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# Low-cost Hydroponic system for growing Italian lettuce: preliminary results

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## ABSTRACT

**Objective**: To design a hydroponic cultivation setup that is an efficient and sustainable alternative for growing Italian lettuces. It should offer the main advantages of hydroponics, namely low water consumption and soilless cultivation. Additionally, it should be low-cost, installable in a small space for urban agriculture or areas with adverse climatic conditions, and capable of remote monitoring.

**Methodology**: This Nutrient Film Technique hydroponic system uses three different sensors to monitor natural light, the temperature of the nutrient solution, and the level of the nutrient solution. It also uses a microcontroller with WiFi communication, and its structure is made of PVC material.

**Results**: The Nutrient Film Technique setup can send alerts via a free app, which controls the switching on and off of the artificial light (Red LED light) and the level of the nutrient solution; these sensors are remotely monitored in real time. It also stores sensor data using the ThinkSpeak platform. This setup uses only low-cost materials, free digital platforms, and consumes low water. The Italian lettuce harvest was obtained in a period of 22 days.

**Conclusions**: The system can be optimized, but at this stage, compactness and minimal sensors were the criteria employed in the design. The free tools serve to visualize sensor data and, simultaneously, control the nutritional solution. Cloud platforms enable access to information at any moment and from any location with internet access.

**Keywords**: Soilless cultivation; Microcontroller; Automatization; Smart farming.

## INTRODUCTION

Food scarcity is becoming a serious problem in agriculture. Technologies such as greenhouses, vertical farming, and precision agriculture are effective ways to address this problem. In traditional agriculture, factors that influence harvest are the weather, season of the year, soil type, and irrigation efficiency. Addressing the deficit irrigation in regions currently experiencing it can increase agricultural output by up to 30% (Pfister *et al.*, 2011). Another option in increasing harvest efficiency is soilless agriculture. Although sometimes soilless and hydroponic are used as synonyms, it is important to mention that some

differences stand out. Soilless cultivation can be conducted using an aerated nutritive solution, whereas a water reservoir is necessary in hydroponics. Hydroponics, aquaponics, and aeroponics fall in this category, as shown in Figure 1.

In hydroponic cultivations, the roots are floating. This means a structure supports plants while their roots are submerged in the nutrient solution. To prevent algae proliferation, the water container should be opaque to light. On the other hand, maintaining water movement is necessary for temperature control and oxygenation. This is achieved using water or air pumps. Some of the advantages of this system include water saving, nutrient control, and reduced infrastructure requirements. As a drawback, it is worth noting that this technique is limited to cultivating short, low-weight plants that can withstand direct humidity conditions. Species with an extensive root system can be problematic. Furthermore, this system facilitates rapid disease spread because all plants are closely spaced.

On the other hand, natural light promotes the development of some molecules necessary for plant growth, such as chlorophyll, carotenoids, and phytochromes. Phytochromes are proteins sensitive to light that regulate plant growth and development, responding to 660 nm and 725-735 nm (Homes & Smith, 1975). Therefore, plants must have the necessary light at an adequate wavelength for growing. However, since red light (627-655 nm) increases crop growth and leaf expansion in Italian lettuce (Tosti *et al.*, 2018; Alrajhi *et al.*, 2022), it was selected as the artificial light source for this system.

Plants obtain oxygen, water, minerals, and nutrients through their roots, all of which are necessary for growth. In the hydroponic system, the essential minerals are provided by the nutritive solution (Thapa *et al.*, 2022). It means that nutrients are water-solubilized, and then the chemical components forming the fertilizers are ionized; in this way, nutrients are absorbed by the roots.

Although the literature reports several Nutrient Film Technique (NFT) hydroponic setups, most of them are focused on economical profit (Pertierra Lazo & Quispe Gonzabal,

