International Journal of Environment and Climate Change

Volume 13, Issue 10, Page 2403-2410, 2023; Article no.IJECC.105089
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Hydroponic Cultivation: Factors Affecting Its Success and Efficacy

Kailashkumar B. [a++*], **Priyadharshini K.** [a#] **and Logapriya M.** [a†]

[a] *Department of Agricultural Engineering, Mahendra Engineering College (Autonomous), Salem-Tiruchengode Highway, Mahendhirapuri, Mallasamudram West, Namakkal, Tamil Nadu-637503, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2023/v13i102905

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/105089

Review Article

Received: 16/06/2023
Accepted: 22/08/2023
Published: 06/09/2023

ABSTRACT

Hydroponics or soilless method of cultivation, has revolutionized modern agriculture by offering a sustainable and efficient alternative to traditional soil-based farming. However, the success of hydroponic cultivation relies heavily on various factors that influence plant growth and overall system performance. This review study aims to investigate the effects of different factors on hydroponic cultivation. Factors such as light intensity, quality, and duration; nutrient composition and balance; water quality; temperature and humidity; air circulation and ventilation; growing medium; pH and electrical conductivity; plant variety and genetics; system design and maintenance; and monitoring and control were discussed. By understanding the impact of these factors, farmers and researchers can optimize their hydroponic cultivation to achieve higher yields, healthier plants, and sustainable agricultural practices. The discussion of this study will contribute to the advancement and implementation of hydroponics as a viable solution for future food production.

[++] *Assistant Professor (Farm Machinery and Power Engineering);*
[#] *Technical Assistant (Hydroponics);*
[†] *Final year student (B.E. Agriculture Engineering);*
**Corresponding author: E-mail: kkailash35@gmail.com, kailashkumarb@mahendra.info;*

Keywords: Hydroponic cultivation; soilless method; soil-based farming; nutrient.

1. INTRODUCTION

Hydroponics or soilless method of cultivation, has gained significant attention in recent years as a sustainable and efficient way to grow plants [1]. By providing essential nutrients directly to the plant's roots through a nutrient-rich water solution, hydroponics offers numerous advantages over traditional soil-based farming. However, the effectiveness and productivity of a hydroponic system are influenced by various factors that need to be carefully managed. Understanding and optimizing these factors is crucial for achieving successful hydroponic cultivation. By gaining insights into the factors of hydroponic system, farmers, researchers, and enthusiasts can enhance their understanding of hydroponics and unlock its full potential as a sustainable agricultural practice. Hydroponic cultivation method represents a revolutionary leap in modern agriculture, transcending the boundaries of traditional soil-based farming practices. Rooted in ingenuity and scientific innovation, hydroponics is a sophisticated system that enables plants to flourish in nutrient-rich water solutions, free from the constraints of natural soil. This method, often hailed as a pinnacle of sustainable and resource-efficient agriculture, offers a novel approach to cultivation by meticulously controlling every facet of a plant's environment. Unlike conventional farming, where soil serves as the primary medium for nutrient absorption and support, hydroponics orchestrates an environment where water and essential nutrients are precisely delivered to plant roots. Through this method, plants can access nutrients more efficiently, resulting in accelerated growth rates and optimized yields. The hydroponic system operates within a meticulously designed framework that tailors factors such as water composition, nutrient concentration, pH levels, and light exposure to the specific needs of the cultivated plants. Hydroponics embodies a union of technological prowess and ecological responsibility. By eliminating the reliance on large tracts of arable land and significantly reducing water consumption, this cultivation method offers a viable solution to the challenges posed by a burgeoning global population and dwindling natural resources. Moreover, hydroponics has the potential to transcend geographical limitations, enabling the growth of crops in environments previously deemed unsuitable for traditional agriculture, such as arid deserts or urban settings. The sophistication of hydroponic systems spans a spectrum of techniques, each tailored to suit various plant types and growth requirements. From the elegant simplicity of the Nutrient Film Technique (NFT), where a thin film of nutrient-rich water is circulated over plant roots, to the intricacy of Deep Water Culture (DWC), where plants are suspended in oxygenated nutrient solutions, hydroponics offers a diverse toolkit to nurture a wide range of crops, from leafy greens to sprawling fruits.

