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# TRENDS IN THE USE OF HYDROPONICS IN HORTICULTURAL CROPS

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**ABSTRACT**

Soil based cultivation is now facing difficulties due to different man made reasons such as industrialization and urbanization. Also, sudden natural disasters, climate change and unrestricted utilization of chemicals for agricultural purposes cause the depletion of soil fertility and quality. That is why, scientists have developed a new alternative approach for cultivation system namely soil-less cultivation or hydroponics. The practice of hydroponic farming is widely used in modern agriculture where crop cultivation takes place without the use of soil and instead makes use of nutrient solutions. There are many forms of hydroponics such as nutrient film technique (NFT), drip system, aeroponics, Ebb Flow, water culture, wick system and the list continues as different designs emerge and are renamed. Through hydroponics a large number of plant crops can be grown. The quality of yield, taste and nutritive value of end products produced hydroponically is generally higher than the natural soil based cultivation. This cultivation is cost effective, disease free, eco-friendly and is gaining popularity all over the world including both the developed and the developing countries.

**Keywords:** Hydroponics, horticultural crops, drip System, nutrient film technique, aeroponics, wick system and Ebb flow

## Introduction

The science of growing plants without soil is referred to as hydroponics. In this type of farming, inert medium is used as a mechanical support system together with an aerated water-enriched nutrition solution. The medium might be made of an organic material like coconut fiber, peat moss, or pine bark or an inorganic substance like gravel, perlite, or rock wool. 'Hydroponics' is a term derived from the Greek words 'hydro' for water and 'ponos' for labor. Dr. Gericke, a professor and scientist from California, coined the name in 1929 and started to expand what had previously just been a laboratory technique for growing crops (Stein *et al*., 2014). The practice of hydroponic farming is widely used in modern agriculture where crop cultivation takes place without the use of soil and instead makes use of nutrient solutions (Khan *et al*., 2020). According to Maharana *et al*. (2011), hydroponics is a method for growing plants in soil-free environments with their roots dipped in nutrient solutions. Savaas *et al*., 2003 defined hydroponics as the practice of growing plants without the need of soil. The popularity of hydroponic culture has persisted for a number of reasons. This method does not require soil and allows for the cultivation of a high number of plants in a relatively little area. Additionally, maximal output is possible when properly fed. Finally, careful management of fertilizers, water, and aeration is possible. This level of control is challenging to duplicate in solid material. It is possible to grow a variety of crops with hydroponics. Crops grown hydroponically frequently outperform those grown natively in soil in terms of yield, flavor, and nutritional value (Jan *et al*., 2020). Regarding fertilizer and water efficiency, hydroponic greenhouse technologies are thought to be superior to field production techniques (Zimmermann and Fischer, 2020). On the other hand, a hydroponics-based system's structure and the management of its fertilizer and water solutions have a significant impact on its production. Hydroponic systems are ideal for recovering water and nutrients since the discharged solution may be easily collected for reuse. Closed hydroponic greenhouse vegetable systems have been shown to greatly reduce water pollution while also reduced watering and fertilizer (Khan *et al*, 2020). Hydroponic technique effectively grows crops in deserts, parched plains, mountainous areas, city roofs, and concrete schoolyards. Similar to manufacturing, agriculture should use technical advancements to offer creative solutions to persistent problems. Crops grown using high-yield hydroponic technology can be automated. Compared to greenhouses, where the soil is replaced with non-soil components and nutrients are obtained from water-rich nutrients, plant factories offer far more closely controlled environments (Kuncoro *et al*, 2021).