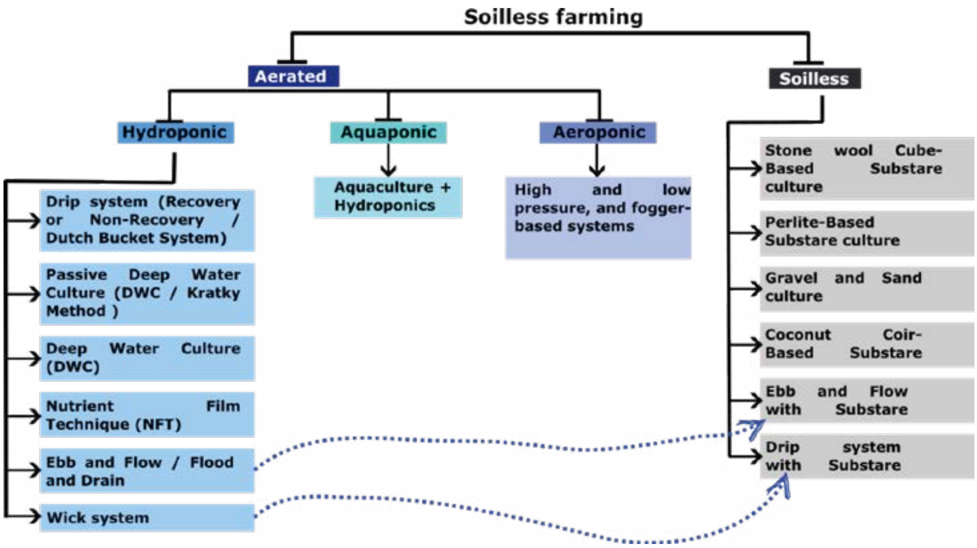

**Figure 1**. Soilless farming classification and its different setups. Blue arrows point out the combination of hydroponics and substrates in soilless cultivation.

2020), the effect of the different hydroponic systems (Frasetya *et al.*, 2021), aeration (Kratky, 2005), nitrogen levels (Martínez-Moreno *et al.*, 2024; Thapa *et al.*, 2022), or even control laws and techniques (Lenni *et al.*, 2020). Literature is scarce regarding low-cost systems with sensor monitoring. Despite the low-cost label, the hydroponic systems require significant investment for basic infrastructure, which is particularly critical in regions with limited financial resources (Gumisiriza *et al.*, 2022). On the other hand, successful hydroponics require specific knowledge and skills in nutrient management, system maintenance, and sensor monitoring. Lack of expertise can lead to poor yields and system failures (Gumisiriza *et al.*, 2022; Baker *et al.*, 2023).

Lakshmi and coauthors report a low-cost hydroponic system using Arduino Uno, but the use of LabVIEW software increases the cost due to licensing (Lakshmi Prasanna *et al.*, 2024).

When hydroponic cultivation does not have the right conditions, the harvest is reduced. Then, it is necessary to monitor at least illumination, water temperature, and water nutrients. The water temperature must be in the range of 20° C to 28° C for optimal nutrient absorption; temperatures higher than this range can affect the plant (Azhari *et al.*, 2022).

Due to limited research on low-cost hydroponic systems, this work introduces a design for such a system. The hydroponic system, equipped with automatic illumination, water temperature measurement, and nutrient monitoring, was evaluated for its effectiveness in lettuce cultivation. In addition, a smartphone app is connected to the hydroponic system for remote monitoring.

## MATERIALS AND METHODS

A Nutrient Film Technique (NFT) system was developed using a transplantation technique for eight Italian lettuces, meaning lettuces are set in the hydroponic system when seedlings have 10 cm roots or 4-5 true leaves. After setting the lettuces in the hydroponic system, the growth is monitored until harvest. The lettuce survey period comprises thirty days, eight days for germination, and twenty-two days for monitoring.

This design comprises a microcontroller, a set of sensors, a wireless module, and some actuators to interact with an NFT hydroponic system. Temperature is monitored using a digital sensor (DS18B20), light is measured by using a light-dependent resistor (LDR), and water level is determined using an ultrasonic sensor (HC-SR04). Data from sensors is acquired and processed using a microcontroller (ESP8266 NodeMCU). It is important to mention that all variables (light, temperature) were collected in triplicate, and the reported measurements are the result of averaging the three measurements. The methodology followed in this work is illustrated in Figure 2 as a schematic.

The microcontroller is programmed to detect a low light level using the LDR; when the light intensity follows a predetermined slope, artificial illumination is turned on. The use of automatic control of artificial light aims to reduce energy consumption while providing plants with as much light as possible. Thus, increasing the plants' growth. A red light was selected to provide artificial illumination for the plants. The LDR and microcontroller control this light and can be monitored both on-site and remotely.