2. MATERIALS AND METHODS

2.1 Components of Hydroponic System

Hydroponic cultivation is a method of growing plants without soil, instead using a nutrient-rich water solution. Growing container holds the plants and the nutrient solution. It can be made of various materials such as plastic, glass, or metal [2]. Nutrient solution is a water-based solution that contains all the necessary nutrients for plant growth, including macronutrients such as nitrogen, phosphorus, and potassium, as well as micronutrients such as iron, zinc, and copper. The pump is used to circulate the nutrient solution throughout the growing container. This ensures that all plants receive an adequate supply of nutrients and oxygen. The growing medium of hydroponic systems do not use soil, they still require a growing medium to anchor the plants and provide some support. Common growing mediums include rockwool, perlite, vermiculite, coconut coir, and clay pellets. The lighting for photosynthesis and hydroponic systems often use artificial lighting to provide a consistent source of light. LED lights are commonly used in hydroponic systems because they are energy-efficient and can be tailored to provide the specific wavelengths of light that plants need. The pH level of the nutrient solution is crucial for plant growth, and it needs to be carefully monitored [1]. A pH meter is used to measure the acidity or alkalinity of the solution, and adjustments can be made as necessary to ensure that the pH level remains within the optimal range for plant growth. Plants grow best in specific temperature and humidity ranges, and these factors need to be controlled in a hydroponic system. Fans, heaters, and humidifiers can be used to maintain the ideal conditions for plant growth. These are some of the essential components of a hydroponic system, but there are many variations and additional features that can be added depending on the specific needs of the plants being grown and the scale of the operation [3].

2.2 Effect of Coir Pith on Hydroponic Cultivation

Coir pith is a by-product of the coconut industry and is a popular growing medium in hydroponic agriculture. Hydroponic cultivation of Amaranthus using coir pith as a substrate has been found to have several benefits. Coir pith has a high-water holding capacity, which means it can retain water for a long time. This helps in maintaining the required moisture level for the plants, which is crucial for their growth. Coir pith also has good drainage properties, which prevents water logging and helps in the proper aeration of the roots. This ensures the roots get enough oxygen and prevents the occurrence of root diseases. Coir pith could retain nutrients, which is essential for the proper growth and development of plants. This reduces the need for frequent fertigation. Coir pith has a neutral pH, which means it does not affect the pH level of the nutrient solution. This is important because the pH level of the nutrient solution plays a crucial role in the absorption of nutrients by the plants [4]. Coir pith is an eco-friendly and sustainable substrate as it is a by-product of the coconut industry.

2.3 Effect of Temperature on Hydroponic Cultivation

Temperature plays a critical role in the success of hydroponic cultivation. The temperature affects the rate of photosynthesis, which is crucial for plant growth. Most plants grow well within a temperature range of 18-28°C. If the temperature falls below or rises above this range, plant growth may be stunted or even halted. The temperature affects the absorption of nutrients by the plant roots. And the temperature is too low, the uptake of nutrients by the roots slows down [5]. When the temperature is too high, the uptake of nutrients may be hindered or even damaged. In both cases, the plant growth can be negatively impacted. The temperature can influence the occurrence and spread of diseases in hydroponic systems. Higher temperatures can lead to increased humidity levels and can create a favorable environment for the growth of pathogens, while lower temperatures can cause a delay in the development of pathogens [5]. The temperature can also affect the amount of oxygen available to the plant roots [6]. Lower temperatures can lead to decreased oxygen availability, while higher temperatures can increase the rate of oxygen consumption. Maintaining a suitable temperature range can ensure adequate oxygenation of the root zone. In general, it is important to maintain the optimal temperature range for the specific plant species being grown in hydroponics. Monitoring the temperature of the nutrient solution and the air temperature in the growing area is important for successful hydroponic cultivation.

2.4 Effect of Air on Hydroponic Cultivation

Air plays a critical role in hydroponic cultivation. Plants grown in hydroponic systems rely on dissolved oxygen in the nutrient solution for healthy root growth and nutrient uptake. Without adequate oxygen, roots may become suffocated and unable to absorb nutrients, leading to poor plant growth and health [7]. Air also helps to promote healthy microbial activity in the nutrient solution, which can aid in nutrient uptake by the plants. Additionally, proper air circulation can help to prevent the buildup of harmful pathogens and pests in the hydroponic system. Proper ventilation and air exchange are important in hydroponic cultivation, as excess humidity and high temperatures can lead to the growth of mold and other harmful organisms. In some hydroponic systems, such as deep-water culture, air stones or diffusers may be used to increase oxygen levels in the nutrient solution and promote healthy root growth. The clean air is essential for successful hydroponic cultivation, and growers should ensure that their systems are properly ventilated and oxygenated for optimal plant growth and health.

