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Horticultural Plant Production Using Hydroponic Technique †

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Abstract

Lettuce (*Lactuca sativa* L.) is a leafy herb that contains many useful nutrients, allowing it to easily overcome the threats to food security in countries of the Global South by adding fiber/bulk, folate and other available nutrients. In 2020, almost 220 metric tons of lettuce was produced in Pakistan. This high production needs attention to meet the demand. Southern Pakistan is facing water crises and the hydroponic system is one revolutionary technique which can allow the region to meet its food demand. In this experiment, different treatment combinations were used to study their effects and evaluate the best combination of nutrients to get the maximum production of lettuce. Results are concluded on the basis of last-week (5th week) production of shoot and root mass. Treatment one (T1) performed outstanding overall out of all four treatments across all parameters. Maximum average root and shoot length (RL, SL) was observed in treatment one (T1) at 5.94 cm and 15.50 cm respectively. Shoot length is directly proportional to production of the head of the plant. For root and shoot weight (RW, SW) treatment 1 (T1) is more effective than treatment 2 (T2). For treatment 1, root weight (RW) was recorded at 0.09 g and shoot weight (SW) was 0.22 g. The hydroponic system demands huge capital investment, which can be compensated by high production of crops. To increase the efficiency of the system, there is a dire need to calculate optimum nutrient combinations for application to the crop for a sound food security plan.

Keywords: hydroponics; shoot length; root mass; Nutrient Film Technique; controlled environment agriculture; lettuce

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1. Introduction

Fruits and vegetables and medicinal, aromatic, and ornamental plants all are examples of horticultural crops. These plants have substantial aesthetic value for people as well as being key dietary nutritious components, sources of medications, and scents. Adopting horticulture is crucial to supply nutrition to the world's expanding population through fruits, vegetables, and other horticultural products. Horticultural crops face significant difficulties from abiotic stresses like temperature extremes, drought, flooding, salinity, and pH. Understanding the stress physiology, molecular biology, genomics, and assessment of the stress tolerance in horticulture crops would aid in the discovery of opportunities

and the creation of counter-measures to these difficulties [1]. Lettuce (*Lactuca sativa* L.) is widely distributed around the world but has its origin in the Mediterranean, and its first cultivation, found in primitive scripts from early 2680 BCE, was as a medicinal herb. Many scholars have reported that *Lactuca sativa* L. is related to *L. serriola* species, which are native to the southern shores of the Mediterranean [2]. Lettuce belongs to the Asteraceae family, which contains almost 23,000 to 30,000 species members [3]. It is an annual, self-fertilized cole crop. It is diploid (2n = 2x = 18), has a genome size of 2.5 Gb, and is one of the most important Nutrient Film Technique (NFT) growing crops worldwide.

China is at the top of the market in terms of production of lettuce. It comprises almost 56.4% of total global production of lettuce. The USA stands second with 14.3%, followed by India at 4.1% [4]. Australia experienced an astonishing increase in lettuce production from 1980 to 2005 of about 118% [5]. Pakistan is producing almost 400 metric tons of lettuce annually and specifically produced 420 metric tons in 2020 according to Tridge Pakistan from FAO code 0372. Lettuce production has been booming in Pakistan since 2012. A small amount, about 6 metric tons, was also exported to other countries during the year 2020. In Pakistan, 734 hectares of land is under cultivation of lettuce.

Lettuce is prone to many pests and diseases from fungal and bacterial to viral diseases. There are many soil-born fungal diseases like *Pythium tracheiphilum*, *Sclerotinia sclerotiorum*, *Rhizoctonia solani*, *Sclerotinia minor* and *Botrytis cinerea*. From all these, *S. sclerotiorum* and *S. minor* are the most important because of their wide range of effects [6]. The main constituent of this vegetable is water, which comprises 94 to 95%. Apart from this, it is a great source of chlorophyll, vitamins, carotenoids, polyphenols and many other bioactive compounds which are very beneficial for human health [7]. Lettuce has a high content of vitamin C [8]. Every variety is different in its phytochemical composition and contents, as red lettuce is higher in phenolics than green lettuce, and antioxidants are better available in red lettuce for daily consumption [9]. Many published findings confirm that lettuce contains many natural antioxidant compounds that improve life style. Awareness makes lettuce a better replacement for synthetic hazardous antioxidants [10].

