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DESIGN AND CONSTRUCTION OF A HOME HYDROPONIC SYSTEM FOR LETTUCE PRODUCTION

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TUTOR APPROVAL

I, Moya Cajas Marcelo, certify that I know the author of this thesis entitled "Design and Construction of a Home Hydroponic System for Lettuce Production", Lozano Tufiño Fernando David, being the sole responsible for both its originality and authenticity, as well as its content

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1. Topic

Design and Construction of a Home Hydroponic System for Lettuce Production.

2. Objectives

2.1. General Objective

Design and implement a hydroponic cultivation system for lettuce harvesting.

2.2. Specific Objectives

- Design and build the hydroponic cultivation system.
- Implement a real-time monitoring and control system to generate a database of pH, flow, and electrical conductivity of the nutrient solution, temperature, lighting, and environmental humidity.
- Perform a comparative analysis of the growth of hydroponic lettuce planted simultaneously with traditional soil cultivation.

3. Problem

Ecuador faces various challenges in terms of food security, as indicated by the Food and Agriculture Organization (FAO) of the United Nations. According to FAO data, approximately 22 percent of the Ecuadorian population lives in poverty and faces difficulties in accessing adequate and nutritious food. Additionally, it is estimated that around 6.4 percent of the population suffers from severe food insecurity, meaning they do not have regular access to enough nutritious food to lead an active and healthy life. The dependency on food imports is also a significant problem in Ecuador. According to the FAO, the country imports a large quantity of staple foods such as wheat, rice, and corn, which increases its vulnerability to fluctuations in international prices and economic instability. This situation is exacerbated by the unequal distribution of land and agricultural resources, which has led to the concentration of food production in certain regions and has left rural and urban communities marginalized with limited access to a variety of fresh and nutritious products. In the face of these challenges, promoting innovative and sustainable agricultural practices, such as hydroponics, can be a viable solution to improve food security in Ecuador. The increasing poverty and uncertainty faced by a large part of the Ecuadorian population in these times, due to the country's instability, is reflected in the rising prices of agricultural inputs and basic food items, as well as the reduction of biodiversity due to ongoing deforestation and soil pollution used in agriculture.

The FAO, in collaboration with the Ministries of Agriculture, has implemented the Global Campaign Against Hunger (GCAH) in several countries in Latin America and the Caribbean, including agricultural development programs. Among the proposed technologies is the adoption of hydroponic cultivation, aiming to increase productivity and utilize infertile land, as well as promoting cultivation in urban areas.

Hydroponics is highlighted by the FAO as an efficient and adaptable alternative for food cultivation in urban and peri-urban spaces, using less water and space compared to traditional soil cultivation methods. This project focuses specifically on lettuce cultivation, given its rapid growth cycle, high nutrient content, and constant demand in the domestic market. Additionally, it provides greater access to vegetable consumption for the population since in Ecuador, the per capita consumption is 30 kg/person per year, while the Latin American average is 60 kg. [1]

Promoting hydroponic cultivation projects at the household and community levels can significantly contribute to increasing the availability of fresh and healthy foods, reducing dependency on vegetable imports, and strengthening the food autonomy of Ecuadorian communities, especially in cities like Quito where urban agriculture is practiced by 1.48 percent of the population and is considered a sustainable food source for the city. It generates annually 1,350 thousand kilograms of food, 57 percent for self-consumption, and 43 percent for surplus sales. [1]

Urban agriculture can also become a livelihood, generating enterprises initially focused on subsistence with the potential for scalability and replication. For this reason, the municipality of Quito is focused on implementing organic gardens with the community to revive food self-production within Quito's food system and achieve greater sustainability. A hydroponic cultivation system would allow increasing the production of such gardens and could be implemented in urban environments, thereby providing greater food sovereignty. [1] In the city of Quito, Ecuador, growing urbanization and population density pose significant challenges in terms of food security, access to fresh foods, and environmental sustainability. In this context, hydroponic cultivation emerges as a potential solution to address these issues by enabling the production of food in urban settings efficiently and sustainably.

On the other hand, one of the disadvantages of a hydroponic system is maintaining nutrient solution levels, watering times, and lighting at an optimal state for the plant. In a domestic system, this would typically be done manually, consuming a significant amount of the user's time. Therefore, there is a proposal to monitor and control all these factors automatically.

4. Characteristics of Hydroponic Lettuce

Hydroponic lettuce exhibits several distinct characteristics that make it an attractive option for cultivation in urban environments like Quito, Ecuador:

- Rapid Growth: Due to the precise control of nutrient delivery and environmental conditions, hydroponic lettuce tends to grow faster than its soil-grown counterparts. This rapid growth allows for quicker harvests and higher yields, meeting the demands of a fast-paced urban market [2].

- High Nutritional Value: Hydroponic cultivation ensures that lettuce plants receive optimal levels of essential nutrients, resulting in higher nutritional content compared to traditionally grown lettuce. This makes hydroponic lettuce a valuable source of vitamins, minerals, and antioxidants for consumers [3].

- Consistent Quality: With hydroponic systems, growers can maintain consistent environmental conditions, leading to uniform growth and high-quality lettuce heads.

Consistency in size, texture, and taste is essential for meeting consumer expectations and building trust in the product [4].

- Water Efficiency: Hydroponic systems recycle water, minimizing water usage and waste. Compared to traditional soil-based cultivation, hydroponic lettuce requires significantly less water, making it an environmentally sustainable option, particularly in regions prone to water scarcity like Quito.
- Space Optimization: Hydroponic lettuce can be cultivated vertically or in compact systems, maximizing space utilization in urban environments. This allows growers to produce a high volume of lettuce in limited spaces, contributing to food security and resource efficiency in densely populated areas [5].
- Year-Round Cultivation: Hydroponic systems offer greater control over growing conditions, enabling year-round cultivation of lettuce regardless of external environmental factors such as seasonality or climate variations. This ensures a consistent supply of fresh lettuce to the market throughout the year, reducing dependence on seasonal fluctuations. [6]

The characteristics of hydroponic lettuce make it a highly desirable crop for urban agriculture initiatives in Quito, Ecuador, and similar settings. Its rapid growth, nutritional value, consistent quality, water efficiency, space optimization, and year-round cultivation capability position hydroponic lettuce as a sustainable solution to address food security challenges and meet the dietary needs of urban populations. [6]

4.1. Lettuce and its Hydroponic Cultivation in Quito

Lettuce (Lactuca sativa) is one of the most popular and widely consumed crops worldwide due to its culinary versatility, low calorie content, and high nutritional value. In the context of Quito, Ecuador, lettuce is a vital component of the local diet, and its demand in the national market is constant due to its fundamental role in salads, snacks, and typical dishes.

The traditional soil-based production of lettuce in Quito faces several challenges, such as limited availability of fertile land, competition for urban space, and issues related to soil-borne diseases. In this regard, hydroponics offers an innovative and efficient solution for cultivating lettuce in urban environments like Quito. [7]

Hydroponic lettuce cultivation involves growing plants in nutrient solutions rather than soil, which eliminates many of the challenges associated with traditional production. By not depending on soil, hydroponics allows precise control of the nutrients that plants receive, resulting in faster and healthier growth. Additionally, by using water recirculation systems, waste is minimized, and water consumption is reduced compared to conventional agriculture.

