International Journal of Innovative Research in Science and Engineering
Volume 11, Issue 07, 2025
www.ijirse.com
ISSN: 2454-9665

Precision Agriculture in Soilless Systems

Yashdeep P. Nimje[1], Prof. Chandrahas C. Handa[2]

[1] Research Scholar, Department of Mechanical Engineering,
Karmaveer Dadasaheb Kannamwar College of Engineering Opposite Telephone Exchange,
Nandanvan, Nagpur, Maharashtra, yashdeepnimje@gmail.com
[2]Department of Mechanical Engineering,
Karmaveer Dadasaheb Kannamwar College of Engineering Opposite Telephone Exchange,
Nandanvan, Nagpur, Maharashtra, chandrahashanda@rediffmail.com

Abstract:
Hydroponics, a technique that dates back nearly 2,500 years, is an age old agricultural practice that has proven to be both land and water efficient. Today, with much of the Earth's surface dedicated to farming, fertile land is gradually diminishing largely due to the expansion of industrial development. As a result, innovative methods like soilless cultivation, known as hydroponics, are gaining attention. A strategically designed hydroponic system offers a modern agricultural alternative that requires minimal human intervention. This paper aims to contribute to the advancement of hydroponic technologies by conducting an in depth analysis of the essential factors involved in hydroponic farming. It explores key parameters in automated hydroponic systems, including total dissolved solids (TDS) in the water, adequate air circulation for plant health, water and ambient temperatures, the evolution of automation within hydroponics, and effective cost management strategies.

***Keywords:** Smart agriculture, Controlled Environment Agriculture, Scarcity of water, Hydroponics system*

1. Introduction

As the global population steadily increases and natural resources continue to dwindle, the demand for sustainable agricultural methods becomes more urgent. Projections suggest that by 2050, the world population may reach approximately 9.5 billion up significantly from the six billion reported earlier (Mamta D. Sardare et al., 2013). Hydroponic farming, a method of growing plants without soil, relies on mineral-rich solutions and provides an effective response to the imbalance between rising food demands and shrinking arable land. Though it differs from conventional farming, hydroponics adopts similar methodologies, such as vertical gardening, allowing plants to thrive more efficiently by directly absorbing nutrients from water-based solutions (Muhammad E. H. Chowdhury et al., 2019). Since the roots no longer need to search deep into the soil for minerals, plant energy is primarily focused on producing higher yields (Rakshitha M. et al., 2018). At various stages, researchers have investigated the performance of hydroponic systems. The studies incorporated a combination of theoretical models, numerical simulations, and experimental testing. One such study utilized Design Expert software to examine the differences in plant growth by cultivating two cucumber seed varieties under both hydroponic and soil-based conditions. Results, validated by ANOVA testing, confirmed that plants grown hydroponically displayed more robust and rapid development (Raneem Gashgari et al., 2018). In a soil-less setup with controlled conditions, synthetic fertilizers and drip irrigation techniques are used. For instance, tomato plants grown under these systems yielded approximately 2.16 kg per plant, equating to about 112 tonnes per hectare (Dr. Umesh Barikar et al., 2013). Drip irrigation has also been identified as an effective water delivery system, particularly for fruit-bearing plants. Studies indicate that the optimal yield of 126.7 t/ha and average fruit weight of 46.77 grams were achieved using a growing medium mixture of cocopeat, perlite, and vermiculite (50:25:25), combined with a water supply rate of 100% pan evaporation (R. Parameshwarareddy, 2018).

In 2019, S. M. Ghatage explored how common crops could be cultivated independently of outdoor environmental conditions. This led to the development of "pop-up agriculture," a modular and mobile farming approach that can be deployed in various locations with minimal infrastructure. These compact, closed systems are versatile and can attach to existing spaces or water sources (Gwynn-Jones et al., 2018). Pop-up agriculture offers key benefits such as increased yield and reduced production costs. It also allows farmers to select crop varieties and adjust planting schedules to suit ideal growing seasons. In regions like Bangladesh, where arable land is scarce, this technique has shown promise in addressing agricultural challenges through research and innovation (N.C. Barman, 2016). Automation in hydroponics leverages a closed-loop feedback system, which uses sensors to control various parameters without manual input. Data gathered by these sensors is fed to Android-based applications that help farmers track environmental conditions in real time. This allows for data-driven decision-making, improving yield and efficiency. The app based on PLC (Programmable Logic Controller) technology enables remote access to sensor outputs, with minimal lag. It also allows users to visualize sensor trends over weeks, make timely adjustments, and download real-time data from multiple locations, ensuring effective crop supervision (Rakshitha M., 2018). To further enhance productivity, digital platforms are being developed to store and display real-time data related to crop growth conditions. This accessibility facilitates better monitoring and refined crop management strategies (Palande V. et al., 2017). Additionally, advancements in wireless sensor technology and IoT (Internet of Things) are transforming agriculture. For example, Ayaz M. et al. (2019) highlighted the potential of AI-driven systems in farming. One application involved medical marijuana cultivation, where precise regulation of 138 different variables was achieved using AI tools.

Moreover, the concept of "ontology" in control systems has gained traction. As studied by Phutthisathian A. et al. (2011), the use of ontology in hydroponic control systems enhances adaptability to different environments, sensors, and actuators, making the system flexible and suitable for future agricultural automation.

2. Methodological Framework

The primary objective of this research is to consolidate existing knowledge and current methodologies related to monitoring systems in hydroponics. The foundation of this study is built on a manual analysis of relevant data, identifying key milestones and activities while explaining their significance in the evolution of hydroponic farming. The progression of hydroponic systems is also traced to provide context. A crucial component of modern hydroponic setups is the incorporation of sensor technology, enhanced by smart systems and Internet of Things (IoT) integration. To support this research, a comprehensive review of various sources including academic publications, student dissertations, and online materialswas conducted. These sources were systematically analyzed to understand how different parameters have been explored to develop fully automated hydroponic systems.

3. Water Deficiency

In hydroponic systems, a range of parameters are monitored, each using distinct measurement techniques. For example, pH levels can be measured through simple pH test strips, standalone digital sensors with LCD displays, or advanced analog sensors that transmit data either wirelessly or via wired connections to central control units. To ensure the hydroponic system is reliable, efficient, and economically viable, integrating automated sensing technologies is essential. Researchers have adopted various sensor-based approaches to enhance monitoring and control in hydroponic setups. These include the use of microcontrollers, programmable logic controllers (PLCs), and IoT-enabled devices, all aimed at automating data collection and enabling real-time decision-making. By minimizing manual intervention, these automated systems contribute to consistent plant growth, resource optimization, and increased productivity (Wel et al. 2019).