Nutrient Film Technique (NFT) is a technique used in hydroponic systems, in which nutrients provided to plants are dissolved in a stream of water running through the roots of plants. Channels of the right length with appropriate slope have nutrients and oxygen dissolved in water. The hydroponic technique system is a solution to many problems related to food and agriculture, but at the same time it has some disadvantages like high installation cost, need for experienced labor, attack from pathogens like fungi/nematodes in wet or humid conditions, and the need for specialized knowledge about the whole system to operate a successful system under constant observation. This study aimed to evaluate the optimum fertilizer ratio for the lettuce crop and the installment of a successful hydroponic system with NFT under the extreme conditions of south Punjab, Pakistan.

2. Materials and Methods

This experiment contains two parts: (1) seedling preparation and (2) transplantation of seedlings to a hydroponic system for further study. Seeds of lettuce, cv. iceberg, were purchased from an open market and seedlings were prepared under greenhouse conditions in disposable cups using locally bought compost as the growing medium. In total, 35 cups were used (2 seeds/cup). After 5 days, 95% of seeds had germinated (Figure 1) at 25 °C with regular water sprinkle at suitable intervals. Seedlings remained in a nursery for 20 days to strengthen and for 3 to 4 true leaves to appear. They were then transplanted to a closed hydroponic system with NFT. After transplanting, the experiment was continued for 5 weeks and data was recorded for each week.



Figure 1. Germinated lettuce cv. iceberg seedling.

2.1. Hydroponic System

A closed hydroponic system is mostly used when water is scarce in areas which are facing serious water environmental hazards and which cannot afford to release it into the environment. Nutrients are reused in the system again and again, with all essential nutrients replenished. In this experiment, a closed hydroponic system is used with NFT, involving PVC pipes, fluorescent light bulbs, a submerged fountain pump, plastic cups to hold the plants and a reservoir for solution (Figure 2).



Figure 2. NFT hydroponic system with established plants.

2.2. Water Chemistry

Distilled water was used with Master Blend's Hydroponic Fertilizer 4-18-38 (Table 1) as nutrients for the hydroponic system. A total of 4 treatments were used with 8 replicates over the five-week period. Treatments are listed in Table 2.

Table 1. Master Blend percentage available nutrients.

Nutrient	Percentage
Nitrogen (NO_3, NH_3)	4%
Soluble K_2O	38%
Total Mg	0.50%
P_2O_5	18%
B	0.20%
Zn	0.05%
Cu	0.05%
Fe	0.40%

Table 1. *Cont.*

Nutrient	Percentage
Mo	0.01%
Mn	0.20%

Table 2. Nutrients treatments used.

Treatment	Master Blend	$MgSO_4$	$Ca(NO_3)_2$
T1	9.4 g	6.5 g	9.4 g
T2	11.4	8.5	11.4
T3	13.4	10.5	13.4
To		Distilled water	

2.3. Parameters

Leaf length and leaf width were measured vertically and horizontally, respectively, in centimeters (cm), with the help of a measuring scale. Root and shoot weights were measured in grams (g) with the help of a weighing balance. Root and shoot length were measured in centimeters (cm) with a measuring scale. Shoot and root length was measured after harvesting. Number of leaves per plant was counted once a week for five weeks.

Electrical conductivity was measured every week for five weeks with the help of an EC meter. The unit of EC was micro-Siemens per linear centimeter (μS/cm) to know the exact total salts of the irrigation water. pH of irrigation water was measured once a week with a pH meter to keep a record of the changing pH of the medium, as well as to ensure the essential nutrients' availability to plants at optimum pH.

2.4. Growth Conditions

Growth conditions for plants were maintained for the following parameters: Average Temperature of the system was maintained around 25 °C with the help of an air conditioner, and a thermometer was used to check this parameter. To keep the relative humidity optimum, fans (exhaust fans) were used along with oxygen pumps to provide enough dissolved oxygen to plant roots. Fluorescent lights (40-watt power) are the most popular to be used in hydroponic systems due to their wide range of benefits from seed germination to fruit formation because of their full range of spectrum emission. Flow Rate was 1000 L per hour, managed with a small submerged fountain pump.