In the specific case of Quito, where the availability of agricultural land is limited, and urban pressure is high, hydroponic lettuce cultivation offers a sustainable solution to supply the local demand for this popular crop. Furthermore, by growing lettuce in controlled environments, issues associated with soil diseases and pesticides can be avoided, resulting in safer and higher-quality products for consumers. [7]

In summary, the relationship between lettuce and hydroponics in Quito, Ecuador, represents a unique opportunity to improve food security, promote urban agriculture, and offer fresh and healthy products to the local community. The implementation of hydroponic systems for lettuce cultivation not only provides economic and environmental benefits but also contributes to the resilience and food autonomy of the city.

4.2. Varieties of Lettuce Harvested in Ecuador

Ecuador boasts a variety of lettuces grown in different regions of the country, each with unique characteristics in terms of flavor, texture, resistance, and adaptability to specific growing conditions. When evaluating lettuce varieties for hydroponic cultivation in Quito, it is important to consider their attributes that favor optimal growth in hydroponic systems. Below are some of the most common varieties and their characteristics:

- Butterhead Lettuce: This variety is characterized by its soft, tender, and slightly sweet leaves. It is a popular choice in the market due to its excellent taste and texture. Butterhead lettuce is known for its heat tolerance and ability to thrive in humid conditions, making it suitable for hydroponic cultivation in tropical climates like that of Quito. [8]

Figure 1. Butterhead Lettuce.

- Romaine Lettuce: Romaine lettuce is recognized for its elongated, crunchy leaves that form tight heads. It has a slightly bitter taste and is especially rich in nutrients such as vitamin A and iron. This variety is heat and drought-resistant, making it suitable for hydroponic cultivation in variable environmental conditions. [8]

Figure 2. Romaine Lettuce.

- Iceberg Lettuce: Iceberg lettuce is known for its rounded shape and crisp texture. It has a mild flavor and is a popular choice for salads and sandwiches. Although traditionally grown in soil, iceberg lettuce can adapt to hydroponic cultivation by properly providing nutrients and water.

- Oakleaf Lettuce: This variety is distinguished by its lobed and wavy leaves that resemble oak leaves. It has a mild flavor and tender texture. Oakleaf lettuce is known for its rapid growth and ability to regenerate after harvest, making it ideal for short-cycle hydroponic crops. [8]

Figure 3. Iceberg Lettuce.

Figure 4. Oakleaf Lettuce.

Given the nature of hydroponic cultivation and the climatic conditions of Quito, Butterhead lettuce emerges as the most favorable option. Its heat tolerance, leaf softness, and taste make it suitable for cultivation in hydroponic systems. Additionally, its ability to thrive in humid conditions favors its adaptation to controlled hydroponic growing environments. Butterhead lettuce offers a combination of attributes that make it ideal for meeting the demand of the local market and providing fresh, high-quality products to the Quito community.

4.3. Stages of Lettuce Growth

Hydroponic cultivation of lettuce involves several distinct stages of growth, each crucial for the development of healthy and productive plants. Understanding these stages is essential for successful cultivation and optimal yield. Below are the typical stages of lettuce growth in a hydroponic cultivation cycle:

1. Seed Germination: The first stage of the lettuce cultivation cycle is seed germination. Seeds are sown in a germination medium such as rockwool or perlite, where they are provided with moisture and appropriate environmental conditions for sprouting. Germination usually takes place within a few days, depending on the variety and environmental conditions [9].

2. Seedling Stage: Once seeds have germinated, they develop into seedlings characterized by the emergence of cotyledon leaves and the development of the first true leaves. At this stage, seedlings are delicate and require careful monitoring of moisture levels, temperature, and nutrient supply to ensure healthy growth. Seedlings are typically kept under low-intensity light to prevent stretching and encourage sturdy growth [10].

3. Vegetative Growth: During the vegetative growth stage, lettuce plants develop foliage and establish a strong root system. The vegetative stage is characterized by rapid leaf expansion and the production of new leaves. It is crucial to provide optimal growing conditions, including sufficient light, nutrients, and oxygenation of the nutrient solution, to support vigorous vegetative growth.

4. Pre-flowering Stage: As lettuce plants mature, they enter the pre-flowering stage, marked by the formation of a central stem and the initiation of flower buds. At this stage, it is essential to monitor plant health and nutrient levels closely to prevent premature bolting, which can negatively impact yield and quality. Maintaining consistent environmental conditions and proper nutrient balance is crucial during this critical phase [11].

5. Harvest Stage: The final stage of the hydroponic lettuce cultivation cycle is the harvest stage, where mature lettuce heads are ready for harvest. The timing of harvest depends on the desired maturity level and market preferences. Lettuce heads are typically harvested by cutting them at the base of the plant, leaving the root system intact for potential regrowth in continuous production systems.

By understanding and managing each stage of lettuce growth in a hydroponic cultivation cycle, growers can optimize yield, quality, and resource efficiency, ultimately contributing to the success and sustainability of their hydroponic operations.

4.4. Hydroponic Lettuce Cultivation Process

Hydroponic lettuce cultivation is an efficient and sustainable method that allows for the production of high-quality green leafy vegetables in controlled environments without the need for soil. Below is an outline of the hydroponic lettuce cultivation process:

1. Preparation of the Hydroponic System: The process begins with the preparation of the hydroponic system, which can vary depending on the type of system used, such as the Nutrient Film Technique (NFT), Deep Water Culture (DWC), or vertical systems. Channels, trays, or containers suitable for housing the plants and nutrient solution are set up. [12]

2. Seed Germination: Lettuce seeds are germinated in a sterile germination medium, such as rock wool or perlite, until seedlings emerge. During this stage, maintaining high humidity and a constant temperature is crucial to encourage germination and seedling development. [12]

3. Transplanting Seedlings: Once the seedlings reach an appropriate size, they are transplanted into the hydroponic system. They are placed in the previously prepared channels, trays, or containers, ensuring that the roots are fully submerged in the nutrient solution.

4. Vegetative Growth: During the vegetative phase, lettuce plants develop their foliage and root system. A balanced nutrient solution containing the necessary macro and micronutrients for healthy growth is supplied. It is important to maintain proper pH and electrical conductivity (EC) in the nutrient solution to avoid nutritional deficiencies or toxicities. [12]

5. Control and Maintenance: Environmental conditions and plant health are regularly monitored, with adjustments made to lighting, ventilation, and nutrient solution as needed. Periodic measurements of pH and EC are taken to ensure optimal nutrient balance in the system.

6. Harvesting: Once the plants reach maturity and the desired size, they are ready for harvest. Depending on the variety and market preferences, lettuce heads are carefully cut at the base of the plant. In some hydroponic systems, such as NFT, plants can be harvested continuously, allowing for multiple growing cycles. [12]

The hydroponic lettuce cultivation process is highly controlled and efficient, enabling the production of high-quality lettuce with minimal resources and space. By optimizing growing conditions and hydroponic system management, one can achieve consistent and healthy lettuce harvests year-round.

5. The Nutrient Film Technique (NFT) in Hydroponic Cultivation

The Nutrient Film Technique (NFT) is a widely used hydroponic cultivation method known for its simplicity, efficiency, and suitability for growing leafy greens like lettuce. In the NFT system, plants are grown in a shallow, sloping channel or gutter through which a thin film of nutrient-rich water continuously flows, bathing the roots in a constant supply of oxygenated nutrient solution. [13]

5.1. Characteristics of the NFT System

1. Continuous Flow: The NFT system operates on a continuous flow of nutrient solution, which is pumped from a reservoir to the upper end of the channel and allowed to flow gently over the roots of the plants before returning to the reservoir. This constant circulation ensures that roots remain adequately oxygenated and supplied with nutrients.

