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Standardization of different hydroponic systems in lettuce (*Lactuca sativa* L.)

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Abstract
The present study entitled "Comparative performance of lettuce (*Lactuca sativa* L.) under different hydroponic systems" was conducted during the *kharif* season of 2024 at the Instructional farm, Centre of Excellence for Vegetables, Agricultural Development Trust, Baramati, Maharashtra to evaluate the effect of various hydroponic systems on the growth, yield and quality of lettuce. The experiment was laid out in a Completely Randomized Design (CRD) with three replications and eight treatments, viz., T_1-Flat Bed NFT, T_2-A Frame NFT, T_3-Deep Water Culture, T_4-Dutch Bucket, T_6-Aeroponics, T_5-Trough method, T_7-Grow Tower/Vertistack and T_8-Control. Among the different hydroponic systems evaluated, Deep Water Culture led to the most vigorous vegetative growth, with maximum plant height (20.88 cm), plant spread (28.32 cm), leaf area (200.15 cm²) and number of leaves per plant (18.87). Flat Bed and Dutch Bucket systems also supported substantial plant growth, while Aeroponics promoted notable root development, root length (23.59 cm) and root biomass. With regard to yield performance, Deep Water Culture was superior with the highest fresh weight per plant (103.77 g), yield per system (2.08 kg) and yield per 100 m² (259.42 kg). Overall, this findings shows that the Deep Water Culture and Flat Bed systems are viable for sustainable, high quality lettuce cultivation in protected conditions. While Flat Bed offers operational simplicity and consistent output. While Deep Water Culture demonstrates greater economic feasibility for commercial use due to superior resource efficiency, reduced substrate dependency and higher yield potential.

Keywords: Lettuce, hydroponic systems, deep water culture, yield performance, growth attributes

Introduction

Lettuce (*Lactuca sativa* L.) is a widely cultivated leafy vegetable belonging to the Asteraceae family, valued for its crisp texture, mild flavour and high nutritional content. Globally, it is a key component of salad-based diets and ready-to-eat foods. It is believed to have originated in the Mediterranean region and the Near East, where initial domestication was aimed at seed oil and fodder production (Mou, 2011) [16]. Over time, it evolved into a globally consumed vegetable crop with major types including crisphead, romaine, butterhead and looseleaf, each varying in morphology and nutritional quality.

India accounts for a growing share of global lettuce production, ranking second after China (Shatilov *et al.*, 2019) [20]. This increase is driven by changing food preferences, nutritional awareness and the crop's health benefits, including its richness in carotenoids, vitamins A and K, folate and minerals like calcium and potassium (Thakur *et al.*, 2020) [21]. Lettuce also exhibits pharmacological properties, such as anti-inflammatory, sedative and diuretic effects and is known for its role in weight management, cholesterol reduction and cardiovascular health.

Despite its potential, lettuce cultivation in India faces limitations due to its sensitivity to temperature extremes and soil-borne constraints. Open-field production often leads to issues such as early bolting, nutrient leaching and disease susceptibility, particularly in poorly drained soils (Kristkova *et al.*, 2008) [10]. In response, growers are increasingly adopting hydroponic cultivation as a resilient alternative.

Hydroponics-a soil-less cultivation technique under Controlled Environment Agriculture (CEA)-allows precise regulation of water, nutrients and microclimatic parameters to optimize plant growth. It reduces land dependence, conserves up to 80% more water compared to soil cultivation and supports year-round production (Lakhiar *et al.*, 2018; Woznicki *et al.*, 2021) [12, 26]. Systems such as Deep Water Culture (DWC), Nutrient Film Technique (NFT) and Dutch Bucket are commonly used for leafy and fruiting vegetables, offering benefits in root aeration, water-use efficiency and crop uniformity (Pandey *et al.*, 2009; Sharma *et al.*, 2023) [17, 19].

Among these, DWC is praised for its simplicity and stability, particularly for lettuce, while NFT enables rapid nutrient flow but is more sensitive to interruptions (Majid *et al.*, 2021) [15]. The Dutch Bucket system, traditionally used for fruiting crops, is gaining popularity for its flexibility in plant spacing and use of inert media. Aeroponic systems also offer promising results through root misting and nutrient recycling, especially under greenhouse conditions (Koukounaras, 2021; Gashgari *et al.*, 2018) [9, 6].