## Components of Hydroponics

### Light

Light is necessary for photosynthesis and growth in plants. It is a crucial factor that influences photosynthesis, photorespiration, and photoperiodism, all of which have an impact on plant development. The ideal light intensity for the majority of greenhouse vegetable crops ranges between 50,000 and 70,000 lux (Puengsungwan and Jirasereeamornkul, 2020). In a hydroponic system, plants are cultivated indoors, hence an artificial light source is necessary. Photosynthesis requires light energy which turns into chemical energy. When choosing a light source for a hydroponic system, it's crucial to take the intensity, duration, and wavelength of the light into account. The most popular light sources for hydroponics are LED, High-Intensity Discharge (HID), or Fluorescent lamps. It's crucial to remember that depending on the plants' stage of development, the light intensity and duration should be changed. For instance, young plants and seedlings will require less light, both in terms of intensity and duration, than adult plants (Santosh and Gaidkwad, 2023). Additionally, since many plant species have various light needs, it's critical to choose the proper light source and intensity for the particular plants being produced. By using light quality optimization, crop growth and quality can be enhanced. The studies conducted on *Lactuca indica* L. cv. 'Sunhyang' lettuce by Kim *et al*. (2021) revelaed that the photosynthetic rate, stomatal conductance, and transpiration rate in Indian lettuce's increased as the light intensity increased in DFT hydroponics at 14 days after planting.

### Temperature

The development and health of plants can be significantly impacted by temperature. The right temperature range must be maintained in a contained environment like a growth chamber for the best plant growth. The most common hydroponic systems require temperatures between temperatures for plants range from 20 to 25°C during the day and 15 to 20°C at night (Santosh and Gaidkwad, 2023). However, depending on the particular plant type, this may change because certain plants may need to thrive, temperatures must be higher or lower. Air temperature is the most important environmental component that affects vegetative growth, cluster development, fruit setting, fruit development, fruit ripening, and fruit quality (Jiang *et al*., 2020). Temperature changes have a significant impact on the plant quality and yield (Maucieri, 2019) which is evident from a study conducted by Gent (2006) who applied two different temperature treatments to hydroponically grown lettuce in greenhouses that received direct sunlight. For warm and cool treatments, the ventilation temperatures were 26 and 16°C and the minimum temperatures were 20 or 10°C, respectively. The rise in dry matter content at chilly temperatures was a significant temperature-related effect on hydroponically grown lettuce. The quality of lettuce for human consumption could be enhanced by lowering the temperature within a week of harvest. On the other hand, increasing the temperature would result in a decrease in nutrient concentrations while increasing growth rates. The dry matter content of leaf blades rose more in cool temperatures than in warm ones. Additionally, it is believed that plants grow taller and their leaves get narrower as the temperature difference between day and night increases (Grant, 2020). The organoleptic characteristics of vegetables are directly impacted by low temperatures. Low temperature will definitely be indicated by tomatoes that have reduced juice and a mealy flavor (Gruda *et al*., 2020). Fruits of the tomato, cucumber, and eggplant change in texture, color, and shape when exposed to high temperatures (Rouphael, 2018). It is advised to employ cooling systems, such as fans or air conditioning, to bring the temperature down if it is too high. On the other hand, heating systems can be utilized to increase the temperature if it is too low.

### Relative humidity

Since relative humidity has an impact on plant quality, controlling it inside the greenhouse is crucial. Most hydroponic plants thrive in a humidity range of 40% to 75 % (Khammayom, 2022). High humidity levels can foster the development of mould, mildew, and other pests and have a negative impact on the health of the plants (Xu *et al*., 2016). Conversely, low humidity levels may harm plants lower growth and yield as a result of wilting and drying out. Use of dehumidifiers or fans is advised to lower humidity levels if they are excessively high. On the other side, humidifiers can be used to raise the humidity if it is too low.

### Ventilation

An effective ventilation system is vital in regulating humidity and preventing the formation of fungus and mold. Additionally, it can support preserving the ideal temperature inside the growth room. The ventilation system's ability to remove too much heat and humidity from the chamber is one of its most crucial features. Exhaust fans can help with this by removing hot, humid air from the chamber and replacing it with new, cool air. Additionally, maintaining ideal amounts of carbon dioxide, which is crucial for plant growth, can be accomplished by using intake fans to draw in fresh air. It's also critical to confirm that the ventilation system is sized appropriately for the chamber. A system that is too small might not be able to efficiently remove extra heat and humidity, while a system that is too big might produce draughts and lead to temperature changes (Santosh and Gaidkwad, 2023).