2. Shallow Channels: NFT channels are typically shallow, with a slight slope to facilitate the flow of nutrient solution. The shallow depth allows for efficient oxygenation of the roots while minimizing the risk of waterlogging or root suffocation.

3. Minimal Growing Medium: Unlike other hydroponic systems that require substantial amounts of growing medium, the NFT system utilizes minimal to none growing medium. This reduces the risk of disease, simplifies maintenance, and minimizes waste. [13]

4. Root Zone Temperature Control: The thin film of nutrient solution flowing through the NFT channels helps regulate the temperature of the root zone, preventing overheating and promoting optimal root growth and nutrient uptake. [13]

5.2. Advantages of the NFT System

1. Water and Nutrient Efficiency: The NFT system is highly water-efficient, as it recirculates nutrient solution continuously, minimizing water consumption and nutrient waste. This makes it an environmentally sustainable option, particularly in regions with water scarcity. [14]

2. Space Optimization: NFT channels can be arranged vertically or horizontally, maximizing the use of limited space in urban environments or greenhouse settings. This allows for high-density planting and increased crop yields per unit area.

3. Ease of Maintenance: The NFT system is relatively low-maintenance compared to some other hydroponic systems. With no soil to till or replace, and a simple recirculating nutrient solution, routine maintenance tasks are streamlined, saving time and labor. [14]

4. Optimal Oxygenation: The continuous flow of nutrient solution in the NFT system ensures that roots receive ample oxygen, promoting healthy root development and minimizing the risk of root diseases such as root rot.

5. High Yield Potential: Due to its efficient use of resources and optimal growing conditions, the NFT system has the potential to yield high-quality crops with accelerated growth rates and consistent harvests throughout the year. [14]

In summary, the Nutrient Film Technique (NFT) offers numerous advantages for hydroponic lettuce cultivation, including water and nutrient efficiency, space optimization, ease of maintenance, optimal oxygenation of roots, and high yield potential. Its simplicity and effectiveness make it the selected growth system for this project.

5.3. Components of an NFT System

1. Growing Channel: This is where the plants are placed. The channels are slightly inclined to allow the nutrient solution to flow through them is typically a structure made of plastic or PVC. Channels should be wide and deep enough to accommodate plant roots but not so deep as to accumulate large amounts of solution.

2. Nutrient Solution: This is the “food” for the plants. It contains all the essential nutrients that plants need to grow, it consists of a balanced mixture of water and nutrients. It should have adequate capacity to hold enough solution for the system and be equipped with a pH and EC measurement and adjustment system to maintain optimal conditions [15].

3. Water Pump: This is used to pump the nutrient solution from the reservoir to the grow channels, where it is evenly distributed along the surface to form the nutrient film. A return system ensures that excess solution returns to the reservoir for reuse.

4. Nutrient Reservoir: This stores the nutrient solution is pumped through the system, which consists of a balanced mixture of water and nutrients. It should have adequate capacity to hold enough solution for the system and be equipped with a pH and EC measurement and adjustment system to maintain optimal conditions [16].

5.4. Optimal Characteristics for Successful Cultivation

For successful cultivation using the NFT system, the following optimal characteristics should be considered:

- Continuous and Uniform Flow: The nutrient solution should flow continuously and evenly along the growing channel to ensure that all roots receive nutrients and oxygen adequately.

- Precise pH and EC Control: Maintaining stable pH and electrical conductivity (EC), optimal pH for most lettuce plants is between 5.5 and 6.5, in the nutrient solution is essential to ensure optimal nutrient uptake by the plants.

- Water and Ambient Temperature: Both water and ambient temperature should be maintained within optimal ranges for plant growth and to avoid issues such as algae development or pathogen proliferation.

- Proper Lighting: Adequate lighting should be provided to stimulate vegetative growth and photosynthesis in plants, especially in indoor environments or with limited light.

- Efficient Drainage: The NFT system should allow for efficient drainage of excess nutrient solution to prevent stagnation and accumulation of salts or nutrients.

By meeting these characteristics and components, an NFT system can provide an optimal environment for hydroponic lettuce cultivation, maximizing plant growth, health, and yield.

5.5. Nutrient Solutions for Hydroponic Lettuce Cultivation

Selecting and properly managing nutrient solutions ensures optimal growth and high-quality produce. This section details commonly used nutrient solutions and selects the most suitable one for the specific conditions of Quito.

Components of Nutrient Solutions

Hydroponic nutrient solutions must contain the essential macro and micronutrients that plants need. Macronutrients include nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). Micronutrients, though required in smaller amounts, are equally important and include iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), and boron (B).

Common Nutrient Solutions

1. Hoagland Solution: This is one of the most widely used solutions in hydroponics due to its balanced and comprehensive composition. It contains:

- Calcium nitrate ($Ca(NO_3)_2$)
- Potassium nitrate (KNO_3)
- Monopotassium phosphate (KH_2PO_4)
- Magnesium sulfate ($MgSO_4$)
- Boric acid (H_3BO_3)
- Manganese sulfate ($MnSO_4$)
- Zinc sulfate ($ZnSO_4$)
- Copper sulfate ($CuSO_4$)
- Ammonium molybdate ($(NH_4)_6Mo_7O_{24}$)
- Iron EDTA (Fe-EDTA)

2. Steiner Solution: Known for its versatility and effectiveness under different growing conditions. Its typical composition is:
   - Nitrogen (N): 210 ppm
   - Phosphorus (P): 31 ppm
   - Potassium (K): 235 ppm
   - Calcium (Ca): 200 ppm
   - Magnesium (Mg): 48 ppm
   - Sulfur (S): 64 ppm
3. University of California Solution: Specifically formulated for leafy greens such as lettuce. It contains:
   - Calcium nitrate ($Ca(NO_3)_2$)
   - Potassium nitrate (KNO_3)
   - Monopotassium phosphate (KH_2PO_4)
   - Magnesium
   - Sodium molybdate (Na_2MoO_4)
   - Copper sulfate ($CuSO_4$)

6. Definition of Specific Design

In this section, the system will be dimensioned taking into account the functional and non-functional requirements, as well as the constraints to be considered.

6.1. Design and implementation of the nutrient distribution system:

The available space within the domestic greenhouse, measuring 3 meters in length and 1 meter in width, must be taken into consideration, restricting the design within these dimensions. A traditional planting method will be employed with identical measures to compare the production of both planting methods. With the defined workspace, the following steps are to be followed for defining the system of pipes, pump, and collection tanks.

1. Analysis of requirements and system design:
   - Identify specific requirements of the hydroponic system, such as the quantity of lettuce to be grown, space availability, water and nutrient supply, and environmental conditions.
   - Determine the appropriate location for the system, considering factors like natural or artificial light availability, access to water and electricity, and ease of maintenance.
   - Design the piping system, including channel layout, pump and collection tank placement, and distribution of water and nutrient supply lines.
2. Selection of components and materials:
   - Select suitable materials for the pipes, considering factors like corrosion resistance, durability, and ease of cleaning.
   - Choose a pump capable of providing a constant and uniform water flow through the channels, considering the required lift height and flow rate.
   - Select collection tanks large enough to contain the nutrient solution.
3. System installation:

- Install the pipes according to the established design, ensuring they are properly leveled and secured to prevent leaks or movement.
- Position the pump for easy access for cleaning and maintenance, and connect it securely to the electrical supply.
- Install the collection tanks in a convenient location and connect them to the piping system, ensuring they are properly sealed and leveled.