Given the advantages of hydroponics in improving productivity and resource efficiency, it becomes essential to evaluate the comparative suitability of different systems for key crops like lettuce. Therefore, the present study was undertaken to assess the growth, yield and quality performance of lettuce cultivated under DWC, NFT and Dutch Bucket systems at the Centre of Excellence for Vegetables, Agricultural Development Trust, Baramati. The findings aim to identify the most efficient system for commercial lettuce cultivation under protected conditions.

2. Material and methods

The experiment was conducted at the Hydroponics Demonstration Unit, Centre of Excellence for Vegetables, Agricultural Development Trust, Baramati (18.18° N, 74.54° E, 572 m MSL) during the *kharif* season (Aug 2024-Oct 2024). The site falls in a semi-arid zone with an average annual rainfall of 550 mm and temperatures ranging from 26-28 °C under controlled conditions. The lettuce variety 'Locarno RZ' was used. The trial was arranged in a Completely Randomized Design (CRD) with eight hydroponic systems-DWC, NFT, A frame NFT, Aeroponics, Grow tower/Vertistack, Dutch Bucket, Trough method and Grow bags (control)-each replicated thrice. Plants were spaced at 30 × 30 cm in raised hydroponic beds under a regulated environment with 60-70% relative humidity.

2.1 Growth Parameters

Five healthy and uniform plants were randomly selected from each treatment to record growth observations at 7, 14, 21 days after transplanting and at harvest. Plant height (cm) was measured from the collar region at the base of the plant to the tip of the outermost leaf using a meter scale and the mean was calculated. Plant spread (cm) was determined by measuring the horizontal canopy diameter in both East-West and North-South directions and the average of the two readings was recorded. The number of leaves per plant was counted manually from each tagged plant at weekly intervals and the mean was calculated. Leaf length (cm) was measured from the leaf base to the tip on the longest fully developed leaf. Leaf area (cm²) was assessed by tracing three representative leaves from each plant on graph paper and calculating the area covered using standard area-measuring techniques.

2.2 Biomass and Root Measurements

Leaf fresh mass (g/plant) was measured by weighing freshly harvested leaves from each tagged plant using an electronic weighing balance and the mean was recorded. For leaf dry mass (g/plant), the same leaf samples were oven-dried at 65 °C for 48 hours to constant weight and weighed using a precision balance. Root length (cm) was measured at harvest from the collar region to the root tip using a meter scale. Root fresh mass (g) was obtained by immediately weighing the harvested root samples. For root dry mass (g), roots were oven-dried at 65 °C for 48 hours to ensure complete moisture removal, then weighed using a precision balance. The shoot-to-root ratio (dry weight basis) was calculated by dividing the dry shoot weight by the dry root weight of each plant.

2.3 Yield Parameters

Yield data were collected from five randomly selected plants in each treatment. The number of days required to harvest was recorded from the date of transplanting until the first harvest of marketable leaves. Fresh weight per plant (g) was measured using an electronic balance by weighing the harvested biomass from each plant and the average was calculated. Total yield per system (kg) was obtained by weighing all the harvested plants within each hydroponic unit and summing their fresh weight. To assess yield efficiency, the harvested biomass was converted to yield per square meter (kg/m²) by dividing total system yield by the cultivated area of each system. Similarly, yield per 100 m² (kg) was estimated by applying appropriate to standardize the productivity of each hydroponic system on a larger scale.

3. Results and Discussion

3.1 Growth Parameters

3.1.1 Plant height (cm)

Significant differences in plant height were observed across hydroponic systems at all stages of growth. A-frame NFT and Deep Water Culture consistently recorded higher plant heights, with A-frame NFT reaching 20.88 cm at harvest, while the control showed the lowest (12.46 cm). Enhanced root aeration, continuous nutrient supply and better light interception in A-frame and DWC systems likely supported vigorous vegetative growth, as also reported by Acharya *et al.* (2021) [1], Tulasi Ram *et al.* (2021) [23] and Majid *et al.* (2021) [15]. In contrast, restricted growth in the control may be due to inconsistent nutrient availability, similar to observations by Maboko and Du Plooy (2013) [14].

