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RESEARCH ARTICLE

# Optimizing the cultivation of lettuce (*Lactuca sativa* L. var. *longifolia*) in hydroponic systems: A comparative system evaluation

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**Abstract**

The study investigates the impact of five hydroponic systems *viz*., Nutrient Film Technique (NFT), Deep Flow Technique (DFT), Ebb and Flow System (EFS), Dutch Bucket (DB) and Floating Raft System (RFS) on the growth and yield of lettuce (*Lactuca sativa* L.) for the variety Green Wave. The experiment was conducted at the experimental farm of CSK HPKV, Palampur, this research aimed to identify the most efficient system for enhancing lettuce growth, considering parameters such as leaf area index (LAI), number of leaves per plant, number of pickings, stem thickness, stem length, plant height, days to marketable maturity, yield per plant, yield per square meter and root length. The study, designed as a completely randomized experiment, revealed that the NFT system consistently outperformed other systems across most growth parameters, including LAI, number of leaves per plant, stem length, plant height, days to marketable maturity, yield per plant and yield per square meter. The RFS exhibited the highest number of pickings, suggesting quicker harvest cycles. Conversely, the DB system showed the longest time to maturity and root length, indicating less efficient nutrient uptake. The B:C ratio proved that the highest return is given by NFT hydroponic system for the variety Green Wave. These findings highlight NFT as the superior system for lettuce production, providing insights for growers to optimize their hydroponic operations for maximal productivity and crop quality.

**Keywords:** hydroponic system; lettuce; NFT system; yield

## Introduction

Hydroponics uses a system where nutrients are delivered to plants through a nutrient solution, which includes various sources of fertilizers providing essential nutrients for optimal plant development (1). Today, hydroponic systems have become an intensive production method, often requiring high technology and significant economic resources. These systems have been successfully implemented in many countries (2). The high costs of fertilizers and the environmental impact of their excessive use have increased the popularity of closed hydroponic systems (3). These systems capture and reuse drainage water, reducing both water and fertilizer consumption and minimizing the environmental impact of the crop (4). The benefits of hydroponic systems include high planting densities and an ideal balance of water and nutrients (5). However, the disadvantages are the high initial costs and the extensive knowledge required to operate these systems effectively (6, 7).

Lettuce (*Lactuca sativa* L.) is a highly popular salad crop and holds the largest cultivation area among salad crops worldwide, covering approximately 1.24 million hectares and yielding a production of 28 metric tonnes (8). In terms of nutritive value, lettuce is ranked 26$^{th}$ among vegetables and fruits, but it ranks 4th in terms of consumption (9). India is the third-largest commercial producer of lettuce, following China and USA, contributing to 4 % of the world's total production. In India, lettuce is cultivated across 0.20 million hectares, yielding 1.30 metric tonnes (10). Lettuce cultivation is experiencing a surge in popularity in Himachal Pradesh, with an area spanning 49.80 hectares and a production of 1098.60 tonnes (11). This trend is driven by the increasing demand for lettuce in fast food. The crop is primarily grown in the Lahaul Valley under open-field conditions and the produce meets export-quality standards.

Lettuce (*Lactuca sativa* L.) is a vegetable commonly consumed fresh, making cleanliness during the production process a top priority (12). Hydroponic technology in lettuce cultivation offers several advantages over conventional soil cultivation (13). Hydroponically grown lettuce is more hygienic, exhibits more uniform growth and can be planted at closer spacing. Common hydroponic systems for lettuce cultivation include the Nutrient Film Technique (NFT), Deep Flow Technique (DFT), Ebb-Flow System (EFS) and Float Raft System (FRS) (14, 15). Each system has its advantages: NFT systems can be installed vertically because the water flow is relatively shallow, making them lighter than DFT systems (16). DFT systems, on the other hand, can provide water and nutrients even if the nutrient solution pump fails (17). The wide variety of hydroponic systems can make it challenging for beginner farmers and laypeople to choose the most suitable system for their crops (18). Despite their differences, all hydroponic systems are designed to provide water and nutrients to plants. An effective hydroponic system must supply not only water and nutrients but also oxygen to the root zone (19). When choosing a hydroponic system, it is essential to consider factors such as location, productivity, the availability of suitable growing media and the expected crop quality (20). This study aims to recommend a more efficient hydroponic system to enhance the growth of lettuce plant.