Water is a foundational element in hydroponic systems, often termed the "carrier," as it dissolves and delivers nutrients directly to the plant roots. Achieving success in soilless agriculture largely depends on water quality. Maintaining optimal parameters such as pH, temperature, dissolved oxygen, and total dissolved solids (TDS) is vital for plant health and growth. Identifying and managing these water parameters ensures effective nutrient delivery and sustainable plant development ("Lab Water Purification Systems," 2021). ("Lab Water Purification Systems", 2021).

pH is a critical factor influencing nutrient uptake in hydroponic cultivation. Representing the concentration of hydrogen ions in a solution, pH determines the acidity or alkalinity of the water. When pH levels are too high or too low, plants struggle to absorb essential nutrients, which can impair growth or even lead to plant death. Different plant types have unique pH requirements. While most hydroponically grown fruits and vegetables thrive within a pH range of 5.5 to 6.0, some crops have more specific needs. For example, blueberries prefer an acidic solution with a pH between 4.0 and 5.0 (Judith, 2019), while rhizome plants like ginger grow best in a range of 6.0 to 8.0 (Fitria Hidayanti et al., 2020). Epiphytic plants, on the other hand, require a pH between 5.5 and 8.0 for healthy growth (Mamta D. Sardare et al., 2013).

Water temperature plays a vital role in nutrient absorption and overall plant health in hydroponic systems. Ideal water temperatures typically range from 18°C to 26°C. Within this range, plant roots can efficiently absorb nutrients dissolved in the solution. A sudden change in temperature between the nutrient solution and the water can shock plant roots, potentially leading to wilting or death. Hence, maintaining a stable temperature is essential. During colder months, aquarium heaters are often used to raise water temperature, whereas chillers are utilized in warmer seasons to keep it within the optimal range ("London Grow," Jan 31, 2020).

Dissolved oxygen is another crucial parameter in hydroponic systems, as plant roots submerged in water require sufficient oxygen for respiration and growth. A minimum DO concentration of 5 mg/L is necessary; levels below this can compromise plant survival. However, as environmental temperatures rise, the solubility of oxygen in water decreases, which can hinder oxygen availability to roots. To address this, devices such as air pumps, air stones, and oxygen diffusers are employed to enhance DO levels and ensure healthy root development (DO Sensor, Hanna Instruments, 2015).

TDS refers to the concentration of dissolved minerals both organic and inorganic in water. Because water dissolves a wide array of substances, it is often called the universal solvent. In hydroponics, TDS helps determine the nutrient concentration in the solution. Key dissolved elements include calcium, magnesium, and chloride ions. Maintaining TDS levels below 1000 ppm is recommended for optimal hydroponic plant growth, as excessive mineral concentration can damage plants (D. Adidrana & N. Surantha, 2019; "Hydroponics vs. Aquaponics – A Complete and Honest Comparison," 2022).

4. Ecological Variable

For plants to grow effectively, they require a precise balance of temperature and humidity. During the vegetative stage, the optimal temperature is around 25°C, while the flowering or peak growth phase demands a slightly higher temperature of approximately 28°C. Humidity also plays a vital role ideally maintained at 60–70% during the vegetative phase and reduced to 40–50% during the flowering stage. These environmental conditions are crucial, as the biochemical processes responsible for plant development are highly sensitive to temperature and humidity, operating most efficiently when these parameters are within ideal ranges.

To promote healthy and complete plant growth, researchers emphasize the importance of managing environmental factors such as natural light and ambient air temperature. Proper regulation of these elements enables growers to optimize the plant's growth cycle and maximize productivity. (Understanding Optimum Temperature and Humidity for Plant Growth Environment, 2020). For optimum growth of ginger, it is recommended to maintain a distance of 12 inches between each plant, providing sufficient space for ginger to flourish. A Many other crops require a sufficient place to survive so the minimum distance has to be maintained as per the plant. In hydroponic systems, natural sunlight significantly contributes to plant health and development. However, in indoor setups where access to sunlight is limited or unavailable, white LED lights serve as an effective alternative to meet the basic light requirements for plant growth. It is essential to carefully choose the intensity and quality of these lights in soilless farming environments to ensure optimal plant performance. Plants absorb light primarily at both ends of the visible spectrum specifically wavelengths that are not visible to the human eye. According to research conducted by the University of Minnesota, plants perform photosynthesis most efficiently at wavelengths of approximately 445 nanometers (blue light) and 650 nanometers (red light) (Julie Weisenhorn & Natalie Hoidal, 2020). To enhance growth, it is recommended that plants be exposed to a combination of red and blue light, maintaining a red to blue ratio greater than 3, for around 16 hours per day. This lighting strategy ensures efficient photosynthetic activity and supports healthy plant development in indoor hydroponic systems (Pennisi, G., Orsini, F., Blasioli, S. et al., 2019).

5. Air Ventilation

To prevent leaf tip burn in controlled environment hydroponic systems, Jun Gu Lee et al. (2013) conducted a study on the impact of air circulation. The research concluded that horizontal airflow is more advantageous than vertical flow for plant health and development. A low air velocity, combined with reduced intensity of white LED lighting, was found to promote optimal plant growth and is considered the most suitable condition for plant survival. To further support these findings, a 3D computational fluid dynamics (CFD) model was developed using ANSYS software. Ying Zhang et al. (2016) utilized this simulation to visualize and analyze airflow patterns within enclosed hydroponic environments, confirming that optimized horizontal airflow contributes significantly to creating stable and plant friendly microclimates.

6. Smart Soil less Cultivation

Hydroponic systems rely on the accurate measurement and control of various parameters, which can vary across different system configurations. Automation plays a pivotal role in enhancing plant health and productivity by regulating essential factors such as nutrient delivery, pH, temperature, and humidity. In most systems, microcontrollers like the Arduino Nano process input from sensors and trigger outputs to control devices such as motor pumps, sprinklers, conveyor belts, and solenoid valves. These outputs are executed at predefined intervals to ensure consistent nutrient supply (Soniya Joshi et al., 2018). Aeroponics, a subdomain of soilless cultivation, offers an alternative to traditional hydroponics. Instead of water or soil, it uses atomization nozzles to deliver nutrient rich mist directly to plant roots. Continuous monitoring and regulation of environmental parameters are essential in aeroponic systems to support plant health (Imran Ali Lakhiar et al., 2018).

To maintain optimal conditions, automated systems have been developed for real time monitoring of electrical conductivity (EC) and pH levels. These systems use solenoid valves to adjust nutrient flow based on sensor data processed by microcontrollers. In such systems, any deviation from preset thresholds prompts automatic corrections. Research has shown a direct correlation between temperature and pH specifically, a 10°C increase in water temperature can cause a 0.06 unit drop in pH, making the solution more acidic (Diego S. Domingues et al., 2012). Advanced tools with embedded actuators and control logic have been designed to maintain pH within an ideal range of 6.5 to 7.5 (Fitria Hidayanti et al., 2020). The use of Internet of Things (IoT) technology further enhances hydroponic automation by enabling remote monitoring of parameters like pH and air quality index. In case of deviations, automated alerts are triggered. Android applications have also been developed to display live sensor data from these IoT systems, facilitating real time management (B. S. Shubhashree et al., 2020).