6.2. Implementation of the Nutrient Solution Monitoring and Control System

1. Selection of components:
    - Select the necessary sensors to measure electrical conductivity (to determine nutrient levels within the system), water pH, and ambient temperature.
    - Choose the controller required to gather data from the sensors and store it in a database.
    - Select the solenoid valves that will be used for the nutrient solution dosing system.
2. Instalation:
    - Install the sensors, controller, and solenoid valves of the system.
3. Programing:
    - Activate and deactivate the solenoid valves as needed to maintain pH and EC levels within the required values.

6.3. Requirements and Constraints

This section details the necessary requirements for the system and its proper functioning to achieve the established objectives.

Functional Requirements:

- Measure the electrical conductivity of the nutrient solution.
- Measure the pH of the nutrient solution.

- Record the temperature.
- Store the data recorded by the sensors.
- Maintain the pH level and electrical conductivity within established parameters.
- Maintain the necessary flow for nutrient distribution.
- Turn on and off the solenoid valves to adjust the nutrient solution.

Non-functional Requirements:

- Use a voltage of 110V.
- Data acquisition frequency of at least one minute from the sensors.
- Capacity to deliver the necessary volume for the nutrient distribution network (defined by the system volume).

Constraints:

- Distance of 20cm between each lettuce plant.
- Greenhouse space of 3 square meters.
- Water pH must be between 5.5 and 6.5 for proper lettuce growth. [17].
- Water electrical conductivity must be between 800 and 1400 PPM. [18].

7. Mechatronic System Diagram

The system is based on the distribution of nutrients to the plants. Starting with this, we have the nutrient distribution network, which is composed of pipes, irrigation channels, and the system's reservoir tank. This network is supplied with nutrients from the reservoir tank where the water pump is located. This pump is activated through a driver controlled by the processing unit.

The processing unit activates the pump only when the values received from the sensors are within the correct parameters; otherwise, the solenoid valve is activated to adjust the nutrient mix.

The diagram shown in figure 5 illustrates how the essential foundation of the system is to distribute the necessary nutrients to the plants. In this case, the distribution network consists of pipes and reservoir tanks that house the nutrients and water of the system. The solenoid valves regulate the concentration of nutrients and the pH level of the

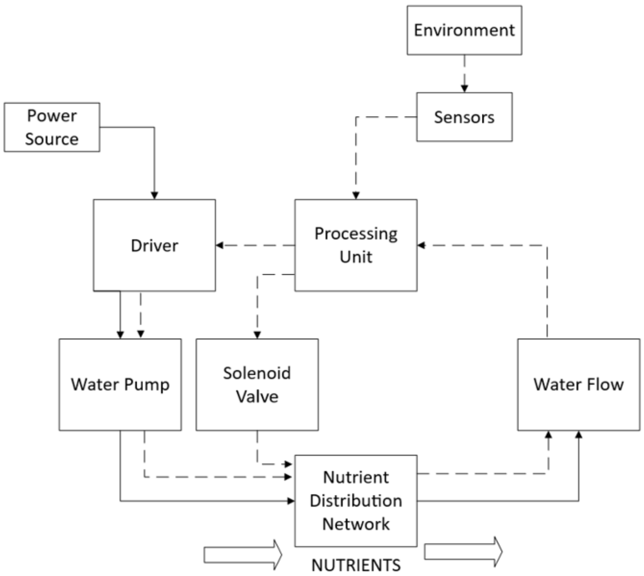

Figure 5. Mechatronic diagram

nutrient solution. This regulation is governed by the controller, which receives pH and electrical conductivity values from sensors placed inside the reservoir tank. Once the solution is in optimal conditions, the pump is turned on for nutrient distribution.

7.1. Programing and flowchart:

- Activate and deactivate the solenoid valves as needed to maintain PH and EC levels within the required values. The valves and the pump are activated according to the conditions of the flowchart shown in figure. 6 As observed, the process begins by measuring the current PH and EC values. If these values are within the optimal parameters for the plants, the pump is activated, starting the irrigation cycle. Otherwise, the solenoid valve opens to adjust the mixture until it falls within the established parameters. Once the mixture is within these parameters, the irrigation cycle begins. After the cycle is completed, the data collected by the sensors is saved.

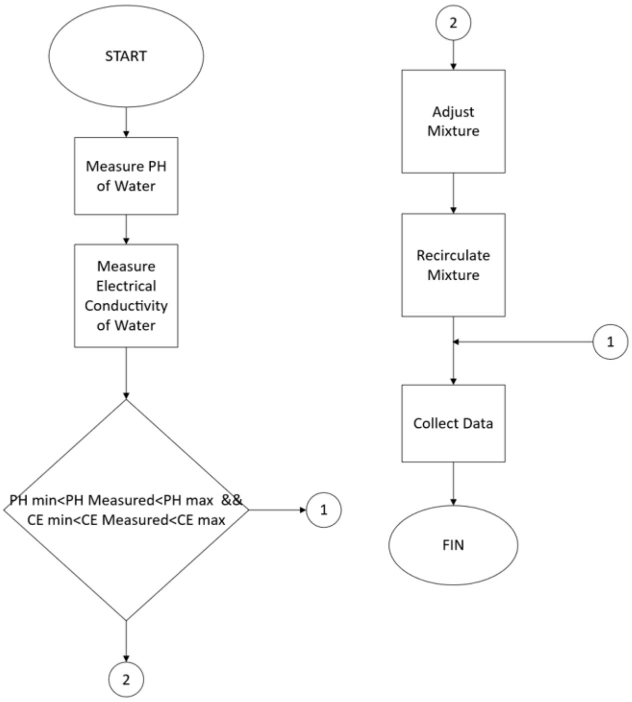

Figure 6. Flowchart

8. Construction process

Considering the system requirements and constraints, the construction process of the piping system began with the purchase of the materials, which included 3 PVC pipes, each 3 inches in diameter and 3 meters long. These had to be cut to 2.50 meters because the total space for the system is 3 meters, and a little extra space is needed for the reservoir tank and other components. To prepare the pipes, holes were drilled through which the nutrient distribution 1/8-inch hoses were connected with a PVC sealant, as shown in figure 7.

Holes were drilled to place the plants with a diameter of 2 inches and at a distance of

Figure 7. Nutrient Distribution Conection

25 cm between each plant to ensure they have the necessary space for proper growth.

The drilled pipes are shown in figure 8.

The irrigation piping system, which connects to the water pump placed in the reser-

Figure 8. Drilled Pipes

voir tank, was built with half-inch pipes, measuring 2.5 meters in length and 1 meter in width. This system transports the nutrient solution from the reservoir tank, located at the end of the plant housing pipes, to the top of the pipes as shown in figure 9.

The construction proceeded using PVC pipes along with a 55-liter tank that provides sufficient nutrients for the plants. The supports for the pipes were constructed from wood with a height of 1.20 meters to provide comfortable access to the plants. Two of these supports were built to place at each end of the pipes, thus keeping them stable. Additionally, they were treated with a water-resistant coating to prevent damage that could be caused by water. The constructed supports are shown in figure 10.