### Carbon Dioxide

$CO_2$ concentration is one of the most significant environmental factors. The rate of photosynthesis typically increases until it is controlled by another variable because, in the light-independent process, a rise in $CO_2$ concentration increases the rate at which carbon is integrated into carbohydrates (Daneshwar *et al*., 2022). Therefore, it may be said that $CO_2$ concentration and photosynthetic rate are connected (Voutsinos *et al*., 2021)

### Water

When growing plants hydroponically, reverse osmosis (RO) water with little to low total dissolved salts (TDS) is used, allowing salts to be added based on the crop and plant stage. Hydroponics has lately started using wastewater treatment as a method of reducing environmental pollution. Although wastewater contains micro and macronutrients, a lack of knowledge about the right addition of nutrients can limit plant growth due to nutritional abundance or deficit (Kumar and Singh, 2023).

### Nutrients

The hydroponic nutrition solution must deliver soluble forms of water, oxygen, and essential mineral ingredients to the plant roots. For a plant to properly grow, seventeen components are necessary which includes nine macronutrients which are required in large amounts for plant growth: Carbon (C), Hydrogen (H), Oxygen ($O_2$), Sulfur (S), Phosphorus (P), Calcium (Ca), Magnesium (Mg), Potassium (K), and Nitrogen (N) and eight macronutrients that are needed in small amounts: Iron (Fe), Zinc (Zn), Copper (Cu), Manganese (Mn), Boron (B), Chlorine (Cl), Cobalt (Co), and Molybdenum (Mo) (Patel *et al*., 2020). A study conducted by Khodijah and Kusmiadi (2021) R on different concentrations of NPK + Gandasil while using chicken feather waste on lettuce using the straightforward wick system revealed that while the composition of the nutrient media had no bearing on plant height, it did have a significant bearing on leaf length. Another study conducted by Kaur *et al*. (2021) on various nitrogen and potassium ratios in tomatoes observed that the wicked system produced higher fruit yield and better-quality sugars in winter with a solution containing N and K in the ratio of 1.4:3 at the vegetative stage and 1.7:3.5 at the reproductive stage.

### Media

A successful culture medium must be able to give the plant the maximum quantity of water that is accessible (high water retention capacity) while also giving the roots appropriate aeration (Cascone 2019). In other words, there should be a good balance between macroporosity (porosity-free, consisting of all pores that do not retain water and are filled with air) and microporosity (consisting of pores capable of retaining water after complete saturation at the end of drainage). The suitability of various organic and inorganic substrates for crop cultivation was examined by Jagtap *et al*. (2022) who demonstrated that vegetables can be cultivated without soil, in water-filled containers, or on inexpensive natural substrates like sand, rice hulls, pumice stone, and other materials. Asnew sophisticated root zone substrates are currently being researched as a replacement to natural soils in hydroponic and greenhouse agriculture, these media ought to offer improved rooting conditions, anchoring and aeration for the root system as well as water and nutrients for the plants. A research was conducted by Subramani *et al*.in 2020 on the tomato hybrid 'ArkaRakshak' using various combinations of cocopeat, vermiculite, cocopeat, perlite, sand, and sawdust. According to the findings, cocopeat + sawdust (1:1 v/v) produced the best number of fruits per plant (12.33), fruit weight (51.2 g/fruit), and fruit output (631 g/plant), and was comparable to coco peat + vermiculite + sawdust (1:1:2).