Specific sensors such as ultrasonic sensors (HC SR04) for measuring nutrient solution levels and LM35 for temperature detection transmit data wirelessly to Arduino Uno microcontrollers. These controllers display the data on an attached screen and regulate nutrient flow using if else logic. Users can view the system status via Android smartphones for comprehensive control (P. Sihombing et al., 2017). A nutrient delivery mechanism using pumps allows for consistent weekly feeding in tomato cultivation, where water and nutrient mixtures are recycled, supporting sustainable farming (Vijendra Sahare et al., 2015). In studies involving Stonecrop family plants, artificial lighting for 16 hours daily was found to yield optimal growth outcomes (Sang Yong et al., 2016). Real time data integration through AVR microcontroller boards and tools like NI LabVIEW allows complete automation and centralized monitoring of hydroponic processes. These platforms are increasingly used in IoT applications to support large scale operations (S. Adhau et al., 2017).

Titan Smarphonics, a prominent name in hydroponics innovation, has introduced several IoT based solutions for remote system management. Their hardware suite includes a variety of sensors and actuators capable of controlling critical variables like pH, humidity, and temperature. Their smartphone compatible software, built using Arduino and Raspberry Pi platforms, delivers high levels of automation and scalability to hydroponic farming (Dr. Asawari Dudwadkar et al., 2020).

7. Growing of plants in soil less farming

Hydroponic systems are known for their efficient use of water, consuming significantly less than traditional farming methods. This advantage is particularly valuable in arid regions such as the Arabian Gulf, where crops like tomatoes, peppers, and lettuce hold high commercial importance. Notably, the growth cycle and developmental stages of hydroponically grown plants closely resemble those observed in conventional farming systems (Sabrina Naz et al., 2021). Horticultural crops such as strawberries, lettuce, tomatoes, and carnations have shown promising results under hydroponic cultivation. These systems rely on minimal inorganic nutrients, combined with essential elements like water, oxygen, and sunlight, to sustain plant health and vitality (Shailesh Solanki et al., 2017).

An experimental study comparing the nutrient content of vegetables grown through hydroponics and traditional farming revealed that hydroponically grown vegetables contained up to 50% more vitamins A, B, C, and E. Additionally, since hydroponics eliminates soil use, it also reduces the need for pesticides and remains less affected by external environmental factors (Satya Prakash et al., 2020). In another experiment conducted in

September 2019, crops like radish, beetroot, and turnip were initially grown in soil and then transplanted into a hydroponic system after 15 days. Colocasia, however, was cultivated directly in a hydroponic setup. Results showed that Colocasia successfully grew under the Nutrient Film Technique (NFT) system, reaching cormlet maturity in 90 days, while radish, turnip, and beetroot were harvested within 48–70 days (Agarwal A. et al., 2021).A separate study analyzed the influence of seed variety and planting systems over a 30 day period using two different seed types. Observations were evaluated using Design Expert software and an ANOVA test. The results indicated that plant growth was largely independent of seed type but heavily influenced by the planting system. Hydroponic cultivation consistently outperformed traditional methods in terms of plant development (Raneem Gashgari et al., 2018). In the broader context of smart farming, the development of large scale IoT based hydroponic systems introduces new business models. Researchers have highlighted the importance of addressing security concerns, privacy issues, and robust data governance. Several challenges and limitations associated with scaling up such systems were also identified, indicating the need for comprehensive planning and system architecture (Brewster C. et al., 2017).

8. Minerals required for Plant growth

The world's largest vertical farm, located in Dubai, spans 130,000 square feet and produces approximately 2,721 kilograms of food daily, using only 0.0004 times the water typically required by conventional agriculture. Remarkably, 85 out of every 100 people in the region consume food grown hydroponically ("Hydroponics: The Power of Water to Grow Food," 2019). Hydroponic systems are characterized by controlled nutrient management, which becomes particularly crucial when harvesting plant roots using downward stream flow applications. Plant responses are monitored to optimize nutrient induction and to prevent the accumulation of toxic or non essential substances. Earlier generations developed nutrient rich solutions to support plant growth (Nguyen NT et al., 2016). One innovative approach involved creating a liquid fertilizer from distillery slop, sugarcane leaves, and filtrate water in ratios of 1:0.1:0.25 and 1:0.25:0.25. This mixture was fermented over 30 days and then diluted with water at a 1:100 ratio. The resulting fertilizer displayed a germination index exceeding 100%, confirming its non phytotoxic properties. Plants grown using this fermented fertilizer showed a growth life cycle similar to those cultivated with chemical fertilizers (Phibunwatthanawong, T. et al., 2019).

Hydroponic systems are designed to circulate minimal yet effective amounts of nutrients directly to the plant roots, enhancing both growth quality and sustainability. The integration of plant growth promoting rhizobacteria (PGPR) is encouraged to foster healthier development. Advanced systems now leverage sensor data and machine learning algorithms to analyze plant conditions in real time and adjust nutrient composition accordingly (Paolo Sambo et al., 2019). To further optimize nutrient regulation, a Fuzzy Inference System (FIS) is used as a fitness function for mineral control, while genetic algorithms help reduce fluctuations in mineral delivery. A convergence error function is employed to minimize errors within the FIS framework (Lenord Melvix J.S.M. & Sridevi C., 2014). Thirteen essential nutrients are typically introduced into hydroponic systems to support lettuce growth (J.E. Rakocy et al., 2005). Metal analysis has shown that macro elements accumulate more in the shoots, whereas micronutrients such as Fe, Cd, and Zn are found in higher concentrations in the roots. To support these experiments, specialized lab setups including autoclaves, fume hoods, and temperature controlled rooms (at 40°C) are required (Nguyen NT et al., 2016). Researchers also study transcriptional responses of roots using qRT PCR after modifying nutrient elements such as calcium, magnesium, potassium, and sodium, while keeping other ionic contributions constant (Simon J. Conn et al., 2013). Nutrient supplementation using amino acids and seaweed extract has been shown to prolong the life cycle and improve the physicochemical quality of bell pepper plants, particularly by reducing decay (Rashid Iqbal Khan et al., 2018).