## Materials and Methods

### Study area

This research was conducted in a closed hydroponic system with polycarbonate sheeting at the experimental farm of the Department of Vegetable Science and Floriculture, CSK HPKV, Palampur. The site is situated at an elevation of 1290.8 m above mean sea level, at 32°6′ North latitude and 76°3′ East longitude, representing the mid-hill zone of Himachal Pradesh. The study took place from July to September in 2022 & 2023. Severe winters and mild summers, with high rainfall, characterize the place from an agro-climatic perspective, the area is situated in the mid-hill regions and experiences a humid sub-temperate climate, receiving an annual rainfall of 2500 mm, with 80 % of the rainfall occurring during July to September. In hydroponic system 18-26 °C temperature and 75 % relative humidity was maintained through foggers and air conditioners. The monthly maximum and minimum temperature ranged between 18.7-29.9 °C and 7.7-16.8 °C, respectively. The average relative humidity ranged between 48.35 % and 72.50 %.

### Plant material and research method

The tools and materials used in this study included an EC-meter, pH-meter, hygrometer, aerator, water pump, digital scale and lettuce seeds. The variety used for the current study was Green Wave who was maintained at CSK HPKV Palampur. The research method employed was a completely randomized design (CRD) with five treatments, each replicated five times. The treatments included five types of hydroponic systems *viz*., Nutrient Film Technique (NFT), Deep Flow Technique (DFT), Ebb and Flow System (EFS), Dutch Bucket (DB) and Floating Raft System (RFS). NFT system, a thin film of nutrient-rich water continuously flows over the roots of the plants, which are supported by a slight slope in channels or gullies. DFT also known as Deep Water Culture (DWC), involves plants being suspended in a deep container filled with nutrient solution, with their roots submerged. EFS also known as Flood and Drain, this system periodically floods the grow bed with nutrient solution and then drains it back into a reservoir. DB systems use individual containers filled with a growing medium, with nutrient solution delivered to each bucket and drained away. In an RFS, plants are placed on rafts that float on a nutrient-rich water solution, allowing roots to grow directly into the water.

In an RFS, the combination of water and nutrients plays a vital role in supporting healthy plant growth. Instead of soil, plants are placed on rafts that float on a reservoir filled with a nutrient-rich water solution. The roots extend directly into this solution, which provides a continuous supply of both water and essential nutrients. This constant access to moisture ensures that plants do not experience drought stress, which promotes uniform and vigorous growth. The dissolved nutrients, including primary macronutrients like nitrogen, phosphorus and potassium, along with secondary nutrients such as calcium, magnesium and sulfur and trace micronutrients like iron, zinc, manganese, copper, boron and molybdenum, were added to the water in balanced amounts. These nutrients were immediately available for root uptake, eliminating the delays associated with nutrient breakdown in soil. This efficient delivery system helps plants develop strong root systems and healthy foliage. Additionally, the water was aerated to supply sufficient oxygen to the roots, preventing problems like root rot and maintaining overall plant health. Together, the balanced supply of water, nutrients and oxygen creates optimal conditions for fast and productive growth, making the RFS especially suitable for crops like leafy greens.

### Plant growth and yielding traits

In hydroponic system crop was raised by applying Hoagland solution and fertigation scheduling was based on the electrical conductivity and pH variation of the nutrient solution. The values of electrical conductivity and pH during the cropping period were maintained for growth and development of lettuce. EC ranged from 1.4 to 1.8 mS/cm and pH range was 6.0-7.0. In polyhouse besides the application of vermicompost @ 5 tons per hectare, chemical fertilizers were applied as per adhoc recommendation of CSK HPKV for protected cultivation (50 kg each of N, P and K/ha) through straight fertilizers. Whole of the vermicompost and chemical fertilizers were applied in pits before transplanting. The fertigation was given twice a week by applying liquid fertilizer (19:19:19) @ 2.2 g/m$^2$ of the effective area of polyhouse after third week of transplanting and was stopped 15 days before final harvest. The parameters observed to measure the effectiveness of each system in promoting plant growth were leaf area index (LAI), number of leaves per plant, number of pickings, stem thickness (cm), stem length (cm), plant height (cm), days to marketable maturity, yield per plant (g), yield per square meter (g/m$^2$) and root length (cm). Data for these parameters were recorded for each replication. Hoagland hydroponic nutrient solution, which provides every essential nutrient for plant growth was used for the study.

