters of the produce from the automated hydroponic system (controlled setup) and conventional hydroponic system (uncontrolled setup). Simultaneously, several laboratory experiments were also conducted to facilitate the investigations in assimilation manner of the lettuce plant. For the two setups (automated hydroponics and conventional hydroponics), two methods of analyses were done: (1) Laboratory chemical analysis or Nutrient Uptake Analysis and (2) virtual or physiological analysis. The two analyses provided information on potential response of lettuce to nutrient solution applied, on managing nutrient solution more efficiently and imminent diagnosis of suspected nutrient deficiency and toxicity. Each of the methods has operational advantages and limitations because of differences in reliability, costs, subjectivity, and technical skills required. However, as this activity would like to address the issues of nutrient uptake of hydroponic lettuce as affected by the pH and EC values, the emphasis was applicable and relevant.

3.1. Nutrient Uptake Analysis

This activity was done to determine the plant nutritional status and to find whether the plants were taking up the nutrient balance they require. This activity verifies how the factors of pH and EC values affect the nutrient uptake. Two setups were observed and analyzed. First is the automated hydroponic setup (controlled) where the pH and EC were being monitored and automatically controlled and second is conventional hydroponic setup (uncontrolled) where the pH and EC are being monitored but not controlled. These methods are based on the assumption that both systems would respond to the nutrient solution as initially applied to the hydroponic setups. The initial solutions have the same pH level, adjusted to near 6.0, all other conditions are the same, except for application of phosphoric acid or potassium hydroxide to the controlled pH as needed. Ample volumes (20 liters) for each setup were used to ensure that the EC of initial solutions were no stronger than EC 1.5 mS/cm.

The nutrient solution in the root zone of lettuce plants was monitored and analyzed by spectrophotometry and titrimetric methods. The amount of the concentration diminished from the remaining solution taken from the root zone of plants represents the actual amount of uptake by the plants. In a hydroponic system, the only nutrient usage is what the plant takes up. [11]

Table 1: Weekly Phosphate Uptake of Lettuce plants in Hydroponic System

Number of Weeks	Uptake/Concentration of phosphate (mg/L)		
	Controlled		Uncontrolled
		H_3PO_4 added	
0	0	0	0
1	132.8802	39.33606	93.54416
2	264.0004	170.45626	93.54416
3	342.6725	249.12838	93.54416

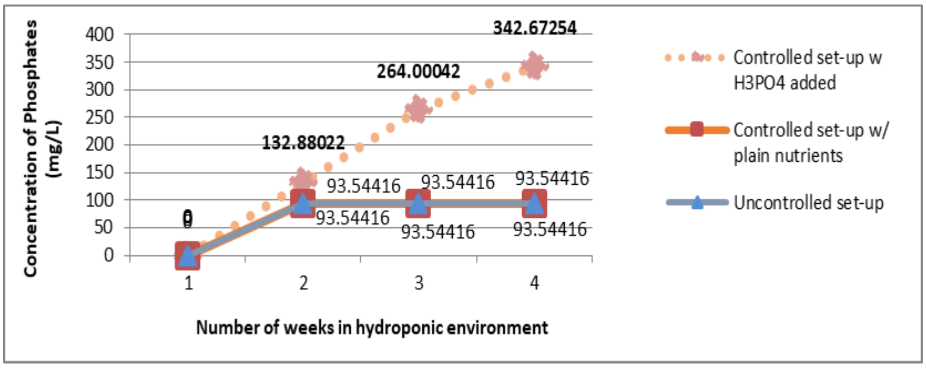


Figure 4: Phosphate Nutrient Uptake

As shown in figure 4, comparing the uptake of the two setups from the prepared nutrient solution, there was no significant difference between the two uptakes. Referring to table 1 and figure 4, both in the nutrient solutions of the controlled hydroponic setup (represented by the red line) and the uncontrolled hydroponic setup (represented by the blue line), fast assimilation of phosphate was noted on the first week. However, as the pH becomes higher to both setups, phosphoric acid was already being added to the controlled system to decrease the pH (represented by the dotted line). A total of 39.33606 mg/L of phosphoric acid was recorded on the first week, representing the reading of phosphate in the controlled system. A total of 170.45626 mg/L and 249.12838 mg/L of phosphoric acid were added during the second and third week, respectively. This acid was taken up by the plants in the form of ions, the same as the other elements of the nutrient solution.