8.1. Plant Conditioning Process

Before placing the plants into the hydroponic system, they must undergo an adaptation process to water. For this, seeds are planted in sponges placed in a tray covered with water and nutrient solution. After germination, the plants are kept in these trays until they reach an adequate size to be placed into the system. The plants ready to be placed in the system can be seen in figure 11 Once the plants are ready to

Figure 9. Irrigation Piping System

Figure 10. System Supports

be transferred to the system, they are removed from the preparation trays. It can be observed that the roots have grown into the sponge in figure 12 , which is kept during the transfer process. The plant is then placed into each of the holes in the PVC pipes, where it will remain for the rest of its growth process until it is ready for harvest.

8.2. Control System Installation

According to the system requirements, the necessary sensors were selected to measure pH, EC, and temperature variables. For temperature measurement, the DS18B20

Figure 11. Adaptation Process

Figure 12. Adapted Plant

sensor was chosen, which features a one-wire communication protocol and an internal 12-bit circuit for sampling the information, which is then sent through the mentioned protocol. Additionally, the device has a measurement range of -55℃ to 125℃ [19], which covers the necessary temperature range. Furthermore, the device is encapsulated, allowing it to be submerged in water. To measure PH, the PH-E201-C sensor is used, this device is one of the most commercially available, making it accessible in the domestic market. It features a BNC connector and an electronic board with an I2C communication interface to transmit the information from the measurements [20]. To

Figure 13. DS18B20 Sensor

Figure 14. PH-E201-C Sensor

measure EC the ESP32 TDS sensor is used. This sensor is designed to measure the Total Dissolved Solids (TDS) in water The sensor includes a probe that measures the electrical conductivity of the water, translating it into TDS values. It can measure frem 0 PPM to 2000 PPM wich cover the necessary range [21], is also a sensor commercially available in the local market thus making it the selected sensor for this application. To

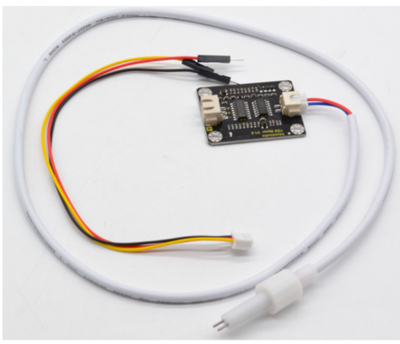

Figure 15. TDS Sensor

control the system, an Arduino Mega is used due to its availability. A custom shield-style circuit board was developed as seen in figure 16 with all the necessary components and installed along with the sensors. After installing the sensors, a database

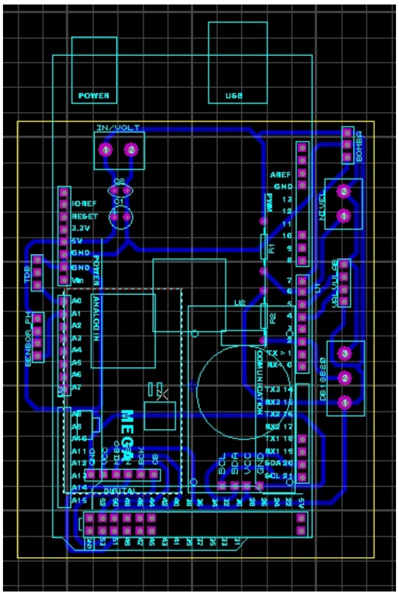

Figure 16. Circuit Board

was created to collect pH, electrical conductivity, and temperature information. This information is automatically saved on an SD card for later analysis.

9. Data analysis

After installing the sensors, a database was created to collect PH, electrical conductivity, and temperature information. This information is automatically saved on an SD card for later analysis.

9.1. Data per day

The data collected by the sensors is stored every 10 minutes to ensure a substantial amount of data, allowing for averaging of hourly and daily data points. This approach ensures better data quality. The Table 1 shows the data collected on June 11th, it was generated averaging the data taken per minute to get the data per every hour. This same process was carried out with the data collected from June 12th to June 21st to analyze the recorded data for this period. The following tables: 2, 3 and 4 ,reflect the data from june 15th, june 18th and june 20th. The data from this tables is analyzed to recognise the relations between this variables. Starting from June 15th, data was collected from 4:00 PM to 3:00 PM the following day, thus completing the 24-hour information for each day. Figure 17 shows the graph of temperature evolution over

Table 1. Data of june 11th.

Time	PH	Temperature	PPM
16:00	6.84	24.14	1227.76
17:00	6.57	23.24	1056.16
18:00	6.85	22.13	871.57
19:00	6.77	21.40	785.33
20:00	6.83	20.58	727.64
21:00	6.59	19.92	902.91
22:00	6.65	19.32	1288.65
23:00	6.22	18.68	1283.89
24:00	6.05	18.20	1282.49
1:00	6.06	17.50	1276.97
2:00	6.09	17.11	1276.09
3:00	6.11	16.48	1272.89
4:00	6.08	16.16	1270.97
5:00	6.07	15.50	1272.38
6:00	6.09	15.18	1268.58
7:00	6.03	14.86	1270.55
8:00	6.05	14.69	1269.58
9:00	6.07	14.94	1261.67
10:00	6.07	15.71	1256.15
11:00	6.12	16.67	1252.43
12:00	6.17	17.54	1248.36
13:00	6.60	18.43	1244.77
14:00	6.70	19.13	1242.04
15:00	6.77	20.07	1241.50
Average	6.35	18.23	1181.31

time, Figure 18 shows the PH evolution over time, and Figure 19 shows the evolution of PPM over time. In Figure 17, we can observe that the maximum temperature recorded during the day was 21.69 degrees Celsius at noon, and the minimum temperature was 13.71 degrees Celsius at 6:00 in the morning. Therefore, the temperature remained within the optimal growth parameters throughout the day. In Figure 18, we observe a minimum PH of 4.50 at 3:00 PM. This was due to the manual PH regulation process where PH adjuster was added to lower the PH level of the mixture. The maximum PH observed was 8.50 at 7:00 PM, which occurred during the nutrient regulation of the mixture when a large quantity of nutrients was added to reach the established maximun limit of 1400 PPM . In Figure 19, we can observe a similar relationship between PH and TDS (Total Dissolved Solids), where there is an increase in nutrients to 1400 PPM at 7:00 PM performed by the system. At that moment, there is a rise in the PH level.

Table 2. Data of june 15th.

Time	PH	Temperature	PPM
16:00	6.02	21.49	833.42
17:00	6.35	20.84	750.02
18:00	8.12	20.04	1382.81
19:00	8.12	19.26	1383.43
20:00	8.12	18.46	1384.03
21:00	8.13	17.73	1384.64
22:00	8.38	17.03	1306.54
23:00	8.40	16.45	1325.94
24:00	8.51	15.92	1340.58
1:00	8.47	15.49	1356.82
2:00	8.42	15.08	1367.28
3:00	8.39	14.70	1382.52
4:00	8.50	14.39	1390.50
5:00	8.46	14.05	1405.96
6:00	8.49	13.71	1418.40
7:00	8.23	13.76	1420.60
8:00	6.83	14.95	1391.00
9:00	6.11	16.89	1332.20
10:00	5.51	19.18	1266.41
11:00	5.50	21.19	1214.11
12:00	5.47	21.69	1196.11
13:00	5.40	21.63	1192.07
14:00	5.73	20.51	1226.53
15:00	4.58	18.76	1270.65
Average	7.26	17.63	1288.44

Conversely, when manually adjusting the PH, there is a decrease in the PPM level of the solution, indicating better nutrient absorption with a lower PH. Moving on to the data analysis of June 18th, we have Figures 20, 21, and 22, which show the temperature, pH, and PPM respectively, illustrating their evolution throughout each hour of the day. In these data, we can observe similar results regarding temperature, as it remains within optimal parameters with a maximum recorded temperature of 22.10 degrees Celsius and a minimum of 13.82 degrees Celsius. Regarding pH and PPM, there is again an inversely proportional relationship between pH levels and nutrient absorption. Lowering the pH at 9:00 AM results in a decline in PPM at the same hour, which continues to decrease gradually until 4:00 PM when it reaches the limit of 800 PPM. At this point, the system regulates the nutrient quantity back to 1400 PPM, which also increases the pH level of the mixture. Finally, we have the data collected on June 20th, which can be

Table 3. Data of june 18th.