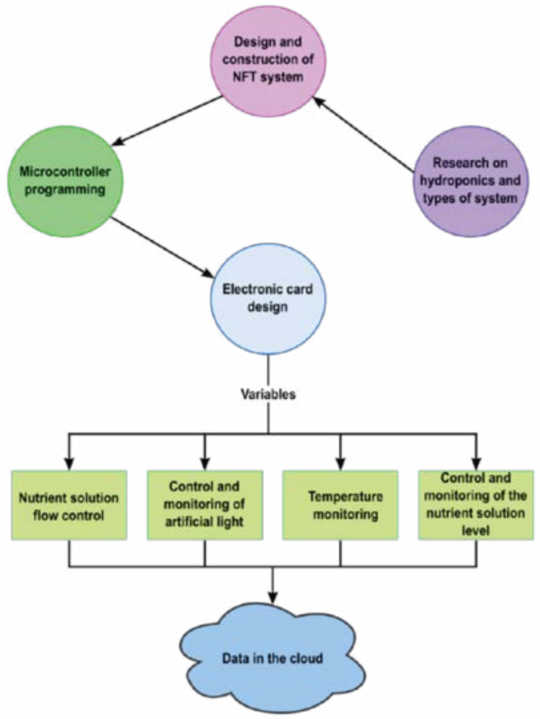

**Figure 2**. Schematic diagram of the steps used to design the NFT system.

Since red light (627-655 nm) increases the crop growth and leaf expansion in Italian lettuce (Tosti *et al.*, 2018), red led light was selected as an artificial light source for this system (620-630 nm), 13 W, placed 20 cm from each lettuce. Red lights are controlled to activate when the ambient light is scarce; thus, plants receive light for 18 hours, including both natural and artificial light.

In NFT systems, the roots are in permanent contact with the nutritive solution; for lettuce, 1 to 2.5 g of nutrients per liter must be dissolved in the water, depending on the brand. In this case, two water containers were set up: one to dissolve the inorganic solution and the other to manage the hydroponic water flow. 1.5 g per liter of inorganic solution (Hidroponia, Intergarden®) was dissolved. The main container stores the necessary nutritive solution for the entire system. In contrast, a small container is used to dissolve nutrients and replenish the necessary nutrient volume when it falls below the desired quantity. The dissolving container is equipped with a magnetic stirrer to ensure adequate dissolution of the nutrients. On the other hand, the flux of the water pump supplying the nutrient solution was controlled to aerate it and avoid turbulence that can affect correct root development.

The plant's support is the costly part; therefore, the NFT system uses polyvinyl chloride pipes (PVC) as both a structural component and a conduit for the nutritive solution. PVC pipes offer low weight, high chemical resistance, waterproof properties, and, with adequate maintenance, can last for years. Figure 3 shows the main parts of the developed system and their connection.

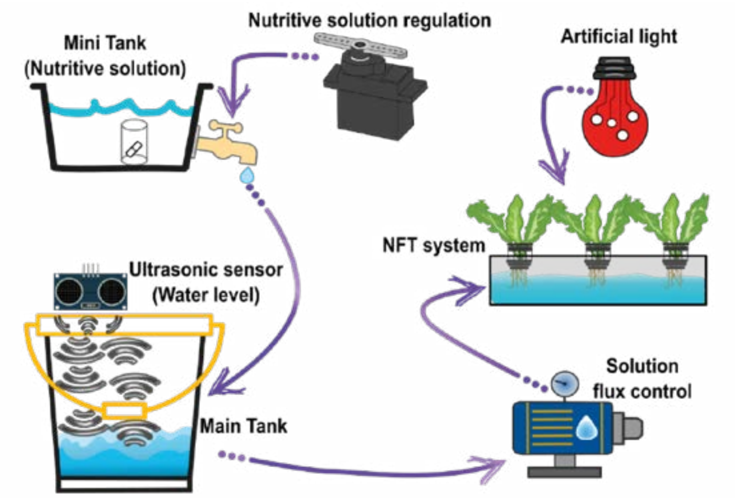

**Figure 3**. Schematic representation of sensors and actuators used in the NFT system.

The temperature of the nutrient solution is critical for the adequate development of roots; when the temperature of the solution is in the 20 °C to 28 °C range, roots can efficiently obtain the nutrients from the solution. Temperatures above 28 °C can result in poor root oxygenation and damage. Thus, the temperature sensor monitors the temperature of the nutrient solution and sends an alert via the app when the temperature exceeds a safe level. A liquid crystal display (LCD) was implemented to monitor all system variables. The LCD shows information about the temperature and nutrient solution level using an I2C communication protocol. Figure 4 shows the data flow. Data originates from the sensors monitoring the system and is sent to the microcontroller, which then stores the data in the cloud, allowing users to access it.