3.1.2 Plant spread (cm)

Significant differences in plant spread were observed among the hydroponic systems throughout the crop cycle. At harvest, Deep Water Culture recorded the highest plant spread (28.32 cm), followed by A-frame NFT (maximum at earlier stages), while the control consistently showed the lowest spread (12.25 cm). The superior canopy development in DWC can be attributed to optimal root zone conditions and uniform sunlight exposure, particularly from the southern aspect, which facilitated horizontal leaf expansion and reduced shading within the plant. These conditions promoted broader foliage growth, enhancing light interception and overall vegetative performance. Similar observations were reported by Divya Manoj (2023) [3], Lei and Engeseth (2021) [13], Majid *et al.* (2021) [15] and Maboko and Du Plooy (2013) [14], who highlighted the role of consistent light and nutrient availability in improving leaf spread under soilless cultivation.

3.1.3 Number of leaves per plant

The data pertaining to the number of leaves per plant presented in Table 4.3 and graphically depicted in Fig. 4.3. The number of leaves per plant was significantly influenced by various hydroponic systems at 7, 14, 21 and at harvest days after transplanting (DAT). At 7 DAT, the maximum number of leaves per plant was recorded in Deep Water Culture (7.24), which was at par with Flat Bed NFT (7.22). However, the minimum number of leaves was observed in Control (3.12). At 14 DAT, the maximum number of leaves per plant was observed in Deep Water Culture (11.16), which was at par with Dutch Bucket (10.99). However, the minimum number of leaves per plant was seen in Control (5.26). At 21 DAT, maximum number of leaves per plant was observed in Deep Water Culture (15.46). Whereas, the minimum number of leaves was observed in Control (8.07). At harvest, the same trend was continued, the maximum number of leaves per plant was recorded in Deep Water Culture (18.87). While, the minimum number of leaves was recorded in Control (10.08). Hydroponics ensures constant nutrient access and high root zone oxygenation, promoting efficient root respiration and minimizing stress. With stable EC and pH, nutrient uptake remains optimal, driving rapid vegetative growth and increasing leaf production in lettuce. Similar Findings Divya Manoj (2023) [3], Acharya *et al.* (2021) [1], Yadav and Singh (2025) [27] demonstrated that higher in hydroponic systems resulted in greater leaf production, ensuring faster canopy establishment and increased vegetative mass.

3.1.4 Leaf area (cm2)

At harvest, significant variation in leaf area was recorded across hydroponic systems, with Deep Water Culture showing the highest value (200.15 cm²), closely followed by Dutch Bucket (197.12 cm²), while the lowest was observed in Grow Tower/Vertistack (131.82 cm²). The enhanced leaf area in DWC and Dutch Bucket systems can be attributed to efficient nutrient and water uptake, which maintain optimal turgor pressure and promote cellular expansion. Despite the challenge of uniform light distribution in hydroponic setups, consistent nutrient flow and sustained hydration likely supported better mesophyll development and leaf enlargement. These findings are supported by Divya Manoj (2023) [3], Acharya *et al.* (2021) [1] and Ahmed *et al.* (2021) [2], who reported similar improvements in leaf area under optimized light and nutrient conditions in hydroponic lettuce cultivation.

3.1.5 Leaf length (cm)

Significant differences in leaf length were observed across hydroponic systems at all recorded stages. The Grow Tower/Vertistack consistently showed the highest leaf length, reaching 17.13 cm at harvest, followed by Dutch Bucket (16.75 cm), while the control system recorded the lowest values throughout. The elongated leaf growth observed in the Vertistack system may be attributed to its vertical structure, which limits horizontal expansion due to partial light shading. As a result, plants likely responded with vertical elongation of leaves to optimize light interception. This adaptive mechanism, driven by spatial constraints and light competition, contributed to the increased leaf length. Similar trends have been reported by Majid *et al.* (2021) [15], Frezza *et al.* (2005) [5], Ahmed *et al.* (2021) [2], Williams *et al.* (2016) [25], Tulsi Ram *et al.* (2021) [23] and Yadav and Singh (2025) [27], highlighting vertical growth tendencies in compact or shaded growing environments.