To minimize nutrient waste, hydroponic systems often employ nutrient recirculation methods. Research shows that leachates can remove up to 51% of essential minerals; however, perlite substrates can retain these nutrients until they reach concentrations of approximately 5% calcium, 6% nitrogen, and 7% phosphorus (David Sanjuan et al., 2020). Nutrient delivery systems for crops like tomatoes use advanced recirculation techniques such as Direct Leachate Recirculation (DLR), Chemical Precipitation (CP), and Membrane Filtration (MF) to maintain an efficient supply of essential minerals (Rufí Salís et al., 2020). Lastly, salinity levels play a critical role in hydroponic systems. Experiments on barley plants under elevated Na^+ and Cl^- conditions revealed that hydroponic cultivation is more sensitive to salinity stress compared to traditional farming. These findings underscore the importance of managing osmotic pressure to prevent reduced plant growth in soil less environments (Tavakkoli et al., 2010).

9. Optimizing water usage.

Water management in hydroponic systems is centered on the recirculation of nutrient rich solutions, which has been shown to benefit a wide variety of crops (Liliana Cifuentes et al., 2020). A critical component of such systems is the treatment of water, particularly when integrating wastewater into hydroponic operations. Pre treatment is essential to eliminate excess nutrients from wastewater, preventing the oversupply of certain elements that may harm plant development. Various water treatment processes such as activated sludge treatment, zoning, and biological activated carbon filtration are implemented to ensure water quality. In these systems, nutrient levels, especially nitrogen, are closely monitored and treated when concentrations exceed 40 mg/L (Alexa Bliedung et al., 2020).

Carmelo Maucieri et al. (2018) evaluated different delivery and flow methods for hydroponic pilot plants and concluded that plant biomass yield remained satisfactory regardless of the initial nutrient content in the wastewater. Recirculation remains one of the most promising techniques for reducing water consumption and maximizing nutrient reuse within hydroponic systems. Earlier work by N. Sigrimis et al. (2001) explored timed nutrient delivery, providing mixed nutrient water for 10 minutes every 70 minutes over a span of 11 to 13 hours daily. This approach was found to be both economically and environmentally sustainable by significantly lowering water pumping requirements. Similarly, in aquaponic systems, optimal performance for fish health, plant growth, and nutrient removal was achieved by reusing treated water at a flow rate between 0.8 and 8.0 liters per minute.

Advanced irrigation models, such as those developed by A. Anastasiou et al. (2019), utilize real time data from greenhouse environments to optimize water supply. These models integrate inputs from drainage meters and soil moisture sensors, and apply linear or nonlinear optimization techniques to minimize water loss and error in irrigation cycles. Marwan Haddad et al. (2011) supported the development of decentralized impure water treatment systems, citing their low cost construction, maintenance efficiency, and long operational life. These systems often utilize simple materials like barrels or channels to form the hydroponic framework.

A comparative study by Guilherme Lages Barbosa et al. (2015) revealed the superior efficiency of hydroponics over conventional farming. In hydroponic systems spanning 815 m^2, stem less crops yielded 41 kg/m^2 with a predictable variation of 6.1 kg/m^2. Water use was recorded at just 20 L/kg of produce, and energy consumption stood at 90,000 KJ/kg (±3.8 L/kg and ±11,000 KJ/kg, respectively). In contrast, soil based farming over the same area produced only 3.9 kg/m^2 (±0.21 kg/m^2), requiring 250 L/kg of water and 110 KJ/kg of energy (±25 L/kg and ±75 KJ/kg). These findings underline the significant resource efficiency and yield advantages of hydroponic systems.

10. Basic Hydroponic system

In a brief study, Nisha Sharma et al. (2018) constructed a basic hydroponic system on the terrace of a residential flat. The setup included essential components such as a grow tent, grow light, PVC pipes and end caps, a submersible water pump, plant growing minerals, and pH adjustment solutions. To automate the system, a motherboard and various sensors were integrated, including an Arduino microcontroller, pH sensor, EC sensor, air temperature and humidity sensor, water flow sensor, water temperature sensor, a water filtration and cooling system, and a light intensity sensor. The system employed an Ebb and Flow hydroponic technique, where plants were placed on a growing medium submerged in a water mineral solution. The submersible pump facilitated the flow of this nutrient mixture into the grow bed. Once the cycle completed, the solution drained back into the reservoir, allowing for reuse in subsequent irrigation cycles.

11. Applications

Hydroponic systems have a wide range of applications, including home gardening, indoor cultivation, and the growth of medicinal plants. The ability to precisely control nutrient content and influence plant characteristics reduces the need for chemical pest control, thereby lowering associated costs. These systems can be implemented both vertically and horizontally, allowing for high density cultivation in limited spaces. This makes hydroponics particularly well suited for countries that depend heavily on food imports, especially those located in arid or resource scarce regions.

12. Results

The proposed work demonstrates the efficient automation of hydroponic farming through the use of minimal resources and cost effective components. The system is designed for easy installation, even under challenging environmental conditions. Experimental results validate its performance, highlighting strong system stability and precise control actions.

13. Conclusions

The purpose of this article is to bridge the gap between technology and agriculture by introducing farmers to the automation of hydroponic systems through neural networks, the Internet of Things (IoT), and SMART applications. It offers in depth insights into nutrient management and biological processes in hydroponics, catering specifically to professionals in Mechanical, Electrical, and Electronics engineering. This paper presents a comprehensive overview of advancements in the field of hydroponics, with the intent to attract attention and encourage further research contributions. The fully automated hydroponic system discussed operates autonomously, requiring human intervention only for initiating the monitoring process. Cultivation using this automated approach has proven to be efficient, as environmental and nutrient parameters are precisely regulated. As proposed, hydroponics shows significant promise for sustainable development, capable of meeting the food demands of a rapidly growing global population.

14. Declaration of competing interest

The authors assert that there are no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Mamta D. Sardare, Shraddha V. Admane, 2013, "A review on plant without soil– Hydroponics", IJRET: International Journal of Research in Engineering and Technology ISSN: 2319 1163, Volume: 02 Issue: 03 DOI: 10.15623/ijret.2013.0203013

[2] Muhammad E H Chowdhury , Amith Khandakar, Saba Ahmed , Fatima Al Khuzaei , Jalaa Hamdalla , Fahmida Haque , Mamun Bin Ibne Reaz , Ahmed Al Shafei , Nasser Al Emadi, 2020, Design, Construction and Testing of IoT Based Automated Indoor Vertical Hydroponics Farming Test Bed in Qatar Sensors Published by MDPI, Online ISSN: 1424 8220 20(19):5637, DOI: 10.3390/s20195637

[3] Rakshitha M. , Shwetha. H. L , Roopa , Tejashwini. R , Anitha S Prasad , 2018, "Automation of Hydroponics System using Android Application and Ubidots Platform "INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH & TECHNOLOGY (IJERT) NCESC – 2018 (Volume 6 – Issue 13)

[4] Raneem Gashgari, Khawlah Alharbi, Khadija Mughrbil, Ajwan Jan, Abeer Glolam, 2018, Comparison between Growing Plants in Hydroponic System and Soil Based System Proceedings of the 4th World Congress on Mechanical, Chemical, and Material Engineering (MCM'18) Madrid, Spain ICMIE 131, DOI: 10.11159/icmie18.131.