Table 2: Weekly Nitrates Uptake of Lettuce plants in Hydroponic System

Number of Weeks	Uptake/ Concentration of Nitrates (mg/L)	
	Controlled	Uncontrolled
0	0	0
1	66.0201	62.13756
2	63.7849	57.29439
3	67.01368	65.53108

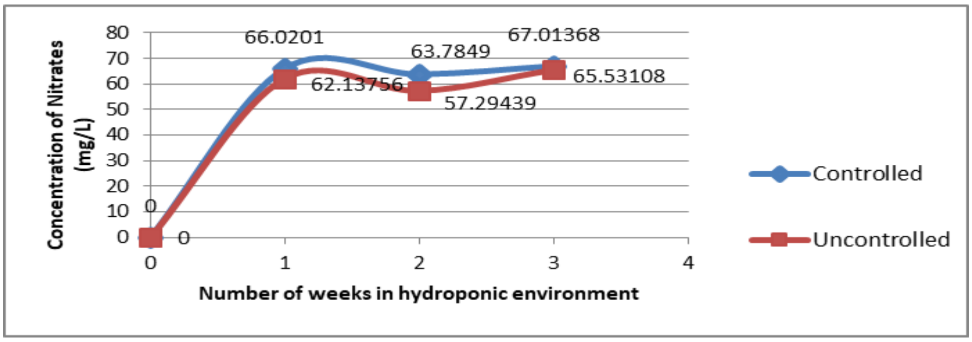


Figure 5: Nitrates Nutrient Uptake

In figure 5, there was uniformity with the trend line of the level of uptakes in both controlled and uncontrolled systems. However, assimilation of nitrogen in controlled system was higher, indicating a faster uptake. In effect, as indicated in Table 2, the decline in concentrations of nutrient solutions represents a rise in the graph of nitrates nutrient uptake. This significant decrease in concentration of elements was represented in the graph of nitrate nutrients uptake. The graph also shows that much of the nitrates were taken up during the first week of growth as may be verified in the proceeding section of physiological analysis. The formulation of nutrient solutions which included ammonium nitrogen (NH_4) have been useful in stabilizing the pH. Nitrogen metabolism is also being affected by Potassium (K), which plays a vital role and a required mineral element for plant growth [7,11].

Table 3: Weekly Ammonium Uptake of Lettuce plants in Hydroponic System

Number of Weeks	Uptake/Concentration of Ammonium (mg/L)	
	Controlled	Uncontrolled
0	0	0
1	0.014614	0.176219
2	0.2622	0.239783
3	0.26589	0.166855