2.5 Effect of Water pH on Hydroponic Cultivation

Water pH is a critical factor that affects hydroponic cultivation. The pH of the nutrient solution in a hydroponic system can impact the availability and uptake of essential nutrients by plants. Most plants prefer a slightly acidic pH between 5.5 and 6.5, although some plants may require a more alkaline or acidic environment [8]. If the pH of the nutrient solution is too high or too low, certain nutrients may become unavailable to the plants, leading to nutrient deficiencies and poor plant growth. For example, if the pH is too low, iron and manganese may become too available and cause toxicity to plants. On the other hand, if the pH is too high, phosphorus, calcium, and magnesium may become unavailable to the plant, leading to deficiencies. Maintaining a consistent pH in hydroponic systems is essential for optimal plant growth and health. Growers can test the pH of the nutrient solution regularly using pH meters or test strips and adjust it as necessary using pH-adjusting solutions or acids and bases. Many hydroponic nutrient solutions are designed to have a pH within the optimal range for plant growth. It's essential to note that different plants have different pH requirements, so growers should research the pH requirements of the plants they are cultivating and adjust the nutrient solution pH accordingly. Monitoring water pH in hydroponic cultivation is crucial, as it can have a significant impact on the overall health and productivity of plants.

2.6 Effect of Nutrient Solution on Hydroponic Cultivation

The nutrient solution is a critical component of hydroponic cultivation as it provides essential nutrients to the plants [9]. Nutrient solutions typically contain a balanced mixture of macronutrients (nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur) and micronutrients (iron, manganese, copper, zinc, boron, molybdenum, and chlorine) that are necessary for healthy plant growth. The composition of the nutrient solution can have a significant impact on plant growth and health. If the solution lacks certain nutrients, plants may experience nutrient deficiencies, leading to stunted growth, chlorosis (yellowing of leaves), or other symptoms. On the other hand, if the nutrient solution contains an excess of nutrients, it can lead to nutrient toxicity, which can also harm plants. To ensure optimal plant growth, it's crucial to provide the right balance of nutrients in the nutrient solution. The nutrient solution may need to be adjusted based on the type of plant, growth stage, and environmental conditions. For example, plants in the vegetative stage may require higher levels of nitrogen, while those in the flowering stage may require higher levels of phosphorus and potassium. It's also important to maintain the pH and electrical conductivity (EC) of the nutrient solution within the appropriate range for the plants being grown [10]. EC measures the concentration of dissolved salts in the nutrient solution, which can affect plant growth and health. To maintain a healthy nutrient solution, growers should monitor the nutrient solution regularly, adjust nutrient levels as necessary, and periodically replace the solution entirely. By carefully managing the nutrient solution, growers can optimize plant growth and maximize yields in hydroponic systems.

2.7 Effect of Relative Humidity in Hydroponic Cultivation

Relative humidity (RH) is an important environmental factor in hydroponic cultivation, as it can affect plant growth and health. RH refers to the amount of moisture in the air relative to the maximum amount of moisture that the air can hold at a given temperature. High RH levels can increase the risk of fungal and bacterial diseases, as the excess moisture can create a favorable environment for pathogens to thrive. Additionally, high humidity can reduce transpiration (the release of water vapor through the plant's leaves), which can inhibit nutrient uptake and reduce plant growth. On the other hand, low RH levels can cause excessive transpiration, which can lead to water stress in plants. Low humidity levels can also cause plants to lose water through their leaves faster than they can absorb it from the roots, leading to dehydration and reduced growth [10] and [11]. The ideal RH level for hydroponic cultivation depends on the stage of plant growth, with different crops having varying requirements. Generally, during the vegetative stage, RH levels between 60-70% are considered optimal, while during the flowering stage, lower humidity levels of around 40-50% are preferred to prevent mold growth. To maintain optimal RH levels, growers can use a dehumidifier to remove excess moisture from the air, or a humidifier to add moisture when RH levels are too low. Proper ventilation can also help to regulate humidity levels by promoting air circulation and preventing the buildup of excess moisture.

2.8 Effect of Light on Hydroponic Cultivation

Light is a crucial environmental factor in hydroponic cultivation, as it directly affects plant growth and development [12,13]. Light is essential for photosynthesis, the process by which plants convert light energy into chemical energy to fuel growth and development. Light quality, intensity, and duration all play a role in plant growth. Light quality refers to the spectrum of light wavelengths, with different wavelengths affecting plant growth differently. Blue light is essential for vegetative growth, while red light is necessary for flowering and fruiting. Green light,

Fig. 1. Hydroponic system (Dutch Bucket and Nutrient Film Technique)