3.1.6 Leaf fresh mass (g)

At harvest, variation in leaf fresh mass among the hydroponic systems was evident. Deep Water Culture produced the highest leaf fresh mass (84.47 g), followed by Flat Bed NFT (83.33 g) and Dutch Bucket (82.13 g), while the control recorded the lowest value (21.40 g). The increased biomass in these systems may be attributed to the continuous availability of nutrients, optimal root zone hydration and efficient evaporative cooling, all of which promote cell expansion and maintain leaf turgidity. These physiological advantages enhance photosynthetic activity and support greater assimilate accumulation in the foliage. Comparable outcomes were reported by Williams *et al.* (2016) [25], Thomas (2018) [22] and Ahmed *et al.* (2021) [2], who found that hydroponically grown lettuce demonstrated improved leaf mass due to superior nutrient uptake and water-use efficiency under controlled conditions.

3.1.7 Leaf dry mass (g)

At harvest, notable differences in leaf dry mass were recorded among the hydroponic systems. Deep Water Culture achieved the highest dry mass (4.09 g), statistically comparable to Flat Bed NFT (3.90 g), while the control treatment exhibited the lowest value (1.01 g). The elevated dry matter accumulation in DWC can be linked to uninterrupted nutrient delivery-particularly nitrogen which supports sustained protein synthesis and structural biomass formation. Additionally, the oxygen-enriched root environment in DWC likely promoted efficient respiration and energy production, further enhancing growth. These outcomes align with findings by Thomas (2018) [22] and Ahmed *et al.* (2021) [2], who reported that stable nutrient supply and optimized root zone conditions in hydroponic systems contribute to greater tissue development and higher dry biomass in lettuce.

3.1.8 Root length (cm)

Root length varied significantly across the hydroponic systems, with Aeroponics recording the highest value (23.59 cm), closely followed by Dutch Bucket (22.98 cm), while the shortest roots were observed in the Control (5.96 cm). The superior root elongation in Aeroponics can be attributed to its mist-based environment, which provided minimal mechanical resistance and high oxygen availability, promoting gravitropic root growth and continuous cell expansion. The localized humid microclimate around root tips further supported elongation by maintaining optimal hydration and reducing stress. Similarly, the Dutch Bucket system allowed for ample aeration and root zone space, encouraging deeper root penetration. These findings are consistent with observations by El-Helaly and Darwish (2019) [4] and Tulsi Ram *et al.* (2021) [23], who reported enhanced root development in aerated, low-impedance hydroponic systems.

3.1.9 Root fresh matter (g)

A noticeable difference in root fresh matter was observed across the hydroponic systems at harvest. Aeroponics resulted in the highest root fresh matter (19.30 g), followed closely by Dutch Bucket (19.03 g), Deep Water Culture (18.67 g) and Flat Bed NFT (18.28 g), whereas the control treatment recorded the lowest value (5.20 g). The superior root mass in aeroponic and related systems can be linked to their oxygen-enriched root environments, consistent nutrient flow and minimal mechanical resistance, which collectively promote extensive root proliferation and nutrient absorption. These outcomes are consistent with previous findings by Jones (1991) [8] and Thomas (2018) [22], who reported enhanced root biomass in lettuce cultivated under hydroponic conditions with efficient aeration and nutrient uptake dynamics.

3.1.10 Root dry matter (g)

Distinct differences in root dry matter were recorded among the hydroponic systems. Aeroponics showed the highest root dry matter (1.45 g), followed by Dutch Bucket (1.38 g), while the control system registered the lowest value (0.49 g). The increased dry root biomass in aeroponic and other efficient systems can be linked to superior oxygenation, uninterrupted nutrient access and enhanced root respiration, all of which support sustained metabolic activity and structural growth. These observations are supported by Wang *et al.* (2022) [24] and Ahmed *et al.* (2021) [2], who emphasized that systems like Deep Water Culture significantly improve root biomass through consistent nutrient supply and well-aerated root environments.