## Various Techniques for Hydroponics

### Nutrient Film Technique

The nutrient film technique (NFT) is a form of hydroponic system where plants are planted with their roots exposed to the water in a shallow tray or channel filled with nutrient-rich water. The plant roots in this system are suspended in channels called gullies through which a thin film of nutritional solution travels, keeping the roots moist but not clogged. The nutrients are mixed appropriately in a primary reservoir, where they flow constantly feeding the plants. Automation can be used to change the system's aeration settings (Sheikh, 2006).The method by which nutrient solutions are circulated for crop production is the foundational idea behind the NFT. This hydroponic technique promotes proficient use of greenhouse area and higher yield(Santos *et al*., 2010), with better crop quality (Lopes *et al*., 2007 and Santos *et al*., 2010) and shortened crop cycles due to better environmental control (Martins *et al*., 2009; Santos *et al*., 2010) which allows cultivation throughout the year. The method is flexible enough to accommodate a wide range of crop production (Burrage, 2006) and is excellent for short-term crops like lettuce, green vegetables, and herbs. Larger NFT systems can adapt to the production of long-term crops like cucumbers and tomatoes.

**Wick System**

A wick irrigation system functions in a closed cycle with minimal runoff, allowing proper plant nutrition and providing options to increase production uniformity. These systems exhibit several benefits like high water and nutrient use efficiency; independence from electricity for operation; water conservation; less labour requirement as management is more straightforward as compared with conventional systems and production quality. Wick irrigation systems can be utilized to grow decorative plants including kalanchoe, poinsettias and chrysanthemums and cyclamen (Ferrarezi & Testezlaf, 2016).There are various studies showing different experiments conducted through the wick irrigation method which were carried out utilising various tools for a variety of crops and climatic situations. These findings identified the ideal wick width and appropriate water depth for wick contact, length of the wick to improve water distribution, the appropriate size of the growing container, the composition of the substrate for satisfactory root wetting and moisture maintenance the potential for disease occurrence and dissemination as well as the effective use of equipment (Ferrarezi and Testezlaf, 2016).

**Drip Systems**

The drip system is a form of hydroponic system that distributes nutrient-rich water to the roots of the plants using a number of drip emitters or nozzles. As a result of its effectiveness and simplicity in automating, this system is frequently utilized for bigger hydroponic gardens. The plants receive water through a network of tubing in small, controlled doses. The drip method is frequently used to grow long-term crops including cucumbers, tomatoes, peppers, onions, and so forth. Drip emitters are used to give nutrient solutions to plants. Depending on the plant's developmental stage and the available light intensity, these timed emitters are set to run accordingly. By flushing the growing medium, the drip cycle feeds the plants with new nutrients, water, and oxygen (Waiba *et al*., 2020).

**Deep Flow Technique (DFT)**

Deep flow technique (DFT), often referred to as deep water method, is growing of plants on floating or hanging support (rafts, panels, or boards) in containers filled with 10–20 cm nutritional solution (Van Os *et al*., 2002). Planting materials are contained in plastic pots whose bottoms come into contact with the nutrient solution dripping via the pipes. The positioning of potted plants is either uniform or zigzag [48]. The depth and volume of the solution, as well as the recirculation and oxygenation techniques, can be used to discriminate among the various application types. The technique is especially intriguing because it reduces expenses and management besides, enhancing the quantity and quality of the produce. A study conducted by Vimolmangkang *et al*. (2009) observed that growing Japanese and spearmint in nutrient solutions using DFT is a successful way of producing a higher quantity of volatile oil. Another example as observed in case of lettuce, where the relatively high volume of solution makes it possible to replenish the nutrient solution only at the end of each cycle and only the oxygen content needs to be periodically monitored, there is only a limited need for automation of the control and correction of the nutrient solution. If oxygen levels are below 4-5 mg $L^{-1}$, root system performance may result in nutrient shortages (Maucieri *et al*., 2019).

**Ebb and Flow Method**

In an ebb and flow hydroponic system, plants are cultivated in a tray that is periodically flooded with nutrient solution during the day. Nutrient solution is pumped from a reservoir into the grow tray, where the liquid is maintained at a particular level (by way of an overflow drain) for a predetermined period of time until the pump shuts off, enabling the nutrient solution to drain back down the input pipe (Daud, 2018). With this approach, plants are commonly grown either in grow plugs housed in trays (for seedlings) or in pots filled with soilless medium (for larger plants). Commercial settings typically employ ebb and flow systems for the development of seedlings. Gross returns from ebband flow system yields of kale and cherry tomatoes were higher than those from basil and chipotle peppers (Wortman, 2015). Ebb and flow irrigation methods increased tomato root characteristics and stem diameter by 9–45% compared to top sprinkle irrigation (Wang *et al*., 2022).