[5] Brewster, C., Roussaki, I., Kalatzis, N., Doolin, K., & Ellis, K. (2017). IoT in Agriculture: Designing a Europe Wide Large Scale Pilot. IEEE Communications Magazine, 55(9), 26–33. doi:10.1109/mcom.2017.1600528.

[6] Dr. Umesh Barikar S. Santhana BosuK.P. RemaA.R. Murumkar, 2013, "Drip irrigation with fertigation in soil less media for tomato under controlled cultivation", Journal of Applied Horticulture, 15(3):195 197, DOI: 10.37855/jah.2013.v15i03.38

[7] R. ParameshwarareddyS.S. AngadiRaveendra H PatilRaveendra H PatilM.S. Biradar, 2018 "Influence of Drip Irrigation Levels and Soilless Media on the Growth, Productivity and Economics of Greenhouse Grown Tomato" International Journal of Current Microbiology and Applied Sciences 7(04):302 308 DOI: 10.20546/ijcmas.2018.704.034

[8] N.C. Barman, M.M. Hasan, M.R. Islam and N.A. Banu, 2016 "A review on present status and future prospective of hydroponics technique", Plant Environment Development , 5(2):1 7 Print ISSN 1994 1501Online ISSN 2311 3529

[9] Shreyash Mahadev Ghatage, Shubham R. Done, Sohail Akhtar, Shrreganesh Jadhav, Revanasiddappa Havaragi, 2019 a hydroponic system for indoor plant growth International Research Journal of Engineering and Technology (IRJET) e ISSN: 2395 0056, p ISSN: 2395 0072 1279 1286

[10] Gwynn Jones, Dylan; Dunne, Hannah; Donisson, Iain; Robson, Paul; Sanfratello, Giovanni Marco; Schlarb Ridley, Beatrix; Hughes, Kevin ; Convey, Peter, 2018, "Can the optimisation of pop up agriculture in remote communities help feed the world?" Global Food Security, 18. 35 43 DOI:10.1016/j.gfs.2018.07.003

[11] Palande V., Zaheer A., George K., 2018, "Fully automated hydroponic system for indoor plant growth". Procedia Computer Science 129,482 488 https://doi.org/10.1016/j.procs.2018.03.028

[12] Ayaz, M., Ammad Uddin, M., Sharif, Z., Mansour, A., & Aggoune, E. H. M. (2019). Internet of Things (IoT) Based Smart Agriculture: Toward Making the Fields Talk. IEEE Access, 7, 129551–129583. doi:10.1109/access.2019.2932609

[13] Dolci, R. (2017). IoT Solutions for Precision Farming and Food Manufacturing: Artificial Intelligence Applications in Digital Food. 2017 IEEE 41st Annual Computer Software and Applications Conference (COMPSAC). doi:10.1109/compsac.2017.157.

[14] Phutthisathian, A., Pantasen, N., & Maneerat, N. (2011). Ontology Based Nutrient Solution Control System for Hydroponics. 2011 First International Conference on Instrumentation, Measurement, Computer, Communication and Control. doi:10.1109/imccc.2011.260.

[15] Sreedevi, T. R., & Santosh Kumar, M. . (2020). Digital Twin in Smart Farming: A Categorical Literature Review and Exploring Possibilities in Hydroponics. 2020 Advanced Computing and Communication Technologies for High Performance Applications (ACCTHPA). doi:10.1109/accthpa49271.2020.9213235

[16] Dr.D.Saraswathi , P.Manibharathy , R.Gokulnath , E.Sureshkumar , K.Karthikeyan , 2018 " Automation of Hydroponics Green House Farming using IOT" in: 2018 IEEE International Conference on System, Computation, Automation and Networking (ICSCA) DOI: 10.1109/ICSCAN.2018.8541251

[17] Pitakphongmetha J., Boonnam N., Wongkoon S., Horanont T., Somkiadcharoen D., Prapakornpilai J., 2016, "Internet of things for planting in smart farm hydro ponics style."International Computer Science and Engineering Con ference (ICSEC) DOI: 10.1109/ICSEC.2016.7859872

[18] Mehra M., Saxena S., Sankaranarayanan S., Tom R.J., Veeramanikandan M., 2018, "IoT based hydroponics system using Deep Neural Networks", Computers and Electronics in Agriculture,155, 473 486, DOI: 10.1016/j.compag.2018.10.015

[19] Zamora Izquierdo M.A., Santa J., Martínez J.A., Martínez V., Skarmeta, A.F., 2019, "Smart farming IoT platform based on edge and cloud computing", Biosystems Engineering 177,4 17 DOI: 0.1016/j.biosystemseng.2018.10.014

[20] Kyle Gabriel 3 June 2020 , " Automated Hydroponic System Build " , [www document] URL: https://kylegabriel.com/projects/2020/06/automated hydroponic system build.html (accessed on 25 may 2022)

[21] Fitria Hidayanti, Fitri Rahmah, Ahmad Sahro , 2020," Mockup as Internet of Things Application for Hydroponics Plant Monitoring System", Engineering Physics Department, Universitas Nasional, Jakarta, Indonesia ,International Journal of Advanced Science and Technology ,Vol. 29, No. 5, (2020), pp. 5157 5164 http://sersc.org/journals/index.php/IJAST/article/view/14025

[22] Ullah A., Aktar S., Sutar N., Kabir R. and Hossain A. , 2019, "Cost Effective Smart Hydroponic Monitoring and Controlling System Using IoT " Intelligent Control and Automation 10, 142 154, DOI: 10.4236/ica.2019.104010

[23] Domingues D.S., Takahashi H.W., Camara C.A.P. and Nixdorf S.L., 2012, "Automated system developed to control pH and concentration of nutrient solution evaluated in hydroponic lettuce production." Computers and Electronics in Agriculture 84: 53 61. DOI: 10.1016/j.compag.2012.02.006

[24] Nisha Sharma, Somen Acharya , Kaushal Kumar , Narendra Singh , O.P. CHAURASIA , 2019, "Hydroponics as an advanced technique for vegetable production: An overview", Journal of Soil and Water Conservation,ISSN: 022 457X (Print); 2455 7145 (Online) 17(4):364 371, DOI: 10.5958/2455 7145.2018.00056.5

[25] Wei, Y., Li, W., An, D., Li, D., Jiao, Y., Wei, Q., 2019. Equipment and intelligent control system in aquaponics: a review. IEEE Access 7, 169306 169326. doi:10.1109/access.2019.2953491

[26] Lab Water Purification Systems 2021 [www document] url https://www.merckmillipore.com/IN/en/water purification (accessed on 22 may 2022)