Fig. 2. Coir pith in hydroponic system

although not as essential for plant growth, can still contribute to healthy growth and development. Light intensity refers to the amount of light energy reaching the plants. Plants have varying requirements for light intensity, with some crops requiring higher light levels than others. Insufficient light can lead to weak and spindly plants, while too much light can cause leaf burn and other damage. Light duration refers to the length of time that plants are exposed to light each day [5]. Plants require a certain amount of light each day to promote healthy growth, and the duration of light exposure can impact the timing of flowering and fruiting. To optimize light for hydroponic cultivation, growers can use artificial lighting systems that provide the optimal spectrum, intensity, and duration of light for the specific crop being grown [14]. LED grow lights are popular choices for hydroponic systems, as they are energy-efficient and allow growers to customize the light spectrum and intensity. It's important for hydroponic growers to monitor light levels regularly to ensure that plants are receiving the right amount of light for healthy growth. By providing the optimal light conditions, growers can maximize yields and promote healthy plant growth and development in hydroponic systems.

2.9 Limiting Factors of Hydroponic Cultivation

Hydroponic cultivation offers numerous advantages over traditional soil-based farming, such as more efficient use of resources and greater control over growing conditions. However, there are also several limiting factors that can affect the success of hydroponic cultivation. Here are some of the most significant factors: The quality of the water used in hydroponic systems is crucial. Water with high levels of dissolved salts, minerals, or other contaminants can harm plants and reduce yields. Water quality must be monitored and treated as necessary to ensure optimal growing conditions. Hydroponic plants require precise amounts of nutrients to grow properly. Overdosing or underdosing of nutrients can cause problems such as nutrient toxicity or deficiency, which can damage plants and reduce yields. The pH level of the nutrient solution is also critical for plant growth. If the pH is too high or too low, the plants will not be able to absorb nutrients properly, and growth will be stunted. Hydroponic plants require specific temperature and humidity ranges to grow properly. Temperature fluctuations or high humidity levels can promote the growth of pathogens or cause other issues that can reduce yields. Artificial lighting is often used in hydroponic systems to provide a consistent source of light. However, the intensity and duration of the light must be carefully monitored and adjusted as necessary to avoid overexposure or underexposure, which can affect plant growth. Hydroponic systems are typically indoors, and highly controlled environments, pests and diseases can spread quickly and cause significant damage to crop if not properly managed. The initial investment required to set up a hydroponic system can be significant, as it often involves purchasing specialized equipment and setting up a climate-controlled environment [15]. However, with proper planning, monitoring, and management, hydroponic farming can be a highly efficient and productive method of growing plants. The development of IoT system for monitoring of hydroponics can be the solution for the above-mentioned limiting factors.

2.10 IOT System for Monitoring of Hydroponics

The development of an IoT (Internet of Things) system for hydroponics can help automate the management of various factors, making it easier to grow healthy, high-yielding plants. The first step is to define the specific requirements of the hydroponic system. This includes the number and type of plants, the desired growing conditions, and the desired level of automation. Next, to select the appropriate sensors to monitor the hydroponic system [16]. This may include sensors to measure temperature, humidity, pH, nutrient levels, water levels, and other factors. A microcontroller, such as an Arduino or Raspberry Pi, is needed to control the sensors and other components of the IoT system. Then the appropriate connectivity options, such as Wi-Fi or Bluetooth, to allow for remote monitoring and control. The software will need to be developed to control the IoT system and to display and analyze the data collected by the sensors. This may include creating a mobile app or web application for remote monitoring and control. Once the IoT system is deployed, it can be used to automate many aspects of hydroponic cultivation, such as adjusting the nutrient and pH levels, controlling the lighting and irrigation system, and monitoring the environmental factors to maintain optimal growing conditions [17,18,19]. This automation can help reduce labor costs and improve the efficiency and yields of the hydroponic system. Additionally, the data collected by the sensors can be analyzed to identify patterns and trends, allowing growers to make informed decisions about how to optimize their hydroponic system for even better results. The integration of data analytics and monitoring systems in hydroponic setups has enabled growers to make informed decisions about plant health, resource management, and growth optimization. This data-driven approach enhances overall crop management.