Because data access allows for better monitoring and post-analysis, data are stored on a cloud server using a ThinkSpeak interface and a WiFi connection, providing real-time

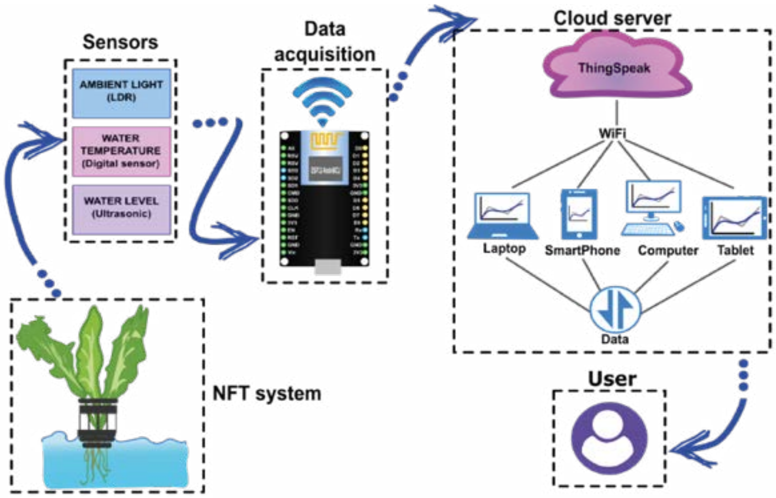

**Figure 4**. Schematic diagram of the NTF system showing the connections and flow of information (blue arrows) among the parts of the system.

monitoring. The ThinkSpeak platform provides real-time analysis by graphing acquired data and allows multiple users access to the data. The platform is programmed to send warning messages to a mobile device using WhatsApp and CallMebot apps, both of which are free. Two alerts are configured: the first is triggered when the solution temperature exceeds 28 °C, and the second is activated when the nutritive solution level falls below a certain level.

## RESULTS AND DISCUSSION

The information is stored in the cloud using a WiFi connection, allowing for remote supervision of the system and the visualization of the nutrient solution over extended time periods and in real-time. Due to the use of freeware, the system remains in the low-cost category (See supplementary material S1).

Because the NTF system can monitor the light level, plants in the system receive as much light as possible. Figure 5 shows the behavior of the light monitoring system under natural light. The slope of the natural light is then used in conjunction with the time of day to activate the artificial light, thereby avoiding activation due to shadows.

Figure 6 shows the NFT system when the artificial illumination is turned on. Light was placed 20 cm above the pipes supporting the plants.

The water temperature was monitored for 22 days. Figure 7 shows the water temperature for 22 days. The green area represents the temperature range optimal for root development. The orange zone (28 to 30 °C) is the temperature range where roots can suffer stress, affecting their development. Temperatures in the red zone can lead to low root oxygen levels.

During the 22 days presented in Figure 7, no temperature control or any other action was taken regarding the temperature of the nutritive solution. A peak temperature was reached within a few hours. The primary reason for not controlling the temperature of the nutritive solution is to assess the high-temperature alert implemented in the system. The

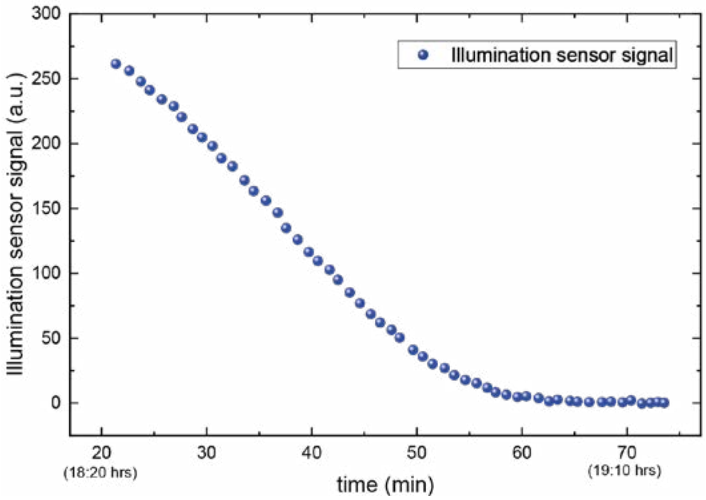

**Figure 5**. Light sensor response showing the signal under the diminishing daylight. The horizontal axis represents time in minutes, and the vertical axis displays the digital value of the sensor signal.