3.1.11 Shoot to root ratio

The shoot to root ratio varied notably among the hydroponic systems tested. Flat Bed NFT recorded the highest ratio (3.23), followed by Deep Water Culture (3.11), while the lowest was found in Aeroponics (1.91). A greater allocation of assimilates toward shoot biomass in NFT and DWC systems may be attributed to enhanced cytokinin activity, efficient nutrient movement and reduced mechanical resistance in the root zone, which together promote shoot elongation. These findings are in agreement with those of Thomas (2018) [22], who reported significantly higher shoot to root ratios in hydroponic lettuce linked to well-aerated root environments and steady nutrient supply.

3.2 Yield parameters

3.2.1 Days required to harvest

The number of days required for harvesting varied significantly across the hydroponic systems. Deep Water Culture exhibited the earliest maturity at 28.60 days, closely followed by Flat Bed NFT (29.00 days), while the longest duration to harvest was observed in the control (41.49 days). The reduced crop duration in hydroponic setups can be linked to continuous nutrient availability, minimal abiotic stress and efficient water and root-zone management, which collectively accelerate vegetative development. These findings are consistent with Divya Manoj (2023) [3], Majid *et al.* (2021) [15], who reported a reduction of up to 15 days in lettuce maturity under DWC, and Lages *et al.* (2015) [11], who similarly attributed early harvest in hydroponic systems to improved aeration and regulated nutrient uptake compared to soil-based cultivation.

3.2.2 Fresh weight per plant (g)
Fresh weight per plant in lettuce varied significantly among the hydroponic systems. Deep Water Culture recorded the highest fresh weight (103.77 g), followed closely by Flat Bed NFT (101.62 g) and Dutch Bucket (100.80 g), while the lowest was observed in the control (26.60 g). The substantial biomass accumulation under DWC reflects the benefits of uninterrupted nutrient access, stable moisture supply and a well-oxygenated root environment, all of which contribute to enhanced metabolic efficiency and vigorous growth. These results are supported by Yadav and Singh (2025) [27] and Acharya *et al.* (2021) [1], who reported significantly higher fresh weights in lettuce cultivated under DWC, attributing it to balanced nutrient availability and continuous water uptake that favour optimal plant development.

3.2.3 Yield/system (kg)
Yield per system in lettuce showed considerable variation among the hydroponic setups. Deep Water Culture produced the highest yield (2.08 kg), which was statistically at par with Flat Bed NFT (2.03 kg) and Dutch Bucket (2.02 kg), while the control system recorded the lowest yield (0.53 kg). The superior productivity in DWC can be attributed to continuous nutrient availability, enhanced root zone aeration and the absence of soil-borne constraints, all of which support efficient physiological processes such as carbohydrate metabolism and water absorption. These findings are in agreement with Tulasi Ram *et al.* (2021) [23], who emphasized that a steady supply of nutrients and moisture plays a critical role in maximizing plant growth and final yield under soilless cultivation systems.

3.2.4 Yield/m2 (kg)
Yield per square meter varied notably among the hydroponic systems evaluated. Deep Water Culture recorded the highest yield (2.59 kg/m²), closely followed by Flat Bed NFT (2.54 kg/m²), while the control system produced the lowest yield (0.32 kg/m²). The superior performance of DWC in terms of space efficiency can be attributed to optimized plant spacing, consistent nutrient availability and controlled environmental conditions that together enhance productivity per unit area. These results are supported by Acharya *et al.* (2021) [1], who reported higher yield per square meter in NFT systems, highlighting the importance of efficient resource use and system design in maximizing output under hydroponic cultivation.

3.2.5 Yield/100 m2 (kg)
Yield per 100 m² differed significantly across the hydroponic systems. Deep Water Culture achieved the highest yield (259.42 kg/100 m²), followed closely by Flat Bed NFT (254.04 kg/100 m²), while the control system produced the lowest (31.92 kg/100 m²). The enhanced productivity in DWC can be attributed to optimized plant population, efficient nutrient and water use and minimal environmental stress, all of which contribute to maximizing yield over a given cultivation area. These findings emphasize the importance of system design and resource optimization in improving large-scale output under hydroponic conditions.