3. CONCLUSION

Hydroponic cultivation requires significantly less water as compared to traditional field cultivation because the water is recirculated in the system. This makes it a more sustainable option for water-scarce regions. It also uses less land, fertilizers, and pesticides compared to traditional farming, making it more resource-efficient. It provide plants with optimal growing conditions, including precise control over nutrients, water, light, and temperature. This consistency allows for more predictable yields and can help reduce the risk of crop failure due to external factors such as weather. These systems are generally easier to manage and require less manual labor than traditional field cultivation. This is because hydroponic systems are usually located indoors and can be monitored and adjusted remotely using technology. It also eliminate the need for soil, which can harbor a range of soil-borne diseases that can damage crops. This makes hydroponic cultivation an attractive option for areas with poor soil quality or contaminated soil. Plants grown hydroponically tend to be healthier and produce higher quality fruits and vegetables. This is because the plants receive a precise balance of nutrients, which helps to promote optimal growth and development. The systems can be designed to suit different plant species and growing conditions. This allows for more flexibility in terms of what can be grown, where it can be grown, and when it can be grown. It also allows for year-round cultivation, making it possible to grow crops even in regions with long winters.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Zhang P, Senge M, Dai Y. Effects of salinity stress on growth, yield, fruit quality and water use efficiency of tomato under hydroponics system. Reviews in Agricultural Science. 2016;4:46-55.
2. Sharma N, Acharya S, Kumar K, Singh N, Chaurasia OP. Hydroponics as an advanced technique for vegetable production: An overview. Journal of Soil and Water Conservation. 2018;17(4):364-371.
3. Patil N, Patil S, Uttekar A, Suryawanshi AR. Monitoring of hydroponics system using IoT technology. International Research Journal of Engineering and Technology (IRJET). 2020; 7(06):5.
4. Gashgari R, Alharbi K, Mughrbil K, Jan A, Glolam A. August. Comparison between growing plants in hydroponic system and soil based system. In Proceedings of the 4th World Congress on Mechanical, Chemical, and Material Engineering Madrid, Spain: ICMIE. 2018;18:1-7).
5. Velazquez-Gonzalez RS, Garcia-Garcia AL, Ventura-Zapata E, Barceinas-Sanchez JDO, Sosa-Savedra JC. A Review on Hydroponics and the Technologies Associated for Medium- and Small-Scale Operations. Agriculture. 2022;12(5):646. Available:https://doi.org/10.3390/agriculture12050646.
6. Zhang J, Wang X, Zhou Q. Co-cultivation of Chlorella spp and tomato in a hydroponic system. Biomass and Bioenergy. 2017;97:132-138.
7. Putra ES, Jamaludin J, Djatmiko MD. Comparation of hydroponic system design for rural communities in Indonesia. Journal of Arts and Humanities. 2018;7(9):14-21.
8. Aliac CJG, Maravillas E. November. IOT hydroponics management system. In 2018 IEEE 10th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM) IEEE. 2018;1-5.
9. Fazaeli H, Golmohammadi HA, Tabatabayee SN, Asghari-Tabrizi M. Productivity and nutritive value of barley green fodder yield in hydroponic system. World Applied Sciences Journal. 2012;16(4):531-539.
10. Tocquin P, Corbesier L, Havelange A, Pieltain A, Kurtem E, Bernier G, Périlleux C. A novel high efficiency, low maintenance, hydroponic system for synchronous growth and flowering of Arabidopsis thaliana. BMC plant biology. 2003;3:1-10.
11. Chow YN, Lee LK, Zakaria NA, Foo KY. New emerging hydroponic system. In Symposium on Innovation and Creativity (iMIT-SIC). 2017;2:1-4.
12. Umamaheswari S, Preethi A, Pravin E, Dhanusha R. Integrating scheduled hydroponic system. In 2016 IEEE International Conference on Advances in Computer Applications (ICACA) IEEE. 2016;333-337.
13. Srinidhi HK, Shreenidhi HS, Vishnu GS. November. Smart Hydroponics system integrating with IoT and Machine learning algorithm. In 2020 International Conference on Recent Trends on Electronics, Information, Communication & Technology (RTEICT) IEEE. 2020;261-264.
14. Palande V, Zaheer A, George K. Fully automated hydroponic system for indoor plant growth. Procedia Computer Science. 2018;129:482-488.
15. Watson C, Pulford ID, Riddell-Black D. Screening of willow species for resistance to heavy metals: comparison of performance in a hydroponics system and field trials. International Journal of Phytoremediation. 2003;5(4):351-365.
16. Mehra M, Saxena S, Sankaranarayanan S, Tom RJ, Veeramanikandan M. IoT based hydroponics system using Deep Neural Networks. Computers and Electronics in Agriculture. 2018;155:473-486.
17. Mashumah S, Rivai M, Irfansyah AN. Nutrient film technique based hydroponic system using fuzzy logic control. International Seminar on Intelligent Technology and Its Applications (ISITIA) IEEE. 2018;387-390.

18. Kularbphettong K, Ampant U, Kongrodj N, An automated hydroponics system based on mobile application. International Journal of Information and Education Technology. 2019;9(8):548-552.

19. Pathak HS, Brown P, Best TA. Systematic literature review of the factors affecting the precision agriculture adoption process. Precis. Agric. 2019;20:1292–1316.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/105089