2.5. Harvesting

Harvesting was done manually after five weeks. Harvested plants were carefully kept under optimum conditions to take further data of roots and shoots.

2.6. Statistical Analysis

Collected raw data was analyzed with the help of Statistix 8.1 software, featuring Tukey's HSD test. Completely randomized factorial statistical design was used [11]. For comparison of all parameters and to perform a significance test, Pearson's Correlation was used. Principal Component Analysis (PCA) was performed with XLSTAT.

3. Results and Discussion

3.1. Number of Leaves

Analysis of data for number of leaves revealed fluctuations with different treatment applications over the five weeks that were highly significant. The maximum mean number of leaves was found in treatment 1 (T1) at 4.00, followed by treatment 2 (T2) at 3.70 and

treatment 3 (T3) at 2.60. This shows that T1 was most effective for maximum production of no. of leaves (Table 3); meanwhile, the maximum mean number of leaves was observed in week 3 (4.19), followed by week 4 (3.47) and week 2 (3.16). This shows that the impact of treatments was most effective in the 3rd and 4th weeks (Table 3).

Table 3. Number of leaves over the five weeks of the experiment with different treatment applications.

Treatments	Week 1	Week 2	Week 3	Week 4	Week 5	Means
To	2.25 ± 0.16 a	2.25 ± 0.49 b	2.63 ± 0.56 b	0.50 ± 0.27 c	0.00 ± 0.00 b	1.53 ± 0.70 B
T1	2.25 ± 0.16 a	4.00 ± 0.27 a	4.75 ± 0.31 a	5.50 ± 0.68 a	3.50 ± 1.10 a	4.00 ± 0.58 A
T2	2.13 ± 0.13 a	3.13 ± 0.40 ab	4.88 ± 0.30 a	5.00 ± 0.68 a	3.36 ± 1.35 a	3.70 ± 0.70 A
T3	2.13 ± 0.30 a	3.25 ± 0.49 ab	4.50 ± 0.46 a	2.88 ± 0.95 b	0.25 ± 0.25 b	2.60 ± 0.66 AB
Means	2.19 ± 0.04 AB	3.16 ± 0.36 AB	4.19 ± 0.53 A	3.47 ± 1.14 AB	1.78 ± 0.96 B	

Means sharing similar letter in a row or in a column are statistically non-significant ($p > 0.05$). Small letters represent comparison among interaction means and capital letters are used for overall mean.

3.2. Leaf Length (LL) (cm) and Leaf Width (cm)

The analysis of data revealed that leaf length (LL) was significant in the treatments, while leaf width (LW) was non-significant. Data of leaf length and leaf width were taken in the first week to compare with later progress of the experiment. Maximum leaf length was observed under T2 (8.34 cm) followed by T3 (8.21 cm) and T1 (7.88 cm); meanwhile, maximum leaf width was observed in To (2.39 cm) followed by T1 (2.18 cm) and T2 (2.11) (Table 4).

Table 4. Mean comparison table: week 1.

Treatments	Leaf Length (cm)	Leaf Width (cm)	Means
To	6.50 ± 0.60 b	2.39 ± 0.44 a	4.44 ± 1.68 A
T1	7.88 ± 0.66 ab	2.18 ± 0.15 a	5.03 ± 2.33 A
T2	8.34 ± 0.23 a	2.11 ± 0.15 a	5.23 ± 2.54 A
T3	8.21 ± 0.27 a	1.88 ± 0.24 a	5.04 ± 2.59 A
Means	7.73 ± 0.42 A	2.14 ± 0.11 B	

Means sharing similar letter in a row or in a column are statistically non-significant ($p > 0.05$). Small letters represent comparison among interaction means and capital letters are used for overall mean.

3.3. Root Weight (g)

Data analysis for root weight (RW) (g) was non-significant in the treatments of the experiment, and the maximum root weight (RW) was observed in replicates of treatment 1 (T1) at 0.09 g, followed by treatment 2 (T2) at 0.07 g and treatment 3 (T3) at 0.02 g (Table 5).

Table 5. Mean comparison table: week 5.