### Statistical analysis

The average data recorded on various parameters were analyzed for CRD design as suggested by Panse and Sukhatme (21) by using MS-Excel and OPSTAT (22). The results have been interpreted on the basis of ‘F’ test value and critical differences (CD) was calculated at 5 % level of significance.

## Results and Discussion

Table 1 examines the impact of five different growing systems namely Nutrient Film Technique (NFT), Deep Flow Technique (DFT), Ebb and Flow System (EFS), Dutch Bucket (DB) and Floating Raft System (RFS) on various growth parameters of lettuce. These parameters include LAI, the number of leaves per plant, the number of pickings, stem thickness and stem length. The results were analysed with respect to the Standard Error of Mean (SEm ±) and the Critical Difference (CD) at a 5 % significance level (P = 0.05). The NFT system recorded the highest LAI (3.21), indicating more efficient use of the growing area for leaf development. The lowest LAI was observed in the DB system (1.83). The significant CD value (0.07) confirms that these differences are statistically significant. This suggests that the continuous flow of nutrients in NFT provides optimal conditions for leaf area expansion, consistent with studies showing improved LAI in hydroponic systems with better nutrient management. Similar findings for LAI have been reported in earlier reports (23, 24). Lettuce plants in the NFT system had the highest number of leaves per plant (17.56), significantly higher than in other systems, with the DB system showing the least (11.33). The CD value (0.14) confirms these differences are statistically significant. The superior performance in NFT can be attributed to the consistent and optimal nutrient supply which supports vegetative growth. The results are in conformity with earlier reports (25, 26) that documented similar variations of number of leaves in lettuce. Interestingly, the RFS had the highest number of pickings (3.56), followed closely by DFT (3.37) and NFT (3.12). The EFS system had the lowest number of pickings (2.23). The CD value (0.13) indicates these differences are statistically significant. This suggests that while NFT and DFT systems provide good conditions for growth, the RFS may promote quicker maturation or faster harvest cycles. These findings align with previous studies (25). The differences in stem thickness were relatively minor, with NFT having the thickest stems (1.89 cm) and DFT and RFS the thinnest (1.65 cm). The CD value (0.06) confirms the statistical significance of these differences. The thicker stems in NFT could be due to better oxygenation and nutrient availability that supports robust structural development. Stem length was greatest in the NFT system (3.53 cm) and shortest in the DB system (2.23 cm). The CD value (0.08) supports that these differences are statistically significant. This enhanced elongation in NFT might be due to the continuous and balanced nutrient delivery which promotes vertical growth, aligning with findings that optimized nutrient solutions can enhance stem growth. Similar results of stem thickness of lettuce have been reported in earlier studies (27).

From Table 1 it is concluded that NFT generally outperformed other systems in most growth parameters of lettuce, such as LAI, number of leaves per plant and stem length, suggesting it provides superior growing conditions. The RFS showed the highest number of pickings, indicating it may support quicker or more frequent harvests. These results can inform decisions on the best growing systems for maximizing lettuce production, balancing between overall plant growth and harvest frequency. Table 2 investigates the effects of five hydroponic systems on plant height, days to marketable maturity, yield per plant, yield per square meter and root length. The results are statistically analysed and inferred that highest plant height was observed in the NFT system (22.56 cm), significantly taller than plants in the DB system (14.84 cm). The CD value (0.53) confirms these differences are statistically significant. The continuous nutrient flow in NFT likely provides optimal growth conditions, resulting in taller plants. This aligns with findings that efficient nutrient delivery in hydroponic systems can enhance plant growth (28). Lettuce grown in the NFT system reached marketable maturity fastest (41.26 days), while the DB system took the longest (56.92 days). The CD value (0.71) indicates these differences are statistically significant. Rapid growth in NFT can be attributed to continuous and efficient nutrient uptake, which promotes quicker development. Studies have shown that optimized hydroponic conditions can significantly reduce the time to maturity (29). The highest yield per plant was recorded in the NFT system (243.66 g), with the lowest in the EFS system (183.98 g). The CD value (9.34) supports the statistical significance of these differences. NFT's efficient nutrient and oxygen delivery likely enhances biomass production. Higher yields in hydroponics compared to traditional methods have been well-documented (30).