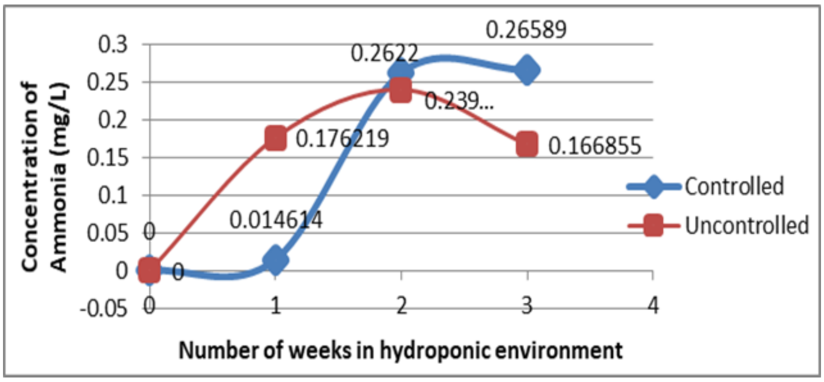


Figure 6: Ammonium Nutrient Uptake

The effect of ammonium and nitrate uptake is especially important in hydroponics, where the roots can affect the pH more quickly because their volume is relatively large compared with the volume of the medium. To prevent the pH from changing too rapidly, an appropriate ammonium/nitrate ratio and substrate temperature are essential, according to the plant's growth stage. Plant cells avoid ammonium toxicity by rapidly converting the ammonium generated from nitrate assimilation into amino acids. [7] The ammonium assimilations, shown in table 3 and graphically represented in figure 6 in the given nutrient concentration, had comparatively higher rate of uptake in the later part of growth than in the early part of growth.

Table 4: Weekly Calcium Uptake of Lettuce plants in Hydroponic System

Number of Weeks	Uptake/Concentration of Calcium (mg/L)	
	Controlled	Uncontrolled
0	0	0
1	88.8697313	88.79865
2	89.5910556	88.89326875
3	89.6027644	88.721775

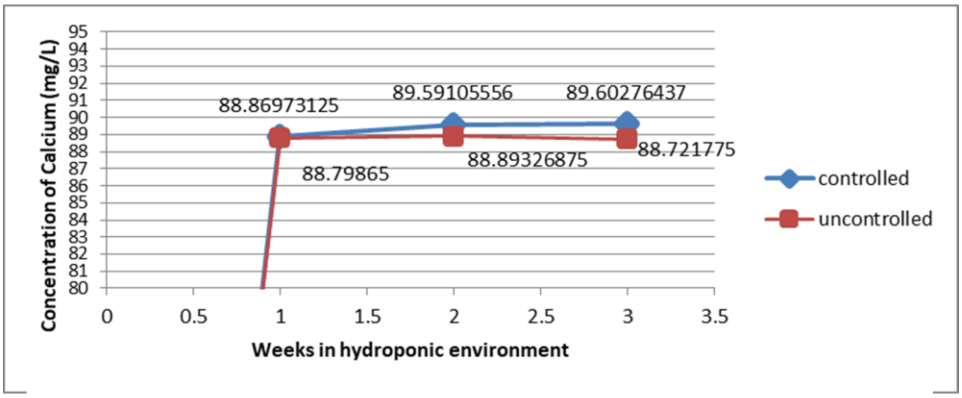


Figure 7: Calcium Nutrient Uptake

Calcium is much lower to compensate for their very fast uptake; in fact, uptake is so fast that the assimilation had almost taken up during the first week for both controlled systems, and the slightly lower uptake of the uncontrolled system, shown in table 4 and graphically in figure 7. The setup with uncontrolled pH shows an increased uptake of calcium, which may also due to proper level of pH during the first week, where the correct nutrient was taken up by the plant.

The summary of the developed system's controlling and monitoring of pH and EC is listed in table 5. The days when the pH was measured and significantly adjusted, the amount of acid that were added to the controlled nutrient solution and the resulting pH after adjustment were documented.

In both setups, the solutions were initially prepared with working strength, of EC at about 1.2mS/cm. This was done in the same sized tank of 20 liters each, which were filled with water and the nutrient compounds added. The solutions were pumped and carried back to the tank for some time in order to thoroughly mix the tank contents. When mixing of the two setups have been completed, the EC and pH of the solution were initially checked. The actual pH and EC of both setups were monitored, where the pH of the controlled setup was also recorded.

As shown in table 5, the pH of the uncontrolled setup, gets gradually stronger each time, and the EC has reach 2.52mS/cm before the harvest time, which implies that had the number of days become longer, the EC and the pH could have been progressively higher. A total of 1.5 ml of H_3PO_4 was added to the controlled hydroponic setup during the first week and the EC were monitored to be within the limit for both setups.

During the second week, a total of 5 ml of H_3PO_4 was added to the nutrient solution of the controlled setup. The EC of both setups were still below 2mS/cm. However, the hydroponic setup with uncontrolled pH already displayed chlorosis in their leaves. Towards the end of the second week, symptoms of leaf twisting and deferred growth had been apparent to the lettuce plants in the uncontrolled hydroponic setup.