Treatments	Root Weight (g)	Root Length (cm)	Shoot Weight (g)	Shoot Length (cm)	Means
To	0.00 ± 0.00 b	0.00 ± 0.00 b	0.00 ± 0.00 c	0.00 ± 0.00 c	0.00 ± 0.00 A
T1	0.09 ± 0.04 a	5.94 ± 2.19 a	0.22 ± 0.07 a	15.50 ± 4.69 a	5.44 ± 3.62 A
T2	0.07 ± 0.03 ab	2.91 ± 1.13 ab	0.21 ± 0.09 ab	11.88 ± 4.73 ab	3.77 ± 2.78 A
T3	0.02 ± 0.02 ab	0.88 ± 0.88 b	0.04 ± 0.04 bc	2.13 ± 2.13 bc	0.76 ± 0.50 A
Means	0.05 ± 0.02 B	2.43 ± 1.32 AB	0.12 ± 0.06 B	7.38 ± 3.74 A	

Means sharing similar letter in a row or in a column are statistically non-significant ($p > 0.05$). Small letters represent comparison among interaction means and capital letters are used for overall mean.

3.4. Root Length (cm)

Data analysis for root length (RL) is significant for the treatments of the experiment. Maximum root length (RL) was observed in treatment 1 (T1) at 5.94 cm, followed by treatment 2 (T2) at 2.91 cm and treatment 3 (T3) at 0.88 cm (Table 5).

3.5. Weight (g)

Data analysis for shoot weight (SW) is significant for the treatments of the experiment. Shoot weight (SW) maximum was observed in treatment 1 (T1) at 0.22 g, followed by treatment 2 (T2) at 0.21 g and treatment 3 (T3) at 0.04 g (Table 5).

3.6. Shoot Length (cm)

Data analysis for shoot length (SL) is highly significant for the treatments of the experiment. Shoot length (SL) maximum was observed in treatment 1 (T1) at 15.50 g, followed by treatment 2 (T2) at 11.88 cm and treatment 3 (T3) at 2.13 cm (Table 5).

3.7. Pearson Correlation Matrix Table for Number of Leaves

The number of leaves (NL) of the first week is highly negatively significantly correlated with electrical conductivity (EC) of the 3rd week and 4th week. The number of leaves (NL) of week 4 was negatively significantly correlated with 3rd-week pH. The number of leaves (NL) of the 5th week is highly negatively significant to pH of the 5th week. pH of the 1st week was significantly correlated with 2nd-week pH, while pH of the 3rd week was highly significantly correlated with week-5 pH. Electrical conductivity (EC) of the 4th week was highly significantly correlated with week-5 electrical conductivity (EC) (Table 6).

Table 6. Pearson Correlation matrix table for number of leaves.

	NLW1	**NLW2**	**NLW3**	**NLW4**	**NLW5**	**PHW1**	**PHW2**	**PHW3**	**PHW4**	**PHW5**	**ECW1**	**ECW2**	**ECW3**	**ECW4**
NLW2	−0.05 0.95													
NLW3	−0.55 0.45	0.84 0.16												
NLW4	−0.24 0.76	0.88 0.12	0.92 0.08											
NLW5	−0.02 0.98	0.70 0.30	0.72 0.28	0.92 0.08										
PHW1	0.69 0.31	−0.69 0.31	−0.97 0.03	−0.87 0.13	−0.69 0.31									
PHW2	0.71 0.29	−0.48 0.52	−0.86 0.14	−0.80 0.20	−0.72 0.28	**0.95** * 0.05								
PHW3	0.40 0.60	−0.69 0.31	−0.89 0.11	**−0.95** * 0.05	−0.92 0.08	0.91 0.09	0.93 0.07							
PHW4	−0.20 0.80	**−0.96** ** 0.04	−0.70 0.30	−0.84 0.16	−0.75 0.25	0.54 0.46	0.35 0.65	0.64 0.36						
PHW5	0.22 0.78	−0.63 0.37	−0.78 0.22	−0.92 0.08	**−0.98** ** 0.03	0.79 0.21	0.85 0.15	**0.97** ** 0.03	0.64 0.36					
ECW1	−0.14 0.86	−0.87 0.13	−0.73 0.27	−0.93 0.07	−0.94 0.06	0.62 0.38	0.55 0.45	0.82 0.18	0.93 0.07	0.86 0.14				
ECW2	−0.52 0.48	−0.13 0.87	0.33 0.67	0.35 0.65	0.50 0.50	−0.51 0.49	−0.76 0.24	−0.62 0.38	0.17 0.83	−0.65 0.35	−0.17 0.83			
ECW3	**−0.98** ** 0.02	0.25 0.75	0.71 0.29	0.42 0.58	0.18 0.82	−0.82 0.18	−0.80 0.20	−0.55 0.45	0.00 1.00	−0.36 0.64	−0.06 0.94	0.50 0.50		
ECW4	**−0.97** ** 0.03	0.04 0.96	0.48 0.52	0.12 0.88	−0.15 0.85	−0.59 0.41	−0.56 0.44	−0.24 0.76	0.23 0.77	−0.04 0.96	0.25 0.75	0.32 0.68	0.94 0.06	
ECW5	−0.93 0.07	0.06 0.94	0.44 0.56	0.07 0.93	−0.24 0.76	−0.54 0.46	−0.46 0.54	−0.15 0.85	0.21 0.79	0.06 0.94	0.28 0.72	0.17 0.83	0.90 0.10	**0.99** ** 0.01