### Aeroponics

Aeroponics is a method of growing plants that are suspended in the air with their roots while receiving nutrients and moisture from a mist (Mangaiyarkarasi, 2020). Plants are placed horizontally or on slanted growth box tops and supported by plastic panels or polystyrene. To create closed enclosures where the suspended root system can grow, these panels are supported by a structure constructed of inert materials (plastic, steel coated with plastic film, and polystyrene boards). Every few minutes, the pump will spray a mist of water due to a timer. Similar to the nutrient film method, the pump must always be running because even a minor interruption could cause the roots to dry out (Fathallah and Ismail, 2022). Due to the expensive initial investment and ongoing management costs, the aeroponics method has not yet gained widespread adoption and is primarily intended for smaller horticultural species like lettuce, spinach, and other such vegetables (Sharma *et al*., 2018).

### Aquaponics

Fish aquaculture and hydroponic cultivation are combined in aquaponics (Lennard and Goddeck, 2019) The nutrient-rich wastewater of the fish tanks is delivered via plant growth beds Aquaponics depends on the preservation of a healthy bacterial community (Kumar *et al*., 2020). Ammonia is naturally converted to nitrate by helpful bacteria found in soil, air, and water, which plants can take quickly (Yep and Jheng, 2019).

## Conclusion

The most effective crop production method available today is hydroponic culture, which is mostly used in industrialized and developing countries for confined agricultural output. Even in areas with moderate to poor soil, such deserts, hydroponically growing is conceivable. It offers a number of benefits, including water conservation and environmentally beneficial practices, but its main drawback is the need for significant financial outlay and specialized knowledge. By providing reliable and accessible nourishment, hydroponics permits up to 50% faster development than soil. But in a short period of time, hydroponics' popularity has expanded significantly, leading to an increase in experimentation and study in the area of indoor and outdoor hydroponic production.

## References

Burrage, S.W. (2006). Nutrient Film Technique in protected cultivation. *Acta Horticulture*, 323, 23-38.

Cascone, S. (2019). Green roof design: State of the art on Technology and Materials. *Sustainability*, 11(11), 3020.

Daneshvar, E., Wicker, R.J., Show, P.L. and Bhatnagar, A. (2022). Biologically- Mediated Carbon Capture and Utilization by Microalgae towards sustainable $CO_2$ Biofixation and Biomass Valorization–A review. *Chemical Engineering Journal*, 427, 130884.

Daud, M., Handika, V. and Bintoro, A. (2018). Design and Realization of Fuzzy Logic Control for Ebb and Flow Hydroponic System. *International Journal of Scientific and Technological Research,* 7: 138–144.

Fathallah, E.O.S. and Ismail, Y.H.A. (2022). Integrated smart system for hydroponic cultivation in Egypt. MSA.

Ferrarezi, R. and Testezlaf, R. (2014). Performance of Wick Irrigation System using Self-Compensating Troughs with Substrates for Lettuce Production. *Journal of Plant Nutrition*.

Gent, M. (2016). Effect of temperature on composition of hydroponic lettuce. *Acta Horticulturae*, 95-100.

Grant, N.P. (2020). Exploring the natural variation of photosynthesis and abiotic stress in wheat varieties and reduced height mutants. Washington State University.

Jagtap, P.P., Bhakar, S.R., Lakhawat, S.S., Singh, P.K. and Kothari, M. (2022). Present status and Future Perspective of Hydroponics Technique: Hope and Hype for Future Welfare. *Journal of Post-harvest Technology,* 10(3), 65-77.

Jan, S., Rashid, Z., Ahngar, T.A., Iqbal, S., Naikoo, M.A., Majeed, S. and Nazir, I. (2020). Hydroponics A review. *International Journal of Current Microbiology and Applied Sciences,* 9(8), 1779-1787.