Time	PH	Temperature	PPM
22:00	7.75	18.03	1279.68
23:00	7.85	17.66	1288.29
24:00	7.72	17.17	1305.38
1:00	7.77	16.86	1312.28
2:00	7.74	16.40	1328.07
3:00	7.80	16.00	1337.37
4:00	7.72	15.61	1351.92
5:00	7.92	14.76	1378.62
6:00	7.95	14.15	1398.04
7:00	7.82	13.82	1411.70
8:00	7.72	13.93	1412.79
9:00	6.41	14.44	1398.45
10:00	6.06	15.56	1358.40
11:00	6.00	17.91	1279.82
12:00	6.00	19.64	1189.74
13:00	5.96	20.62	1090.82
14:00	5.98	21.30	983.60
15:00	5.95	22.10	885.80
16:00	5.90	22.04	785.05
17:00	6.02	21.55	843.67
18:00	6.23	20.98	1286.74
19:00	7.31	20.30	1296.39
20:00	7.02	19.46	1287.41
21:00	6.74	18.88	1293.89
Average	6.97	17.88	1241.00

observed in Figures 23, 24, and 25, showing temperature, pH, and PPM over time. In these data, similar results were obtained that confirm the relationship between pH level and TDS (Total Dissolved Solids). As observed at 6:00 in the morning, when pH was adjusted, the PPM level began to decrease until reaching a minimum of 800 at 9:00 AM, at which point there was a replenishment of nutrients, resulting in an increase in the PH level.

9.2. Tracking lettuce growth

Alongside the collection of data on the quality of the nutrient solution, daily monitoring of plant growth was conducted by measuring leaf length. This can be observed in Figures 28, 29, 30 and 31, which depict two measurements of lettuce grown in water and two measurements of lettuce grown in soil. The measurements were used to

Table 4. Data of june 20th.

Time	PH	Temperature	PPM
1:00	6.77	15.04	1262.34
2:00	6.70	14.64	1256.87
3:00	6.76	13.94	1249.41
4:00	6.74	13.53	1238.95
5:00	6.81	12.81	1226.16
6:00	6.62	12.34	1153.18
7:00	5.57	12.26	1117.82
8:00	5.82	12.22	956.71
9:00	5.89	12.70	823.76
10:00	6.90	13.68	1357.43
11:00	7.59	14.51	1379.26
12:00	7.84	15.43	1405.96
13:00	7.76	16.68	1418.40
14:00	7.76	18.57	1420.60
15:00	7.77	19.24	1391.00
16:00	7.76	20.79	1332.20
17:00	7.71	21.72	1266.41
18:00	7.76	20.76	1214.11
19:00	7.89	20.06	1196.11
20:00	7.95	19.21	1192.07
21:00	7.88	18.68	1192.07
22:00	7.82	17.90	1192.07
23:00	7.69	16.99	1192.07
24:00	7.74	16.10	1192.07
Average	7.23	16.24	1234.46

populate Table 5 that has growth monitoring comparing growth between the standard soil substrate and the water substrate. And also, the table includes the daily average of temperature, TDS, and pH to facilitate a comparison between daily growth and these mixture measurements, examining if any relationship exists between them.

Table 5. Growth of lettuce over a ten day spam

Date	**Growth**	**Temperature**	**PH**	**PPM**
12/6/2024	0,27	17,82	6,84	1234,81
13/6/2024	0,25	17,26	7,42	1346,12
14/6/2024	0,3	17,53	6,45	1217,76
15/6/2024	0,25	17,63	7,27	1288,44
16/6/2024	0,32	16,87	6,14	1123,74
17/6/2024	0,28	16,24	7,23	1327,63
18/6/2024	0,27	17,88	6,97	1241,00
19/6/2024	0,29	17,63	6,74	1238,94
20/6/2024	0,33	18,23	6,35	1161,81
21/6/2024	0,31	17,73	6,57	1187,62

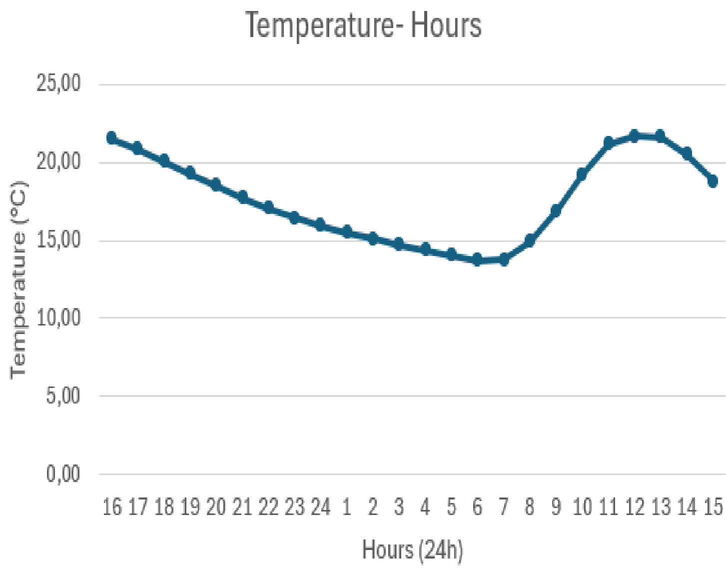

Figure 17. Temperature june 15th

Observing the growth table over ten days, figures 26 and 27 were generated to represent growth according to pH levels and nutrient amounts. Upon examining these graphs, it can be determined that there is greater growth on days with lower pH and TDS levels. This is because a lower pH allows better nutrient absorption from the solution, thereby reducing the average daily nutrient intake as plants absorb more on those days and consequently exhibit greater growth.