[27] Judith August 30, 2019 Hydroponics, pH URL [www document] https://blog.jencoi.com/ph in hydroponics how to maintain the ph levels of hydroponic systems. (accessed on 25 may 2022)

[28] London Grow Jan 31, 2020 URL [www document] https://www.londongrow.com/blogs/grow tips/understanding optimum temperature and humidity for plants. (accessed on 20 may 2022)

[29] HANNA INSTRUMENTS, May 2015, DO sensor URL [www] https://blog.hannainst.com/measuring dissolved oxygen of hydroponic nutrient solutions. (accessed 21 april 2022)

[30] Hardeep Singh, Dunn Bruce, 2016, "Electrical Conductivity and pH Guide for Hydroponics", Oklahoma Cooperative Extension Fact Sheets are HLA 6722 also available on website at: http://osufacts.okstate.edu

[31] How To Grow Hydroponic Ginger (Complete Beginners Guide), November 26, 2020 by Soak And Soil, URL [www document] https://soakandsoil.com/how to grow hydroponic ginger/ (accessed on 1 may 2022)
[32] Hydroponics vs. Aquaponics – A Complete, and Honest Comparison by Trees.com Staff last update on February 10, 2022 URL [www document] https://www.trees.com/gardening and landscaping/hydroponics vs aquaponics (accessed on 23 april 2022)
[33] D. Adidrana and N. Surantha, "Hydroponic Nutrient Control System based on Internet of Things and K Nearest Neighbors," 2019 International Conference on Computer, Control, Informatics and its Applications (IC3INA), 2019, pp. 166 171, doi: 10.1109/IC3INA48034.2019.8949585.
[34] Understanding optimum Temperature and Humidity for Plants Grow EnvironmentLondon GrowJan 31, 2020 URL [www document] https://www.londongrow.com/blogs/grow tips/understanding optimum temperature and humidity for plants (accessed on 28 april 2022)
[35] Growing ginger hydrophonically, hydroponic nutrients Agrifarming, 2021, URL[www documents] https://gardeningtips.in/growing ginger hydroponically hydroponic nutrients (ccessed on 28 april 2022)
[36] Julie Weisenhorn and Natalie Hoidal, Extension horticulture educators 2020, Lighting for indoor plants and starting seeds URL [www document] https://extension.umn.edu/planting and growing guides/lighting indoor plants (ccessed on 28 april 2022)
[37] Pennisi, G., Orsini, F., Blasioli, S. et al. Resource use efficiency of indoor lettuce (Lactuca sativa L.) cultivation as affected by red:blue ratio provided by LED lighting. Sci Rep 9, 14127 (2019). DOI: 10.1038/s41598 019 50783 z
[38] Jun Gu Lee, Chang Sun Choi, Yoon Ah Jang, Suk Woo Jang, Sang Gyu Lee,and Yeong Cheol Um, 2013, "Effects of air temperature and air flow rate control on the tipburn occurrence of leaf lettuce in a closed type plant factory system" Horticulture, Environment and Biotechnology 54(4):303 310 DOI: 10.1007/s13580 013 0031 0
[39] Ying Zhang Murat KaciraMurat KaciraLingling AnLingling An, 2016," A CFD study on improving air flow uniformity in indoor plant factory system", Biosystems Engineering 147:193 205 DOI: 10.1016/j.biosystemseng.2016.04.012
[40] Soniya Joshi, Vrushali Gujar, 2018, "Automation in Hydroponic System using Control Circuit", International Journal of Innovative Research in Science, Engineering and Technology ISSN(Online): 2319 8753 ISSN (Print): 2347 6710 Vol. 7, Issue 10,10891 10897 DOI:10.15680/IJIRSET.2018.0710054.
[41] Imran Ali Lakhiar, Gao Jianmin, Tabinda Naz Syed, Farman Ali Chandio, Noman Ali Buttar, Waqar Ahmed Qureshi, 2018, "Monitoring and Control Systems in Agriculture Using Intelligent Sensor Techniques: A Review of the Aeroponic System", Journal of Sensors, vol. 2018, Article ID 8672769, 18 pages, DOI: 10.1155/2018/8672769
[42] Diego S. Domingues, Hideaki W. Takahashi, Carlos A.P. Camara, Suzana L. Nixdorf, 2012, "Automated system developed to control pH and concentration of nutrientsolution evaluated in hydroponic lettuce production" Computers and Electronics in Agriculture, Volume 84, June 2012, Pages 53 61, DOI: 10.1016/j.compag.2012.02.006
[43] B S Shubhashree, Divya D, Harsha Mohan Hiremath, Jyothi T U, Yashonidhi Yajaman, 2020, "Design of Hydroponics System for Remote Automation", INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH & TECHNOLOGY,ISSN: 2278 0181 NCCDS 2020 (VOLUME 8 ISSUE 13)
[44] P Sihombing, N A Karina, J T Tarigan and M I Syarif, 2017, "Automated hydroponics nutrition plants systems using arduino uno microcontroller based on android", Journal of Physics: Conference Series, Volume 978 012014, 2nd International Conference on Computing and Applied Informatics 2017 28–30 November 2017, Medan, Indonesia doi:10.1088/1742 6596/978/1/012014
[45] Vijendra Sahare, Preet Jain, 2015, "Automated Hydroponic System using Psoc4 Prototyping Kit to Deliver Nutrients Solution Directly to Roots of Plants on Time Basis", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering. ISSN (Print) : 2320 – 3765 ISSN (Online): 2278 – 8875 4:8765 8770 DOI:10.15662/IJAREEIE.2015.0411032
[46] Sang Yong Nam Hyun Seok Lee Soon Yil Soh Raisa Aone Marciales Cabahug Raisa Aone Marciales Cabahug, 2016, "Effects of Supplementary Lighting Intensity and Duration on Hydroponically Grown Crassulaceae Species", Flower Research Journal 24(1):1 9, DOI: 10.11623/frj.2016.24.1.1
[47] S. Adhau, R. Surwase and K. H. Kowdiki, 2017, "Design of fully automated low cost hydroponic system using LabVIEW and AVR microcontroller,"IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing (INCOS), pp. 1 4, doi: 10.1109/ITCOSP.2017.8303091.