Table 1: Effect of different hydroponic systems on plant height (cm) of lettuce

Treatments	Plant height (cm)			
	7 DAT	14 DAT	21 DAT	At harvest
T_1-Flat bed NFT	8.15	11.05	13.32	16.28
T_2-A Frame NFT	8.30	12.38	16.78	20.88
T_3-Deep Water Culture	8.42	12.92	16.41	19.47
T_4-Dutch Bucket	9.27	12.71	15.85	19.09
T_5-Trough method	7.56	10.37	12.97	14.62
T_6-Aeroponics	8.29	11.54	14.84	16.36
T_7-Grow tower/Vertistack	7.49	10.28	11.82	13.94
T_8-Control	6.10	9.58	10.62	12.46
SEm±	0.05	0.07	0.14	0.11
CD at 5%	0.15	0.22	0.43	0.35

Table 2: Effect of different hydroponic systems on plant spread (cm) of lettuce

Treatments	Plant spread (cm)			
	7 DAT	14 DAT	21 DAT	At harvest
T_1-Flat bed NFT	13.04	17.56	20.97	26.03
T_2-A Frame NFT	16.96	19.94	21.86	26.56
T_3-Deep Water Culture	16.17	19.66	22.47	28.32
T_4-Dutch Bucket	10.69	15.96	17.94	20.12
T_5-Trough method	7.44	9.31	10.63	12.38
T_6-Aeroponics	13.99	18.98	21.46	25.67
T_7-Grow tower/Vertistack	8.21	14.73	18.97	21.41
T_8-Control	6.13	7.72	9.59	12.25
SEm±	0.10	0.13	0.16	0.20
CD at 5%	0.31	0.41	0.48	0.60

Table 3: Effect of different hydroponic systems on number of leaves per plant of lettuce

Treatments	Number of leaves per plant			
	7 DAT	14 DAT	21 DAT	At harvest
T_1-Flat bed NFT	7.22	10.56	13.84	16.91
T_2-A Frame NFT	6.68	9.43	12.28	15.59
T_3-Deep Water Culture	7.24	11.16	15.46	18.87
T_4-Dutch Bucket	6.79	10.99	14.56	17.96
T_5-Trough method	3.06	6.94	10.00	12.17
T_6-Aeroponics	4.24	7.36	11.20	13.83
T_7-Grow tower/Vertistack	3.28	5.97	9.50	11.29
T_8-Control	3.12	5.26	8.07	10.08
SEm±	0.03	0.10	0.08	0.10
CD at 5%	0.10	0.32	0.25	0.31

Table 4: Effect of different hydroponic systems on leaf area (cm2) of Lettuce

Treatments	Leaf area (cm2)
	At harvest
T_1-Flat bed NFT	190.07
T_2-A Frame NFT	186.87
T_3-Deep Water Culture	200.15
T_4-Dutch Bucket	197.12
T_5-Trough method	172.09
T_6-Aeroponics	180.05
T_7-Grow tower/Vertistack	131.82
T_8-Control	140.03
SEm±	0.70
CD at 5%	2.10

Table 5: Effect of different hydroponic systems on leaf length (cm) of lettuce

Treatments	Leaf length (cm)			
	7 DAT	14 DAT	21 DAT	At harvest
T_1-Flat bed NFT	6.79	9.44	13.48	15.90
T_2-A Frame NFT	6.91	9.95	13.51	16.07
T_3-Deep Water Culture	6.71	9.12	13.27	15.11
T_4-Dutch Bucket	7.43	11.67	14.19	16.75
T_5-Trough method	6.45	9.06	13.08	14.27
T_6-Aeroponics	7.29	10.07	14.05	16.18
T_7-Grow tower/Vertistack	7.75	11.80	14.46	17.13
T_8-Control	5.11	8.04	12.22	13.62
SEm±	0.06	0.04	0.13	0.11
CD at 5%	0.18	0.12	0.41	0.33