**Table 1.** Effect of different growing systems on leaf area index (LAI), number of leaves per plant, number of pickings, stem thickness (cm) and stem length (cm) of Green Wave

| Systems | LAI | Number of leaves/ plants | Number of pickings | Stem thickness (cm) | Stem length (cm) |
|---|---|---|---|---|---|
| Nutrient Film Technique (NFT) | 3.21$^{a}$ | 17.56$^{a}$ | 3.12$^{c}$ | 1.89$^{a}$ | 3.53$^{a}$ |
| Deep Film Technique (DFT) | 2.36$^{b}$ | 15.14$^{b}$ | 3.37$^{b}$ | 1.65$^{c}$ | 2.65$^{c}$ |
| Ebb and Flow (EFS) | 2.37$^{b}$ | 13.97$^{d}$ | 2.23$^{e}$ | 1.87$^{ab}$ | 2.24$^{d}$ |
| Dutch Bucket (DB) | 1.83$^{c}$ | 11.33$^{e}$ | 2.38$^{d}$ | 1.85$^{b}$ | 2.23$^{d}$ |
| Floating Raft System (RFS) | 2.41$^{b}$ | 14.40$^{c}$ | 3.56$^{a}$ | 1.65$^{c}$ | 2.87$^{b}$ |
| SEm ± | 0.02 | 0.06 | 0.04 | 0.01 | 0.03 |
| CD (P = 0.05) | 0.07 | 0.14 | 0.13 | 0.06 | 0.08 |

**Table 2.** Effect of different systems on plant height (cm), days to marketable maturity, yield/plant (g), yield/m$^{2}$ (kg) and root length (cm) of Green Wave

| Systems | Plant height (cm) | Days to marketable maturity | Yield/plant (g) | Yield/m$^{2}$ (kg) | Root length (cm) |
|---|---|---|---|---|---|
| Nutrient Film Technique (NFT) | 22.56$^{a}$ | 41.26$^{d}$ | 243.66$^{a}$ | 7.55$^{a}$ | 20.86$^{e}$ |
| Deep Film Technique (DFT) | 20.71$^{b}$ | 44.40$^{b}$ | 206.48$^{c}$ | 5.24$^{c}$ | 26.70$^{c}$ |
| Ebb and Flow (EFS) | 18.89$^{c}$ | 44.82$^{b}$ | 183.98$^{d}$ | 5.70$^{bc}$ | 23.72$^{d}$ |
| Dutch Bucket (DB) | 14.84$^{e}$ | 56.92$^{a}$ | 216.30$^{b}$ | 4.30$^{d}$ | 28.27$^{a}$ |
| Floating Raft System (RFS) | 18.21$^{d}$ | 42.56$^{c}$ | 216.12$^{b}$ | 6.35$^{b}$ | 27.56$^{b}$ |
| SEm ± | 0.13 | 0.17 | 2.23 | 0.23 | 0.23 |
| CD (P = 0.05) | 0.53 | 0.71 | 9.34 | 0.06 | 0.68 |

General view of Green Wave under different hydroponic systems has been presented in Fig. 1. Yield per square meter was highest in the NFT system (7.55 kg) and lowest in the DB system (4.30 kg). The CD value (0.06) indicates these differences are statistically significant. The NFT system's superior yield efficiency is due to optimal space utilization and nutrient delivery, corroborated by research indicating higher productivity in well-managed hydroponic systems (8). Root length was shortest in the NFT system (20.86 cm) and longest in the DB system (28.27 cm). The CD value (0.68) confirms these differences are statistically significant. The shorter root length in NFT may be due to the constant availability of nutrients and water, reducing the need for extensive root growth. This is supported by findings that hydroponic systems with ample nutrient supply can result in more compact root systems (27). From Table 2, it is concluded that NFT generally outperformed other systems in plant height, days to marketable maturity, yield per plant and yield per square meter, indicating it provides the most favourable conditions for lettuce growth. The DB system showed the longest time to maturity and the longest root length, which may be due to less efficient nutrient uptake. These findings can guide growers in selecting the most appropriate hydroponic systems based on specific production goals.