[48] Dr. Asawari Dudwadkar , Tarit Das , Sakshi Suryawanshi , Tejas Kothawade, Rajeshwari Dolas, 2020, "Automated Hydroponics with Remote Monitoring and Control Using IoT", INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH & TECHNOLOGY (IJERT), ISSN (Online) : 2278 0181 Volume 09, Issue 06, DOI: 10.17577/IJERTV9IS060677

[49] Shreya Tembe, Sahar Khan, Rujuta Acharekar, 2018, "IoT based Automated Hydroponics System", International Journal of Scientific & Engineering Research, Volume 9, issue 2 ISSN 2229 5518

[50] João Pedro Silvestre, Renan Ribeiro Barzan, 2016, "ELECTRICAL CONDUCTIVITY OF NUTRIENT SOLUTION ON CRISPHEAD LETTUCE FERTIGATED AT SAND" International Journal of Current Research,ISSN: 0975 833X Vol8(Iss10):p:40307 40309

[51] Alejandro Isabel Luna Maldonado, Julia Mariana Márquez Reyes, Héctor Flores Breceda, Humberto Rodríguez Fuentes, Juan Antonio Vidales Contreras and Urbano Luna Maldonado, 2019,"Automation and Robotics Used in Hydroponic System", journal of Urban Horticulture, DOI: 10.5772/intechopen.90438

[52] Miss. Felicia Bernadine Vaz, Miss. Simmi Narayan Bhat, Miss. Shraddha Sakharam Kambli, Mr. Keshav Venkatesh Bhat, 2016, "Cost Effective Irrigation and Fertigation System", International Journal of Science Technology & Engineering | Volume 2 | Issue 09 | March 2016 ISSN (online): 2349 784X

[53] Chapter 1.1 Theory and Technology to Control the Nutrient Solution of Hydroponics, Plant Factory Using Artificial Light Adapting to Environmental Disruption and Clues to Agricultural Innovation 2019, Pages 5 14 DOI: 10.1016/B978 0 12 813973 8.00001 4

[54] Monteiro, J., Barata, J., Veloso, M., Veloso, L., & Nunes, J. (2018). Towards Sustainable Digital Twins for Vertical Farming. 2018 Thirteenth International Conference on Digital Information Management (ICDIM). doi:10.1109/icdim.2018.8847169.

[55] K. P. Ferentinos, & L. D. Albright. (2002). PREDICTIVE NEURAL NETWORK MODELING OF pH AND ELECTRICAL CONDUCTIVITY IN DEEP–TROUGH HYDROPONICS. Transactions of the ASAE, 45(6). doi:10.13031/2013.11412

[56] Sabrina Naz, A. H. M. Rezaul Haq, Md. Mizanur Rahman and Masuma Khatun, 2021, "An Initiative for Developing Low Cost Hydroponic System", Haya: The Saudi Journal of Life Sciences, ISSN 2415 623X (Print) |ISSN 2415 6221 (Online), DOI: 10.36348/sjls.2021.v06i01.003

[57] Shailesh Solanki, Nitish Gaurav, Geetha Bhawani and Abhinav Kumar. (2017); CHALLENGES AND POSSIBILITIES IN HYDROPONICS: AN INDIAN PERSPECTIVE. Int. J. of Adv. Res. 5 (Nov). 177 182] (ISSN 2320 5407). www.journalijar.com, DOI: 10.21474/IJAR01/5752

[58] Satya Prakash , Rajat Singh, A. R. Kumari and Adarsh Kumar Srivastava, 2020, "Role of Hydroponics towards Quality Vegetable Production: An Overview", International Journal of Current Microbiology and Applied Sciences ISSN: 2319 7706 Special Issue 10 pp. 252 259

[59] Agarwal A., Sahay, D., Yadav , P., Prakash, O., Bala, M., 2021, "Cultivation of Colocasia andunderground vegetables under Hydroponics: A Success Report from DIBER.", Academia Letters, Article 2811, DOI: 10.20935/AL2811

[60] Valentina Lagomarsino, 2019, "Hydroponics: The power of water to grow food" url [www document] https://sitn.hms.harvard.edu/flash/2019/hydroponics the power of water to grow food/ (accessed on 20 may 2022)

[61] Nguyen NT, McInturf SA, Mendoza Cózatl DG.,2016 "Hydroponics: A Versatile System to Study Nutrient Allocation and Plant Responses to Nutrient Availability and Exposure to Toxic Elements". J Vis Exp. 2016 Jul 13;(113):54317. PMID: 27500800; PMCID: PMC5091364. DOI: 10.3791/54317.

[62] Rashid Iqbal Khan,Ishfaq Ahmad Hafiz,Muhammad Shafique,Touqeer Ahmad,Ishaq Ahmed &Abdul Ahad QureshiDepartment of Horticulture, Pir Mehr Ali Shah, 2018, "Effect of pre harvest foliar application of amino acids and seaweed (Ascophylum nodosum) extract on growth, yield, and storage life of different bell pepper (Capsicum annuum L.) cultivars grown under hydroponic conditions", Journal of Plant Nutrition, Volume 41, 2018 Issue 18, DOI: 10.1080/01904167.2018.1504966

[63] Phibunwatthanawong, T., Riddech, N., 2019, "Liquid organic fertilizer production for growing vegetables under hydroponic condition." Int J Recycl Org Waste Agricult 8, 369–380 (2019). DOI: 10.1007/ 40093 019 0257 7

[64] Paolo Sambo, Carlo Nicoletto, Andrea Giro1, Youry Pii, Fabio Valentinuzzi, Tanja Mimmo, Paolo Lugli, Guido Orzes, Fabrizio Mazzetto, Stefania Astolfi, Roberto Terzano and Stefano Cesco2, 2019, "Hydroponic Solutions for Soilless Production Systems: Issues and Opportunities in a Smart Agriculture Perspective", Frontiers in Plant Science,Volume 10 article 923 DOI: 10.3389/fpls.2019.00923.

[65] Lenord Melvix J.S.M, & Sridevi C. (2014). Design of efficient hydroponic nutrient solution control system using soft computing based solution grading. 2014 International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC). doi:10.1109/iccpeic.2014.6915356.

[66] Simon J Conn, Bradleigh Hocking, Maclin Dayod, Bo Xu, Asmini Athman, Sam Henderson,Lucy Aukett, Vanessa Conn, Monique K Shearer, Sigfredo Fuentes, Stephen D Tyermanand Matthew Gilliham,2013,"Protocol: optimising hydroponic growth systems for nutritional and physiological analysis of Arabidopsis thaliana and other plants Conn et al. Plant Methods ", 9:4 Page 2 of 11, DOI:10.1186/1746 4811 9 4

[67] J.E. Rakocy, D.S. Bailey, R.C. Shultz, J.J. Danaher, 2005,"PRELIMINARY EVALUATION OF ORGANIC WASTE FROM TWO AQUACULTURE SYSTEMS AS A SOURCE OF INORGANIC NUTRIENTS FOR HYDROPONICS" International Conference and Exhibition on Soilless Culture: ICESC 2005 Acta Hortic. 742, 201 207, DOI: 10.17660/ActaHortic.2007.742.27

[68] David Sanjuan Delmás Alejandro Josa Pere Muñoz Santiago Gassó Joan Rieradevalla Xavier Gabarrell, 2020,"Applying nutrient dynamics to adjust the nutrient water balance in hydroponic crops. A case study with open hydroponic tomato crops from Barcelona" J. Scientia Horticulturae, Volume 261, 108908, DOI: 10.1016/j.scienta.2019.108908

[69] Rufí Salís, M., Calvo, M. J., Petit Boix, A., Villalba, G., & Gabarrell, X. (2020). Exploring nutrient recovery from hydroponics in urban agriculture: An environmental assessment. Resources, Conservation and Recycling, 155, 104683. doi:10.1016/j.resconrec.2020.104683

[70] Tavakkoli, E., Rengasamy, P., & McDonald, G. K. (2010). The response of barley to salinity stress differs between hydroponic and soil systems. Functional Plant Biology, 37(7), 621. doi:10.1071/fp09202.