**Figure 6**. NFT system with the artificial illumination turned on. The figure displays a system designed for eight plants.

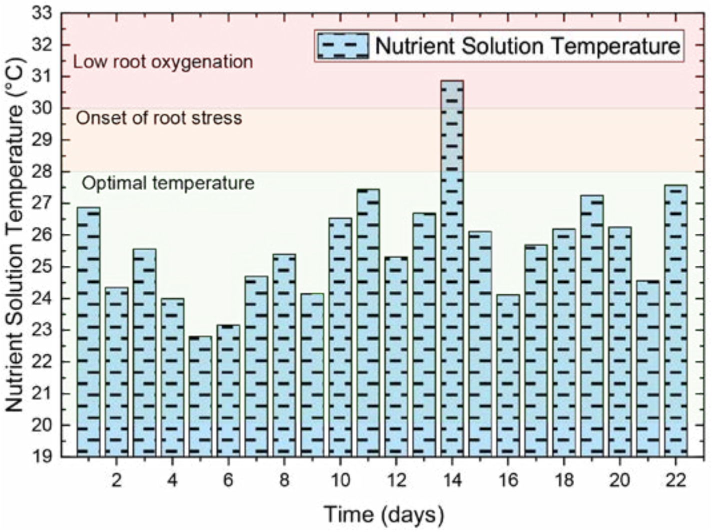

**Figure 7**. Temperature of the nutritive solution monitored for 22 days.

temperature control and messaging systems were tested for temperatures above 29 °C. Figure 8 shows an example of the warning messages sent when the temperature exceeds the upper limit. The system can warn users about thermal variations, and data notifications are correctly sent using ThinkSpeak. Additionally, an alarm was implemented using CallMebot and WhatsApp to notify of a critical temperature condition in the nutritive solution.

There is an increased interest in developing low-cost hydroponic systems, making soilless farming more accessible for small-scale urban agriculture, educational purposes, and food production in resource-limited areas. The final cost is highly dependent on the degree of automation, the type of sensors employed, and the number of variables monitored, all of which increase the cost of the final product.

The most popular microcontrollers used in these types of systems are the Arduino and Raspberry Pi platforms. Those two platforms are preferred due to their high degree of customization and low price, with Raspberry being the more expensive option. Low-cost

Alert: The temperature is 29.75 °C and it is too high! 20:00

Alert: The temperature is 29.69 °C and it is too high! 20:05

Alert: The temperature is 30.38 °C and it is too high! 20:10

Alert: The temperature is 30.38 °C and it is too high! 20:15

**Figure 8**. Screenshot of the alert messages warning of an increase in the nutritive solution temperature.

systems are reported in the literature, but using commercial software causes the system cost to rise (Prasanna *et al.*, 2024). In this work, all software is freeware to lower the final cost. As pointed out by Baker and coworkers (Baker *et al.*, 2023), the lack of expertise can lead to poor yields and system failures; therefore, the possibility of sharing sensor information by cloud storage can improve the user experience by facilitating feedback around the world, thus preventing crop losses and improving growing conditions. Some authors do not use artificial light (Pertierra Lazo & Quispe Gonzabal, 2020), others use low-power LED light (Lenni *et al.*, 2020; Gumisiriza *et al.*, 2022). In this study, LED light, specifically red light, was used to improve crop growth. Lenni and coworkers use a micro-SD card as a storage medium and send SMS messages to the user's mobile phone number in real time (Lenni *et al.*, 2020). Thanks to recent advances in software and hardware, this work is monitored on site, and some parameters are even controlled remotely. It is also monitored remotely in real time, but with the difference that it is stored in the cloud.

This work shows preliminary results; thus, the lack of growth metrics is acknowledged. Future work is expected to incorporate a comparison of an NFT system without sensors or soil-based cultivation. On the other hand, this work provides the foundations for low-cost NFT systems.

## CONCLUSIONS

An NFT system was implemented, and the temperature of the nutritive solution and the amount of light were monitored using low-cost sensors and IoT. All data were stored in the cloud, facilitating the supervision of key variables such as the temperature of the nutritive solution, solution flux, solution level, and light amount. This allowed for maintaining these variables within the optimal growing parameters for Italian lettuces.

Due to its design simplicity, the NFT system can be easily replicated by utilizing commercial sensors and free tools employed in the development of soilless systems. The hydroponic system also enables learners and future developers to acquire the fundamentals of soilless agriculture.

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