* = Significant ($p < 0.05$); ** = Highly significant ($p < 0.01$).

3.8. Pearson Correlation Matrix Table for Week 1 and Week 5

Root weight (RW) was highly significantly correlated with root length (RL), and root weight (RW) was highly significantly correlated with shoot weight (SW). Shoot length (SL) is highly significantly correlated with root weight (RW) and vice versa (Table 7).

Table 7. Pearson Correlation matrix table for week 1 and week 5.

	LLW1	LWW1	RWW5	RLW5	SWW5
LWW1	−0.835				
	0.165				
RWW5	0.6139	−0.1396			
	0.3861	0.8604			
RLW5	0.4589	−0.0472	0.9566 *		
	0.5411	0.9528	0.0434		
SWW5	0.6213	−0.11	0.9858 **	0.8993	
	0.3787	0.89	0.0142	0.1007	
SLW5	0.5548	−0.0614	0.9969 **	0.9578 *	0.9865 **
	0.4452	0.9386	0.0031	0.0422	0.0135

* = Significant ($p < 0.05$); ** = Highly significant ($p < 0.01$).

3.9. pH

The analysis of data revealed that pH is significant to both treatments and weeks, while it is highly significant in treatment x week interaction. Maximum mean pH value in relation to treatment was observed in the control (To) at 7.07, followed by treatment 3 (T3) at 6.63 and treatment 1 (T1) at 6.13 (Table 8). Maximum mean value of pH in relation to weeks was observed in week three (W3) at 6.80, followed by W4 at 6.68 and W5 at 6.64 (Table 8).

Table 8. Mean table for pH.

Weeks	To	T1	T2	T3	Means ± SE
W1	7.00 ± 0.12 abc	6.03 ± 0.09 ef	5.63 ± 0.09 f	6.00 ± 0.12 ef	6.17 ± 0.29 C
W2	7.00 ± 0.06 abc	6.47 ± 0.26 bcde	5.90 ± 0.00 ef	6.47 ± 0.07 bcde	6.46 ± 0.22 B
W3	7.50 ± 0.00 a	6.50 ± 0.20 bcde	6.20 ± 0.12 def	7.00 ± 0.06 abc	6.80 ± 0.29 A
W4	7.07 ± 0.07 ab	6.17 ± 0.15 def	6.73 ± 0.03 bcd	6.77 ± 0.15 bcd	6.68 ± 0.19 AB
W5	7.03 ± 0.09 abc	6.40 ± 0.12 cde	6.23 ± 0.20 def	6.90 ± 0.06 abc	6.64 ± 0.19 AB
Means ± SE	7.12 ± 0.10 A	6.31 ± 0.09 C	6.14 ± 0.18 C	6.63 ± 0.18 B	

Means sharing similar letter in a row or in a column are statistically non-significant ($p > 0.05$). Small letters represent comparison among interaction means and capital letters are used for overall mean.