Table 6: Effect of different hydroponic systems on leaf fresh mass (g) and leaf dry mass (g) of lettuce

Treatments	Leaf fresh mass (g)	Leaf dry mass (g)
T_1-Flat bed NFT	83.33	3.90
T_2-A Frame NFT	69.50	2.88
T_3-Deep Water Culture	84.47	4.09
T_4-Dutch Bucket	82.13	3.64
T_5-Trough method	42.30	1.97
T_6-Aeroponics	63.80	2.78
T_7-Grow tower/Vertistack	26.00	1.46
T_8-Control	21.40	1.01
SEm±	1.58	0.07
CD at 5%	4.76	0.21

Table 7: Effect of different hydroponic systems on root length (cm) of lettuce

Treatments	Root length (cm)
T_1-Flat bed NFT	14.96
T_2-A Frame NFT	14.01
T_3-Deep Water Culture	19.99
T_4-Dutch Bucket	22.98
T_5-Trough method	9.57
T_6-Aeroponics	23.59
T_7-Grow tower/Vertistack	7.54
T_8-Control	5.96
SEm±	0.28
CD at 5%	0.86

Table 8: Effect of different hydroponic systems on root fresh matter (g), root dry matter (g) and shoot to root ratio of lettuce

Treatments	Root fresh matter (g)	Root dry matter (g)	Shoot to root ratio
T_1-Flat bed NFT	18.28	1.21	3.23
T_2-A Frame NFT	18.04	1.16	2.47
T_3-Deep Water Culture	18.67	1.31	3.11
T_4-Dutch Bucket	19.03	1.38	2.62
T_5-Trough method	10.27	0.95	2.07
T_6-Aeroponics	19.30	1.45	1.91
T_7-Grow tower/Vertistack	6.13	0.68	2.14
T_8-Control	5.20	0.49	2.05
SEm±	0.41	0.02	0.08
CD at 5%	1.23	0.06	0.25

Yield parameters

Table 10: Effect of different hydroponic systems on days required to harvest and fresh weight per plant (g) of lettuce

Treatments	Days required to harvest	Fresh weight per plant (g)
T_1-Flat bed NFT	29.00	101.62
T_2-A Frame NFT	30.50	87.54
T_3-Deep Water Culture	28.60	103.77
T_4-Dutch Bucket	30.37	100.80
T_5-Trough method	36.51	52.57
T_6-Aeroponics	31.23	82.83
T_7-Grow tower/Vertistack	34.25	32.13
T_8-Control	41.49	26.60
SEm±	0.19	1.70
CD at 5%	0.59	5.10

Table 11: Effect of different hydroponic systems on yield/system (kg), yield/m2 (kg) and yield/100 m2 (kg) of lettuce

Treatments	Yield/system (kg)	2 (kg)	2 (kg)
T_1-Flat bed NFT	2.03	2.54	254.04
T_2-A Frame NFT	1.75	2.36	236.37
T_3-Deep Water Culture	2.08	2.59	259.42
T_4-Dutch Bucket	2.02	1.12	111.59
T_5-Trough method	1.05	0.88	87.58
T_6-Aeroponics	1.66	2.07	207.08
T_7-Grow tower/Vertistack	0.64	0.80	80.33
T_8-Control	0.53	0.32	31.92
SEm±	0.03	0.03	3.41
CD Q5%	0.09	0.10	10.23

4. Conclusion

The present study clearly demonstrates that different hydroponic systems significantly influence the growth, physiological, quality and yield performance of lettuce. Among the treatments, Deep Water Culture consistently excelled across several parameters including plant height, leaf number, chlorophyll content, fresh biomass and overall yield, followed closely by Flat Bed NFT and Dutch Bucket systems. The superior performance of these systems can be attributed to continuous nutrient availability, enhanced oxygenation and optimized microenvironmental conditions. These advantages not only accelerated vegetative development but also improved nutrient uptake and overall productivity. In contrast, the conventional control treatment consistently showed the lowest performance. Overall, the findings validate the efficacy of recirculating hydroponic setups such as DWC and NFT in promoting sustainable, high-efficiency lettuce cultivation under controlled conditions.

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