10. Cost analysis

This section is a breakdown of the expenses incurred throughout this project for subsequent analysis and economic feasibility determination. On table 6 is detailed the cost of the electronic devices. On table 7 is detailed the total amount of capital invested in

Table 6. Cost of electronic devices

Product	Price
Arduino	$15.00
PH Sensor	$45.00
TDS Sensor	$16.00
Solenoid valve	$9.00
Relay	$4.00
Pump	$30.00
Total	**$119.00**

this project. With this breakdown of costs, we can review Table 8 , where we can see

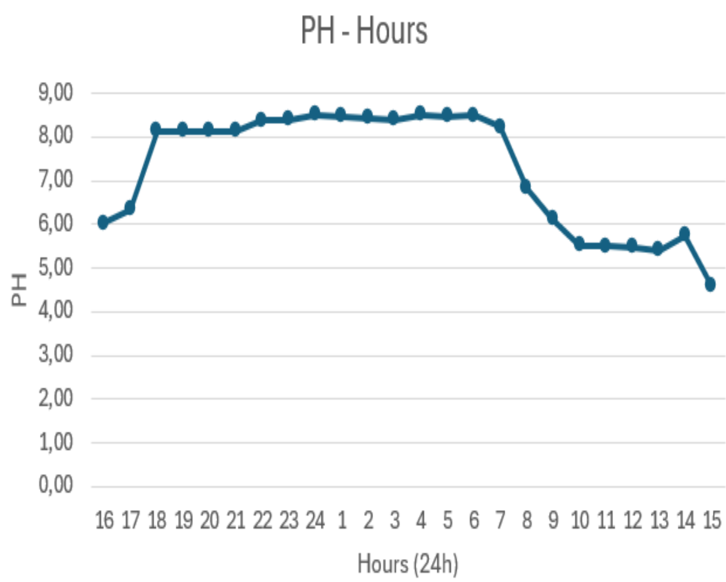

Figure 18. PH june 15th

Table 7. Total amount investeed

Product	**Price**
Plumbing Materials	$50
Electronic Materials	$119
Supports	$60
Labor	$105
Total	**$334**

the profit that can be obtained by selling the lettuces considering a production of 30 lettuces every 4 months. With this, the investment would be recovered in a period of 6 years, therefore, if this system is to be used commercially, it is necessary to have a higher production.

Table 8. Profits

Lettuce Price	$0.45
Quantity	30
Total per production	$13.50
Annual total	$54.00

11. Conclusions

- The system allows for the cultivation of 30 lettuces, which on average have grown 3cm more than lettuces planted in soil, with a daily growth rate approximately 2 to 3mm faster. This is attributed to more efficient nutrient absorption. Both crops

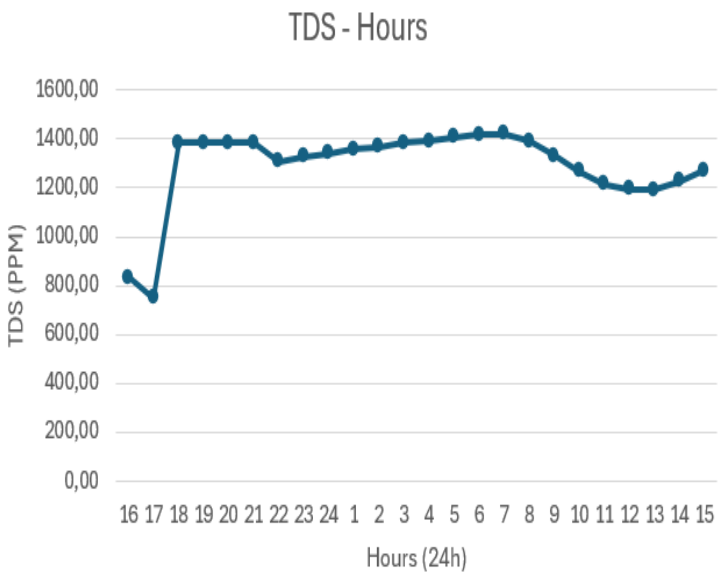

Figure 19. PPM june 15th

received nutrients in their substrate.

- Based on sensor measurements, it was determined that a pH lower than 6 achieves better nutrient absorption, facilitating improved plant growth.
- The system can be scaled to a larger quantity of lettuces if desired to achieve financial viability, as the current production does not yield significant income at the current lettuce price.