## Economics of different growing systems

Understanding the economics helps growers to assess the overall cost of production for lettuce in different growing systems. By comparing the costs with the revenue generated from lettuce sales, growers can determine which growing system is more profitable. Calculating the economics of different growing systems for lettuce crop (having selling price ₹150/kg) provides essential insights into profitability, resource efficiency, risk management and competitiveness. The B:C ratio for the three best hydroponic systems for variety Green Wave is mentioned in Table 3.

### NFT system

The economics of NFT involve assessing the financial aspects of implementing and operating this specific type of hydroponic cultivation method. The cost of cultivation per square meter, including thirty-one plants was ₹250.90 including the cost of soil -less media, seed, manpower, electricity, fertilizer and water charges. The B:C ratio observed for the variety Green Wave was 2.98.

### Dutch Bucket system

The economics of DB hydroponic explores the financial aspects of this soilless cultivation method in which individual buckets or containers filled with inert growing media called clay balls/ pebbles. The cost of cultivation per square meter, having six plants in one meter was ₹150.20 which include the cost of nutrients, clay balls/pebbles, soil-less media, seed, manpower, electricity and water charges. The B:C ratio observed for the variety Green Wave was 2.59.

### Raft system

Evaluating the financial aspects of raft system, this method involves cultivating plants on buoyant floating rafts, over a nutrient-rich water solution. The cultivation cost for various varieties, each with thirty-one plants per square meter was ₹250.90, identical to the cost of NFT system. The B:C ratio observed for the variety Green Wave was 2.54.


**Fig. 1.** General view of Green Wave under different hydroponic systems: (A) Nutrient Film Technique; (B, C) Dutch Bucket System; (D) Floating Raft System; (E, F) Developed lettuce plant.

**Table 3.** Effect of NFT, Dutch Bucket and Raft hydroponic system on yield/m$^2$ (kg) and benefit-cost ratio for Green Wave variety of lettuce

| Systems | Yield/m$^2$ (g) | Cost of cultivation (₹/m$^2$) | Gross returns (₹) | Net returns (₹) | B:C ratio |
|---|---|---|---|---|---|
| NFT | 243.66 | 250.90 | 1000.00 | 749.10 | 2.98 |
| Dutch bucket | 216.30 | 150.20 | 540.50 | 390.30 | 2.59 |
| RFS | 216.12 | 250.90 | 890.00 | 639.10 | 2.54 |

## Conclusion

The study examined the impact of five hydroponic systems-Nutrient Film Technique (NFT), Deep Flow Technique (DFT), Ebb and Flow System (EFS), Dutch Bucket (DB) and Floating Raft System (RFS)-on several growth parameters of lettuce, including LAI, number of leaves per plant, number of pickings, stem thickness (cm), stem length (cm), plant height (cm), days to marketable maturity, yield per plant (g), yield per square meter (g/m$^2$) and root length (cm). NFT generally outperformed other systems in most growth parameters of lettuce, including LAI, number of leaves per plant and stem length, plant height, days to marketable maturity, yield per plant, yield per square meter and root length were investigated indicating it provides superior growing conditions. RFS showed the highest number of pickings, suggesting it may support quicker or more frequent harvests. These results can guide growers in selecting the best growing systems for maximizing lettuce production, balancing overall plant growth and harvest frequency. NFT also outperformed other systems in plant height, days to marketable maturity, yield per plant and yield per square meter, indicating it provides the most favourable conditions for lettuce growth. The DB system showed the longest time to maturity and root length, which may be due to less efficient nutrient uptake. The B:C ratio proved that the highest return is given by NFT hydroponic system for the variety Green Wave. These findings can guide growers in selecting the most appropriate hydroponic systems based on specific production goals.

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## Authors' contributions

PS[1] and PS[2] performed the experiment. PS[1], PS[2], SM and NB designed the research. PS[1], PK and AK wrote the manuscript. PS[1], HT, AP, SK, AK and NB revised and corrected the manuscript. All authors have contributed to different sections of writing, reviewing, correction and statistical analysis. All authors read and approved the final manuscript. [PS[1] - Payal Sharma; PS[2] - Parveen Sharma].

## Compliance with ethical standards

**Conflict of interest:** Authors do not have any conflict of interests to declare.

**Ethical issues:** None

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