3.10. Electrical Conductivity (EC)

The analysis of data revealed that electrical conductivity (EC) is significant for both treatments and weeks, while it is highly significant in treatment x week interaction. Maximum mean electrical conductivity (EC) value in relation to treatment was observed in treatment 2 (T2) at 1519.93 mS/cm, followed by treatment 3 (T3) at 1510.07 mS/cm and control (To) at 1006.87 mS/cm (4.8). Maximum mean value of electrical conductivity (EC) in relation to weeks was observed in week four (W4) at 1467.08 mS/cm, followed by the 5th week (W5) at 1346.83 mS/cm and the 3rd week (W3) at 1243.75 mS/cm (Table 9).

Table 9. Mean table for EC.

Weeks	To	T1	T2	T3	Means ± SE
W1	1590.33 ± 5.78 d	855.00 ± 2.89 h	1139.33 ± 2.60 f	1461.33 ± 3.33 e	1261.50 ± 165.39 C
W2	637.00 ± 2.31 i	506.00 ± 1.15 j	1577.00 ± 4.04 d	506.00 ± 0.00 j	806.50 ± 258.68 D
W3	797.00 ± 0.00 h	1000.00 ± 11.55 g	1595.00 ± 2.89 d	1583.00 ± 9.81 d	1243.75 ± 203.61 C
W4	1010.00 ± 5.77 g	970.33 ± 11.55 g	1788.00 ± 1.15 c	2100.00 ± 57.74 a	1467.08 ± 282.73 A
W5	1000.00 ± 0.58 g	987.00 ± 0.58 g	1500.33 ± 0.33 e	1900.00 ± 5.77 b	1346.83 ± 219.72 B
Means ± SE	1006.87 ± 161.45 B	863.67 ± 93.05 C	1519.93 ± 106.30 A	1510.07 ± 275.31 A	

Means sharing similar letter in a row or in a column are statistically non-significant ($p > 0.05$). Small letters represent comparison among interaction means and capital letters are used for overall mean.

3.11. Principal Component Analysis (PCA) for Four Treatment Applications on Lettuce cv. Iceberg in Hydroponic System with NFT

Principal Component Analysis (PCA) for the four treatments applications on lettuce cv. iceberg in a hydroponic system with NFT shows readable divergence from the axis. The Principal Component Analysis plot was developed on the basis of first and second component factors of 28.75% and 9.37% respectively. Treatments T3 and T1 are equally divergent from the center on opposite axes, while control and treatment 2 (To, T2) show low divergence (Figure 3). The biplot (Figure 4) shows the relationship between the variables within the three-dimensional data. Vector length and direction show the divergence of the variable or parameter from other variables and parameters. Figure 4 represents the treatments, while Figure 5 only represents variables. Figure 5 reveals that number of leaves and shoot weight are highly correlated with each other.

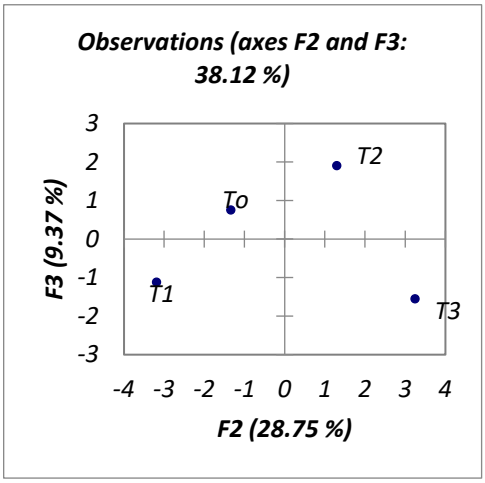

Figure 3. Principal Component Analysis (PCA) for four treatment applications on lettuce cv. iceberg in hydroponic system with NFT.

