Bulgarian Journal of Agricultural Science, 24 (No 5) 2018, 793–800

Effect of water flow rate on quantity and quality of lettuce (*Lactuca sativa* L.) in nutrient film technique (NFT) under hydroponics conditions

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Abstract

Al-Tawaha, A. R., Al-Karaki, G., Al-Tawaha, A. R., Sirajuddin, S. N., Makhadmeh, I., Wahab, P. E. M., Youssef, R. A., Al Sultan, W. & Massadeh, A. (2018). Effect of water flow rate on quantity and quality of lettuce (*Lactuca sativa* L.) in nutrient film technique (NFT) under hydroponics conditions. *Bulgarian Journal of Agricultural Science*, *24*(5), 793–800

In the study of hydroponics, questions have risen concerning about ideal water flow that allow the plant to absorbing highest amount of nutrient from the nutrient solution during irrigating process. Thus, this experiment was aimed to determine the ideal water flow rate in nutrient film technique system in order to optimize the nutrients uptake with growth of lettuce. Different flow rates 10, 20 and 30 L/hour were assigned as T1, T2 and T3, respectively, with lettuce plants and the space between plants 15 cm. Generally, the growth decreased significantly with increasing in water flow rate. The analysis of lettuce hydroponics variable reveals that flow rate at 20 L/hour provides higher mean rank rather than other flow rate 10 L/hour and 30 L/hour. The findings of this research stated that if flow rate is increased to 30 L/hour plant height, number of leaves, number of outer and inner leaves, heat mass and stem mass decreases. On the whole from the analysis it is concluded that for flow rate 20 L/hour enhances the growth rate of lettuce in hydroponics hence it is stated that flow rate of 20 L/hour is good flow rate rather than 10 L/hour and 30 L/hour. Water flow in nutrient film technique is essential to be ideal through allow the plants root to absorb all elements needed form nutrient solutions in hydroponics system. And thus, water movement in the system and the rate of turnover should be designed to ensure good contact time for roots and water flow in the system.

*Keywords***:** lettuce; hydroponics; water flow rate; nutrient film technique

Introduction

Hydroponics (HP) have arisen as a method to further enhance the production of vegetables such of lettuce (Makhadmeh et al., 2017), tomato (Al-Ajmi et al., 2008), sweet pepper (Othman et al., 2008) and medicinal plants (Al-Tawaha et al., 2016) and other high crops value to meet the increasing demand for high quality products. HP is a technique used to grow plants in a nutrient solution with (Al-Tawaha et al., 2016) or without using a substrate and can be classified as liquid hydroponics or substrate hydroponics (Jones, 2005). Moreover, in HP, cultivation of plants does not require the use of soil (Malorgio et al., 2005). According to reports, annually, from 2011-2016, there is a 4.5% growth with positive increasing every year in the hydroponics sector, due to the increasing demand in healthy food crop production. On the other hand, HP offer many advantages such as: improved quality of crop, generally higher rates of production, a reduction of labor requirements, a lower water requirement, increased productivity, uniform plant production, a significant reduction in the area required for production, the possibility of cultivation at any time of the year, rapid economic return, and high-quality products. Hydroponics system (HPS) requires greater amount of production knowledge, experience, technical skill, and financial investment than many other greenhouse systems (Kaiser and Ernst, 2012). In addition, in HPS production, there is a necessity of greenhouses arise in order to provide adequate heat during winter season and either shading or chilling for water in the summer months (Kaiser and Ernst, 2012). Various factors such as time of the day, plant size and season create impact on HP crops such as lettuce production (Gent, 2011; Makhadmeh et al., 2017). In hydroponics, there are general growing systems used such as nutrient film technique (NFT), deep flow technique (DFT), dynamic root floating technique (DRFT) and substrate culture (Koohakan et al., 2008). However, the most widely used HPS to grow leafy greens are NFT (Jones, 2005). Significant hydroponics research has been specifically focused on production of lettuce *(Lactuca sativa* L.) by NFT. Researchers such as Ako and Baker (2009) have conducted experiments to grow lettuce in shallow wooden trays in aquaponics. NFT is not only used in lettuce production, but also in garlic, potato (Wheeler et al., 1990), tomato, cucumber, strawberry and beans (Resh, 2013). Also, Edaroyati et al. (2017) reported that lettuce can be intercropped with other crops such as tomato in hydroponics and aquaponics. Usually, the loose leaf, butterhead, and romaine (cos) are preferred to be hydroponically cultivated (Kaiser and Ernst, 2012). Lettuce (*Lactuca sativa* L.) is one of the leafy vegetables mainly consumed around the world. It is a member of *Lactuca* (lettuce) genus and belongs to *Asteraceae* (sunflower or aster) family. It has traditionally been cultivated by small scale producers and is also widely grown as a vegetable in home gardens which gives it great economic and social importance (Mitova et al., 2017). According to statistic report, 24.98 million metric tons of lettuce was produced globally in the year 2014. It is especially important as a commercial crop in Asia, North and Central America, and Europe. There are various varieties of lettuce available – butterhead (Boston), cos (Romaine), crisphead (iceberg) and loose leaf, of which crisphead is the mostly available fresh market type lettuce. Nutritionally, it is rates low among other vegetable crops; 95% of the crop contains water with varying amounts of phosphorus, iron, sodium and potassium, depending on the morphological type. According to US FDA National Nutrient database, raw romaine lettuce contains high amount of water with calcium, iron, phosphorous, sodium, zinc, vitamins A, B6, C, D, E, K, unsaturated fatty acids and caffeine (US FDA, 2016). Leaf lettuces have higher levels of ascorbic acid, vitamin A and calcium. In addition, omega-3 fatty acids that are essential for normal growth and development exhibit beneficial effects on human health are also present in lettuce (Oh et al., 2009). Furthermore, increased biomass production with minimal contamination makes hydroponics suitable for the production of lettuce *(Lactuca sativa* L.). Under HPS, many experiments were conducted for maximizing the yield of lettuce growing in NFT system. The objective of this study it is to evaluate the growth characteristics and the marketable yield of lettuce under different water flow rates in NFT conditions.