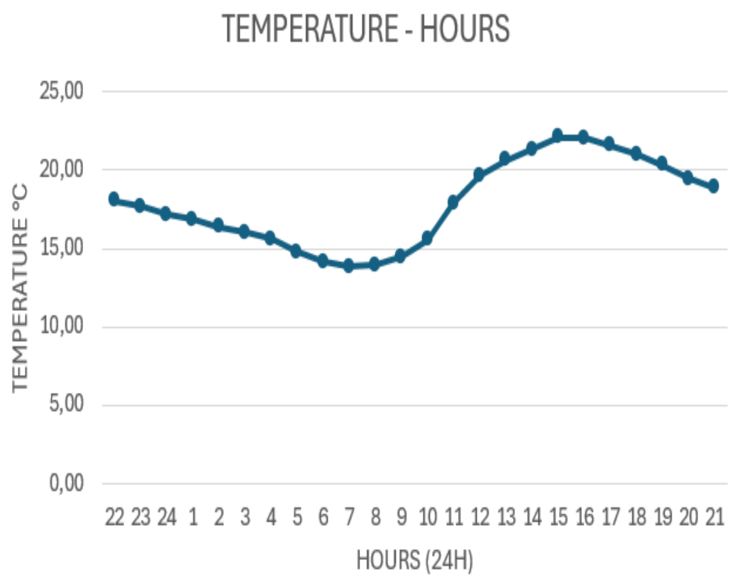

Figure 20. Temperature june 18th

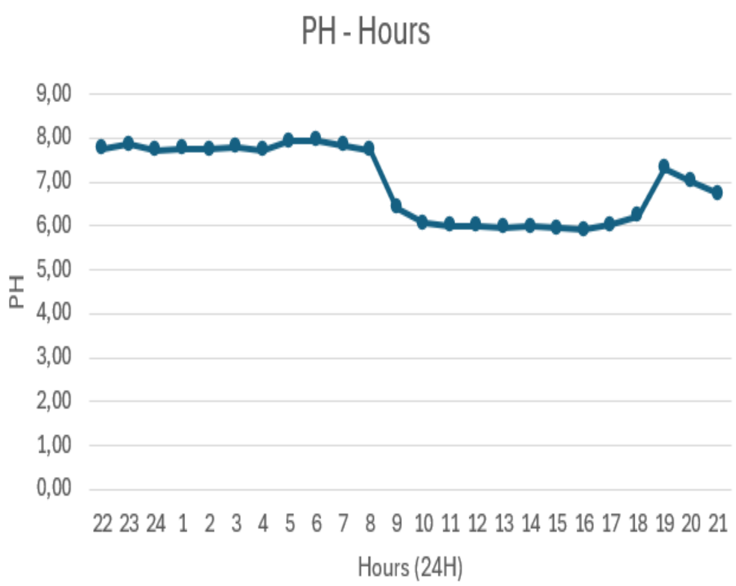

Figure 21. PH june 18th

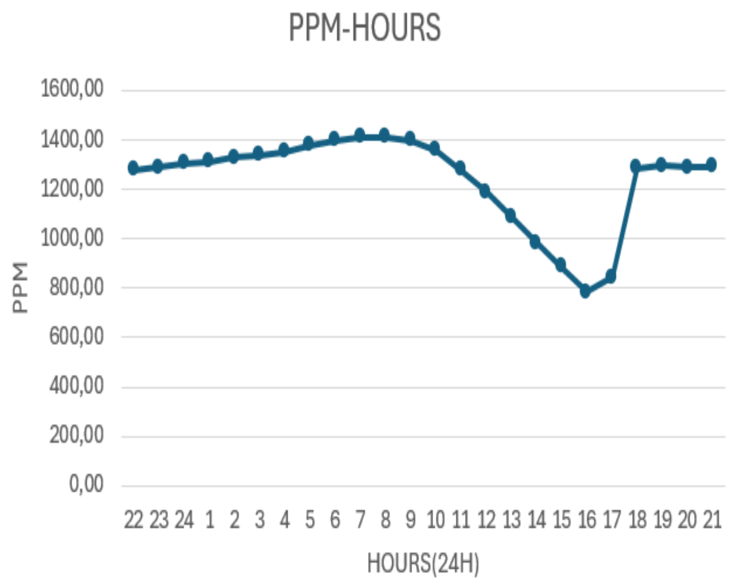

Figure 22. PPM june 18th

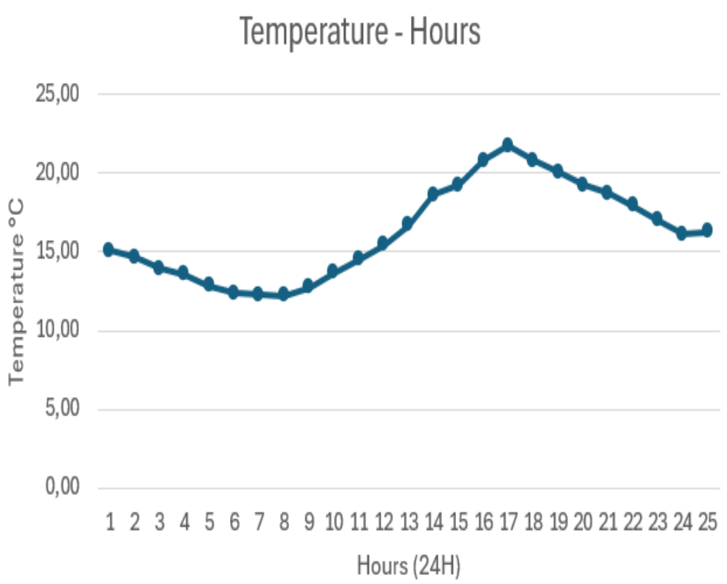

Figure 23. Temperature june 20th

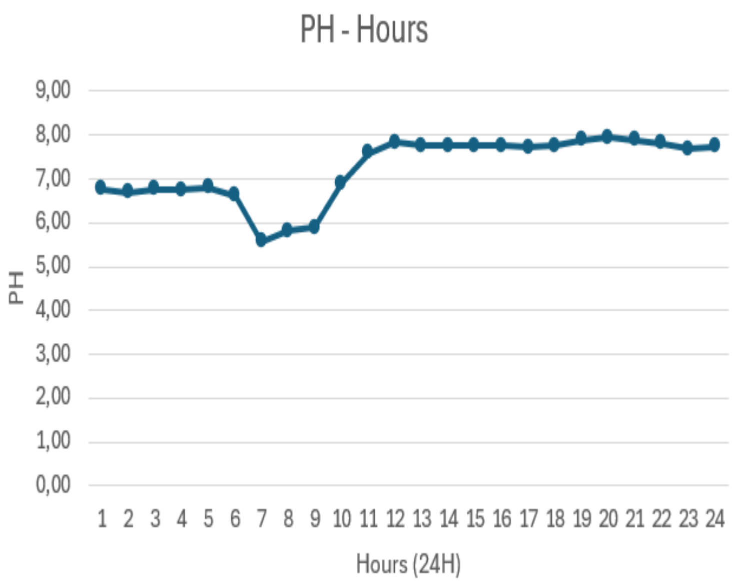

Figure 24. PH june 20th

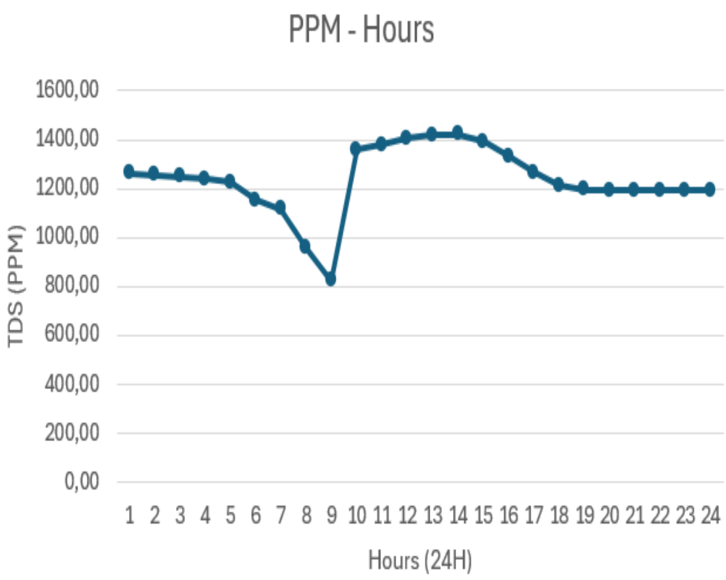

Figure 25. PPM june 20th

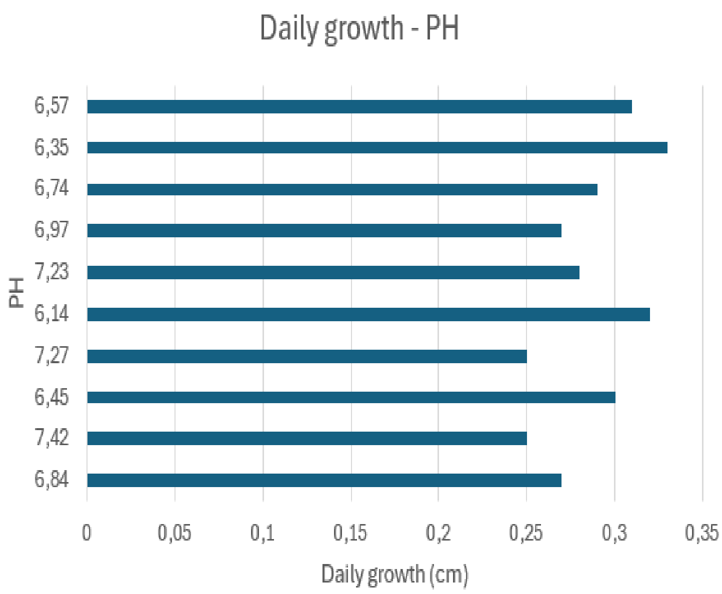

Figure 26. Growth - PH

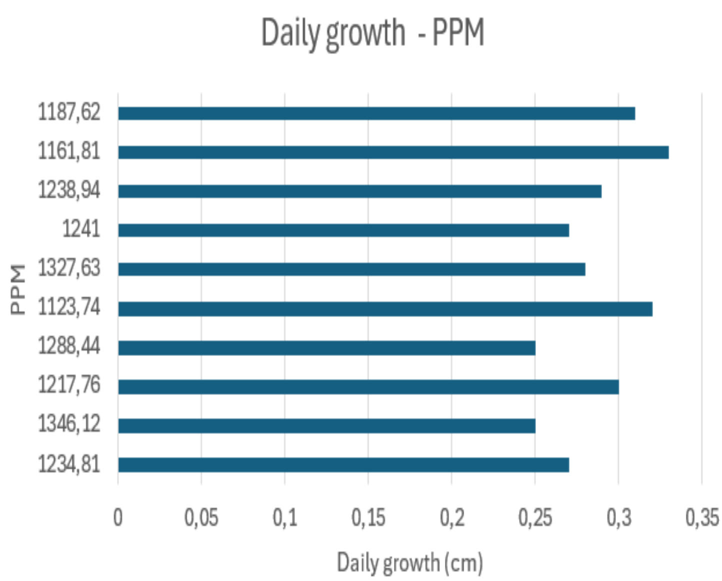

Figure 27. Growth - PPM

Figure 28. Measuring leaf length 1

Figure 29. Measuring leaf length 2

Figure 30. Measuring leaf length 3

Figure 31. Measuring leaf length 4

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