Kang, S.W., Seo, S.G. and Pak, C.H. (2009). Capillary wick width and water level in channel affects water absorption properties of growing media and growth of chrysanthemum and poinsettia cultured in C-channel subirrigation system. *Korean Journal of Horticultural Science & Technology,* 27(1), 86–92.

Kaur, G. and Chawla, P. (2021). All about vertical farming: A review. *Turkish Journal of Computer and Mathematics Education,* 12(2), 1-14.

Khan, S., Purohit, A. and Vadsaria, N. (2020). Hydroponics: Current and future state of the art in farming. *Journal of Plant Nutrition,* 44(10), 1515-1538.

Khodijah, N.S. and Kusmiadi, R. (2021). The growth of Lettuce (*Lactuca sativa*): Hydroponically in simple Wick System on various types of Nutrient Composition. *Jurnal Agronomi Tanaman Tropika* (JUATIKA), 3(2), 180-186.

Kim, J.K., Jang, D.C., Kang, H.M., Nam, K.J., Lee, M.H., Na, J.K. and Choi, K.Y. (2021). Effects of Light Intensity and Electrical Conductivity level on Photosynthesis Growth and Functional material contents of *Lactuca indica* L. Sunhyang in Hydroponics. *Journal of Bio-Environment Control,* 30(1), 1-9.

Kumar and Singh (2023). Trends in Hydroponics Practice/Technology in Horticultural Crops: A Review. *International Journal of Plant and Soil Science,* 35(2): 57-65.

Kumar, S., Singh, M. and Rai, N. (2020). Study of Automated and Controlled Aquaponics System: An innovative and integrated way of farming. *International Journal of Trend in Scientific Research and Development (IJTSRD)* 4(2): 223.

Lee, C.W., So, I.S., Jeong, S.W. and Huh, M.R. (2010). Application of sub irrigation using capillary wick system to pot production. *Journal of Agriculture & Life Science*, 44: 7–14.

Lennard, W. and Goddek, S. (2019). Aquaponics: The Basics. Aquaponics Food Production Systems, 113-143.

Lopes, J.L.W., Boaro, C.S.F., Peres, M.R. and Guimar~aes, V.F. (2007). Growth of lettuce seedlings in different substrates. *Revista Biotemas* 20: 19–25.

Maharana, L. and Koul, D.N. (2011). The emergence of Hydroponics. Yojana (June) 55:39-40.

Mangaiyarkarasi, R. (2020). Aeroponics system for Production of Horticultural crops. *Madras Agricultural Journal* 107.

Martins, C., Medeiros, J.F. de, Lopes, W.A.R., Braga, D.F. and Amorim, L.B. de (2009). Curve of Absorption of Nutrients in Hydroponic Lettuce. *Revista Caatinga*, 22: 123–128.

Maucieri, C., Nicoletto, C., OsEv, Anseeuw, D., Havermaet, R.V. and Junge, R. (2019). Hydroponic Technologies. In: Goddek S, Joyce A, Kotzen B &Burnell GM (eds.) Aquaponics Food Production Systems. Springer, Cham. https://doi.org/10.1007/978-3-030-15943-6_4

Mohammed, S. and Sookoo, R. (2016). Nutrient Film Technique for Commercial Production. *Agricultural Science Research Journal*, 6: 269-274.

Patel, A., Mungray, A.A. and Mungray, A.K. (2020). Technologies for the Recovery of Nutrients Water and Energy from Human Urine: *A review. Chemosphere*, 259 127372.

Puengsungwan, S. and Jirasereeamornkul, K. (2020). IOT Based Root Stress Detection for Lettuce Culture using Infrared Leaf Temperature Sensor and Light Intensity Sensor. *Wireless Personal Communications*, 115(4), 3215-3233.

Rhuanito, S.F. and Roberto, T. (2016). Performance of Wick Irrigation System using Self-Compensating Troughs with Substrates for Lettuce Production. *Journal of Plant Nutrition*, 39(1), 150-164.