[71] I., L., & C., F. (2012). Nutrient Solutions for Hydroponic Systems. Hydroponics A Standard Methodology for Plant Biological Researches. doi:10.5772/37578

[72] Wilson A. Lennard,Brian V. Leonard, 2006," A comparison of three different hydroponic sub systems(gravel bed, floating and nutrient film technique)in an Aquaponic test system" Aquacult Int (2006) 14:539–550 DOI 10.1007/s10499 006 9053 2

[73] Jerônimo L. AndrioloGean L. da LuzMaiquel H. WitterRodrigo dos S. GodoiGisele T. BarrosOrcial C. Bortolotto, 2005,"Growth and yield of lettuce plants under salinity" J. Hortic. Bras. 23 (4), DOI: 10.1590/ 0102 05362005000400014

[74] Rose C.; Parker, A.; Jefferson, B. & Cartmell, E. (2015). The Characterization of Feces and Urine: A Review of the Literature to Inform Advanced Treatment Technology. Critical Reviews in Environmental Science and Technology. 45(17), 1827–1879. DOI:10.1080/10643389.2014.1000761.

[75] Sánchez, H.J.A. Lactuca sativa production in an Anthroponics System. 2015. Available online: https://www.hemmaodlat.se/research/lactuca%20sativa%20production%20in%20an%20anthroponics%20system.pdf (accessed on 28 July 2021).

[76] H.F. Lakma Upendri Brintha Karunarathna, 2021, "Organic nutrient solution for hydroponic system", Academia Letters, Article 1893, DOI: 10.20935/AL1893.

[77] A. C. Bandi Victor Cristea Victor CristeaDediu LorenaDediu Lorena, 2016, "The review of existing and in progress technologies of the different subsystems required for the structural and functional elements of the model of multi purpose aquaponic production system" Romanian Biotechnological Letters, Vol. 21, No. 4, 2016

[78] Liliana Cifuentes Torres,Leopoldo G. Mendoza Espinosa,Gabriel Correa Reyes,Luis Walter Daesslé, 2020,"Hydroponics with wastewater: a review of trends and opportunities", Water and environmental journal promoting sustainable solution Volume35, issue 1, DOI: 10.1111/wej.12617

[79] Alexa Bliedung; Thomas Dockhorn; Jörn Germer; Claudia Mayerl; Marius Mohr, 2020,"Experiences of running a hydroponic system in a pilot scale for resource efficient water reuse " Journal of Water Reuse and Desalination (2020) 10 (4): 347–362. DOI: 10.2166/wrd.2020.014

[80] Carmelo Maucieri Carlo Nicoletto Carlo Nicoletto Ranka Junge, 2018,"Hydroponic systems and water management in aquaponics: A review", Italian Journal of Agronomy 2018; volume 13:1012 DOI: 10.4081/ija.2018.1012

[81] N. Sigrimis, K.G. Arvanitis , G.D. Pasgianos, K. Ferentinos,2001, "Hydroponics water management using adaptive scheduling with an on line optimiser"Computers and Electronics in Agriculture 31 (2001) 31–46 DOI:10.1016/S0168 1699(00)00172 1

[82] A. Anastasiou, Kostas Arvanitis, Nick Sigrimis, 2019,"Precision Irrigation Management using an Adaptive Optimizer", Conference: 1st Conference of the Hellenic Association of ICT in Agriculture, Food and

Environment, pp. 267 280

[83] Marwan Haddad Numan MizyedNuman Mizyed, 2011, "Evaluation of various hydroponic techniques as decentralised wastewater treatment and reuse systems" International Journal of Environmental Studies 68:461 476, DOI: 10.1080/00207233.2011.582701

[84] Guilherme Lages Barbosa , Francisca Daiane Almeida Gadelha , Natalya Kublik ORCID, Alan Proctor ,Lucas Reichelm ,Emily Weissinger ,Gregory M. Wohlleb andRolf U. Halden, 2015, Comparison of Land, Water, and Energy Requirements of Lettuce Grown Using Hydroponic vs. Conventional Agricultural Methods, Int. J. Environ. Res. Public Health 2015, 12(6), 6879 6891,DOI: 10.3390/ijerph120606879

[85] Souza S.V., Gimenes, R.M., & Binotto, E. (2019). Economic viability for deploying hydroponic system in emerging countries: A differentiated risk adjustment proposal. Land Use Policy.83, 357 369

[86] Alatorre Cobos, F., Calderón Vázquez, C., Ibarra Laclette, E. et al. An improved, low cost, hydroponic system for growing Arabidopsis and other plant species under aseptic conditions. BMC Plant Biol 14, 69 (2014). DOI: 10.1186/1471 2229 14 69

[87] Prafulla Kumar Naik, R. B. DhuriBijaya K. SwainBijaya K. SwainN. P. SinghN. P. Singh, 2012, "Cost of Production of Hydroponics Fodder Maize" Conference: 8th Biennial Animal Nutrition Association Conference on " Animal Nutrition Research Strategies for Food Security" (pp. 28 30)

[88] Johanna Suhl ,Dennis Dannehl ,Werner Kloas ,Daniela Baganz ,Sebastian Jobs ,Günther Scheibe UweSchmidt, 2016, "Advanced aquaponics: Evaluation of intensive tomato production inaquaponics vs. conventional hydroponics", J. Agricultural Water Management, 178,335 344 DOI: 10.1016/j.agwat.2016.10.013.

[89] Benke, K., & Tomkins, B. (2017). Future food production systems: vertical farming and controlled environment agriculture. Sustainability: Science, Practice and Policy, 13(1), 13–26. doi:10.1080/15487733.2017.1394054.

[90] Sreedevi, T. R., & Santosh Kumar, M. . (2020). Digital Twin in Smart Farming: A Categorical Literature Review and Exploring Possibilities in Hydroponics. 2020 Advanced Computing and Communication Technologies for High Performance Applications (ACCTHPA). doi:10.1109/accthpa49271.2020.9213235