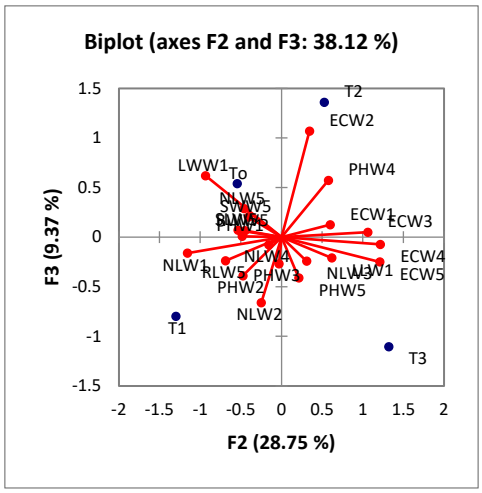

Figure 4. Biplot for application of four treatments and variables on lettuce cv. iceberg in hydroponic system with NFT.

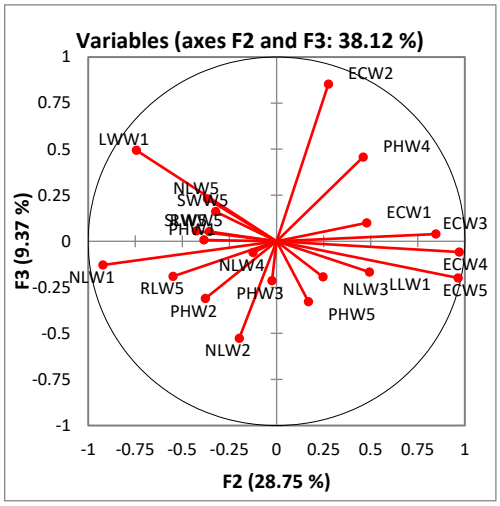

Figure 5. Principal Component Analysis (PCA) for variables of lettuce cv. iceberg in hydroponic system with NFT.

4. Discussion

Lettuce (*Lactuca sativa* L.) is widely distributed around the world but originated in the Mediterranean, and its first cultivation, found in primitive scripts from early 2680 BCE, was as a medicinal herb [2]. Lettuce contains many useful nutrients that can easily compensate the threats to food security in countries of the Global South. Southern Pakistan is facing water crises, and the hydroponic system is a revolutionary technique that can help the region meet its food demand. In this experiment different treatment combinations are used to see their effects and evaluate the best combination of nutrients to get the maximum production of lettuce. Results are concluded on the basis of last-week (week 5) production of root and shoot mass.

Treatment one (T1) performed outstanding across all four parameters. Maximum average root and shoot lengths (RL, SL) were observed in T1 at 5.94 cm and 15.50 cm respectively. Increased shoot length is directly proportional to the increased production of the head of the plant. For root and shoot weight (RW, SW) treatment 1 (T1) is more effective than treatment 2 (T2). For treatment 1, root weight (RW) was recorded at 0.09 g and shoot weight (SW) of 0.22 g was recorded.

A study by [12] suggested that increased concentration of nitrogen can decrease the growth of leafy vegetables in hydroponic systems. This relation may be due to the osmotic pressure of the plant. Ref. [13] also reported the same kind of results, where they stated that increased nitrogen content does not increase the plant metabolism. Phosphorus is also efficiently taken up by plant roots when it is within the required range, which is 35–50 mg/L, as stated in the study conducted by [14]. The same goes with the nitrogen concentration; Ref. [15] reported that if nitrogen is increased in a hydroponic system by 100 to 200 mg/L, plant weight can increase by 23% to 113%. Increases in plant weight are only effective with increases in the nutrient (nitrogen) when it is within the required range. If nitrogen is increased or decreased outside of this range it could be toxic or cause physiological deficiency disorders in plants.

In light of these previous studies, increasing amounts beyond the optimum range of nutrients in T2 and T3 had a negative impact on the lettuce production in the hydroponic system. Similar results were also reported by a recent study [16]. The authors stated that the better the nutrient combination, the better the plant root and shoot growth and, ultimately, weight gain. Ref. [17] also reported that increased amounts of ammonium in a hydroponic system will decrease the root metabolism, resulting in shorter roots.

5. Conclusions

This study suggests that increased concentration of nutrients is not an appropriate option for high production of leafy vegetables in a hydroponic system. Critical analysis is needed to evaluate the optimum nutrient concentration for plants according to their metabolic needs. Nutrient combinations should be prepared according to the hydroponic system type used and crop variety which is being grown in that hydroponic system. A calculated optimum measure can lead to a high production of crops and maximum benefits gained from the huge capital investment in a hydroponic system.

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