During the third week, the EC of the hydroponic setup with uncontrolled pH was measured to be 2.52 mS/cm. The leaves were limped and began to display signs of necrosis. On the other hand, a total of 3 ml of H_3PO_4 was added to the nutrient solution of the controlled setup with the EC still below 2 mS/cm. In general, the controlled hydroponic setup showed better results in the overall development of the lettuce plants.

Table 5: Summary of the recorded monitoring of pH and EC of the two setups done in parallel cultivations of hydroponic systems. The automated hydroponic setup (controlled) where the pH and EC were being monitored and automatically controlled and second is conventional hydroponic setup (uncontrolled) where the pH and EC are being monitored but not controlled.

Day	Controlled setup				Uncontrolled setup		Average temperature
	measured pH	H_3PO_4 added	resulting pH	EC	measured pH	EC	
initial	5.98			1.23	5.98	1.20	18.54ºC
Day 2	6.20	1 ml	6.02	1.25	6.20	1.36	19.5ºC
Day 3	6.10			1.70	6.20	1.90	20.7ºC
Day 5	6.12	0.5 ml	6.04	1.54	6.33	1.92	18.0ºC
Day 12	6.33	2 ml	6.01	1.53	6.38	1.98	18.3ºC
Day 14	6.37	3 ml	6.03	1.52	6.59	1.89	18.1ºC
Day 17	6.30	2 ml	6.02	1.53	6.63	2.21	18.2ºC
Day 21	6.16	1 ml	6.01	1.98	6.68	2.52	19.25ºC

Interpretation of the nutrient uptake analysis suggests that a healthy plant will take up the nutrient balance it requires provided the solution around the roots contains nothing at a deficient or toxic level. If not, the solution within the system gets out of balance and continues to get further out of balance. By monitoring and controlling the pH level, the nutrient solution can be managed; thereby trends and adjusting gently to correct the pH level would avoid severe actions which could lead to failure of the system [12].

3.2. Physiological Analysis

Chemical analyses of the nutrient solution were used in conjunction of physiological analysis, or the foliage extrinsic appeal, to validate the nutrient uptake. Leaf discoloration (chlorosis, necrosis), leaf twisting, wilting and deferred growth are among the variety of symptoms evident that differentiate nutrient deficiency or toxicity of the two setups.

Physiological analysis was conducted to compare the yields of lettuce plants grown in parallel cultivations between the automated and conventional hydroponic setups, with regards to the color of the leaves, the average diameter of the leaves, the height of the plant, the diameter of the main stalk, and the average weight of one (1) plant head. The following table 6 summarizes the comparisons.

Table 6: Physiological Comparisons between the yields of automated and conventional hydroponic setups

Automated Hydroponic system	**Conventional Hydroponic system**
Color of leaves after 1 week in hydroponic environment	
	
At an early stage, automated hydroponic lettuce shows healthier leaves.	Lack of technical care caused chlorosis in conventional hydroponic setup.
The average diameter of leaves during harvest	

23 cm. (9.06 in.)

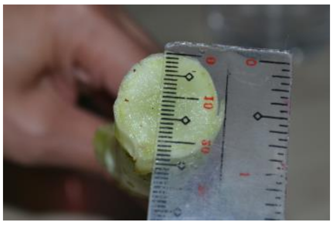
14 cm. (5.51 in.)

The average height of lettuce plants during harvest

43 cm. (16.93 in)

30.50 cm. (12 in)

The diameter of the main stalk of lettuce plants during harvest



2.3 cm (0.906 in)

	1.5 cm. (0.591 in)
The average weight of one head of hydroponic lettuce, including the roots	
	
	
500 grams	280 grams

4. Conclusion

Overall, the lettuce grown in automated system were healthier and taller than the lettuce from conventional hydroponic system. The differences between the values can be explained by the fact that the lettuce in conventional hydroponic setup suffered days of not adjusting to the correct level of pH and EC.