Rouphael, Y., Kyriacou, M.C., Petropoulos, S.A., De Pascale, S. and Colla, G. (2018). Improving Vegetable Quality in Controlled Environments. *Scientia Horticulturae*, 234: 275-289.

Santos, A.N., Soares, T.M., Silva, E.F.F., Silva, D.J.R. and Montenegro, A.A.A. (2010). Hydroponic Lettuce Production with Brackish Groundwater and Desalination Waste in Ibimirim, *PE, Brazil*., 14, 961–969.

Santosh, D.T. and Gaikwad, D. (2023). Advances in Hydroponic Systems: Types and Management.

Savvas, D. (2003). Hydroponics: A Modern Technology Supporting the Application of Integrated Crop Management in the Greenhouse. *Journal of Food, Agriculture and Environment*, 1: 80-86.

Sharma, N., Acharya, S., Kumar, K., Singh, N. and Chaurasia, O.P. (2018). Hydroponics as an advanced technique for vegetable production: An overview. *Journal of Soil and Water Conservation*, 17(4), 364-371.

Sheikh, B.A. (2006). Hydroponics: key to sustain agriculture in water stressed and urban environment. *Pakistan Journal of Agriculture, Agriculture Engineering and Veterinary Sciences*, 22, 53-57.

Stegelmeier, A., Rose, D., Joris, B. and Glick, B. (2022). Plants 11: 2783. 10.3390/plants11202783.

Stein, E.W. (2021). The Transformative Environmental Effects Large-Scale Indoor Farming may have on Air Water and Soil. *Air Soil and Water Research*, 14: 1178622121995819.

Subramani, T., Gangaiah, B., Baskaran, V. and Swain, S. (2020). Effect of Soilless growing Media on Yield and Quality of Tomato (*Solanum lycopersicum* L.) under Tropical Island Conditions. *Int. Journal of Current Microbiology and Applied Science*, 9(5), 2084-2090.

Van Os, E.A., Gieling, H.T. and Ruijs, M.N.A. (2002). Equipment for Hydroponics Installations. In: Hydroponics Production of Vegetables and Ornamentals. *Embryo Publications*, 103-141.

Vimolmangkang, S., Sitthithaworn, W., Vannavanich, D., Keattikunpairoj, S. and Chittasupho, C. (2009). Productivity and quality of volatile oil extracted from *Menthaspicata* and *Marvensis* var. piperascens grown by a hydroponic system using the deep flow technique Journal of Natural Medicines 64: 31-35.

Voutsinos, O., Mastoraki, M., Ntatsi, G., Liakopoulos, G. and Savvas, D. (2021). Comparative assessment of Hydroponic Lettuce Production either under Artificial Lighting or in a Mediterranean Greenhouse during Wintertime. *Agriculture*, 11(6):503.

Waiba, K.M., Sharma, P., Sharma, A., Chadha, S. and Kaur, M. (2020). Soilless Vegetable Cultivation: A review. *Journal of Pharmacognosy and. Phytochemistry*, 9: 631-636.

Wang, K., Ali, M.M., Pan, K., Su, S., Xu, J. and Chen, F. (2022). Ebb-And-Flow Subirrigation Improves Seedling Growth and Root Morphology of Tomato by Influencing Root-Softening Enzymes and Transcript Profiling of Related Genes. *Agronomy*, 12: 494.

Wortman, S.E. (2015). Crop Physiological Response to Nutrient Solution Electrical Conductivity and pH in an Ebb-And-Flow Hydroponic System. *Scientia Horticulturae*, 194, 34–42.

Yep, B. and Zheng, Y. (2019). Aquaponic trends and challenges–A review. *Journal of Cleaner Production*, 228, 1586-1599.

Zimmermann, M. and Fischer, M. (2020). Impact assessment of water and nutrient reuse in hydroponic systems using Bayesian Belief Networks. *Journal of Water Reuse and Desalination*, 10(4), 431-442.