The conventional hydroponic crops usually take the plants to suffer stress. Normally, this occurs due to the delay in adjusting the concentration of nutrient solution, with either deficit or excess of macro and micro nutrients, whose absorption also depends on the pH and EC of the solution.

In the developed automated hydroponic system, the correction was almost immediate, which leads to a more balanced culture, creating healthier and more homogeneous leaves. It was unnecessary to do the manual work of collecting and correction, based on the gathered small aliquots withdrawn from the nutrient solution, made in laboratory, with later corrections in the nutrient solution tank. The correction was made instantly through the automated system integrated to the hydroponic setup. The system allows the producer to have better control over the parameters that influence plant growth by continuous monitoring of data, allowing an appropriate development, leading to reduce of the time spending and manpower, with precocity of harvest, higher productivity and best quality. This was attested by the comparison of two crops done in parallel using the developed automated hydroponic system and the conventional hydroponic system taken as reference of quality.

By implementing the soilless cultivation system, the researchers yielded a better quality of agricultural products, which is expected to meet the consumer preferences. One of the concerns in determining the soilless cultivation system is an understanding of its benefits, which is a flexible growing method that lets the grower have full control over the growing environment, including the active root zone. Since the pH of the solution affects the absorption of nutrients and the electrical conductivity affects solubility of the nutrient compound to the water, pre-established range allows optimum nutrient maintenance for the growth of lettuce plants.

References

[1] Gabriel, A.G. Transparency and Accountability in Local Government: Levels of Commitment of Municipal. Asia Pacific Journal of Public Administration 39(3), July 2017, pp.217-223

[2] Zaldy Commanda. “Baguio posts 1.7-million tourist arrivals in 2017.” Manila Bulletin, March 5, 2018.

[3] PSA, 2016. “Highlights of the 2010 Census-Based Population Projections, Reference Number: 2016-090,” August 9, 2016.

[4] Matuschke, I. “Rapid Urbanization and Food Security: Using food density maps to identify future food security hotspots.” International Association of Agricultural Economists. 2009 Conference, Beijing, China. August 16-22, 2009.

[5] Lagomarsino, V., (2019, September 26). Hydroponics: The power of water to grow food, SITN, [On-line]. Special Edition: Water. Available: https://sitn.hms.harvard.edu/flash/2019/hydroponics-the-power-of-water-to-grow-food/. [September 2020].

[6] Robbins, O., (2021, February 24). Hydroponics: How It Works, Benefits and Downsides, & How to Get Started, Food Revolution Network, [On-line], Available: https://foodrevolution.org/blog/hydroponics/. [2021].

[7] Lincoln Taiz and Eduardo Zeiger, “Chapter 5: Mineral Nutrition.” Plant Physiology, 3rd ed., Sinauer Associates, Aug 30 2002, pp. 67-86; Epstein, E. (1972) Mineral Nutrition of Plants: Principles and Perspectives. Wiley, New York.

[8] Lincoln Taiz and Eduardo Zeiger, “Chapter 12: Assimilation of Mineral Nutrients.” Plant Physiology, 3rd ed., Sinauer Associates, Aug 30 2002, pp. 259-282;

[9] Junior,C.H., Rezende, R., Freitas, P.S.L., Gonçalves, A.C.A., Frizzone, J.A., 2008. Ciênciae Agrotecnologia 4, pp. 1142–1147.

[10] D.S. Domingues, H.W. Takahashi, C.A.P. Camara, S.L. Nixdorf, (2012). Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production, Computers and Electronics in Agriculture 84, [On-line] Available: www.elsevier.com. [September 2019]

[11] Agung Putra P., Henry Yuliando, "Soilless Culture System to Support Water Use Efficiency and Product Quality: a Review," The 2014 International Conference on Agro-industry (ICoA): Competitive and sustainable Agro-industry for Human Welfare, 2014.

[12] Christie, Emerson, "Water and Nutrient Reuse within Closed Hydroponic Systems" (2014). Electronic Theses and Dissertations. 1096. Available: https://digitalcommons.georgiasouthern.edu/etd. pp. 3, 16-17.