Materials and Methods

Plant material, growing conditions and experimental design

Two experiments were conducted in greenhouse located at Jordan University of Science and Technology (JUST) campus in 2014 – the first experiment (Exp-1) in February until March and the second experiment (Exp-2) in March until April, respectively. The experiment period was 40 days during 2014 with three replicates. Seeds of lettuce *(Lactuca sativa* L.) were sown onto peatmoss substrate and germinated in a growing nursery of Jordan University of Science and Technology (JUST) at 16-22°C. On early of February 2014 lettuce (*Lactuca sativa* L.) were transplanted at the third-forth true-leaf stage in a NFT of HPS for Exp-1, while the second experiment on early March 2014 were transplanted at the third-forth true-leaf stage in a NFT of HPS and were harvested at the fifth week after transplanting in Exp-1 and Exp-2, respectively.

Experimental setup and water chemistry

The NFT system consists of channels or gutters laid on a 2-3% slope in which nutrient solution is pumped from a supply tank through an inlet to channels where seedling there and then is returned back into the supply tank. NFT system is considered as proper when the channel slop, channel length and the optimum flow rate are rightly kept and maintained. The channels have holes on the top in which young plants are placed so that their roots are continuously immersed in a few millimeters thin film of the nutrient solution. The nutrient solution concentration, expressed as electrical conductivity (EC) and pH in this system is monitored and adjusted manually. EC and pH values of the applied nutrient solution in the NFT were maintained at 2.0-2.5 ds m^{-1}, and 6.5-7.5, respectively.

Growth conditions

In both experiments, three treatments were applied with different flow rates of water, in liters per hour (L/h): low flow (10 L/h), middle flow (20 L/h) and high flow (30 L/h) in Exp-1 and Exp-2, respectively. Water and nutrient requirements of the plants were covered with nutrient. Nutrient solution was applied in irrigations system through a flow water system.

Quantitative and qualitative parameters

The growth, yield and plant quality of lettuce *(Lactuca sativa* L.) were evaluated under NFT hydroponics. Plant height (cm), head mass (g), marketable head mass (g), total number of leaves, number of inner leaves, number of outer leaves and stem weight (g) were measured at Exp-1 and Exp-2.

Results

Data analysis and interpretation

Based on the objective shared and the data sheet, the following possible data analysis has been conducted. The data collected was statistically analysed using SPSS software (version 21.0, 2012). Mean and standard deviation are measured to find the distribution of the data. All the data were statistically analysed for non-parametric ANOVA. Probabilities of significance among treatments and LSD ($P \leq 0.05$) were used to compare means among treatments. Comparative details of hydroponics under different criteria are presented.

Plant height

Figure 1 presents the comparison of plant height in cm with different flow rates of water. From the evaluation of the graph, it is clearly observed that for 30 L/h plant height obtain 22 cm and 23 cm; for 20 L/h plant height was 27 cm, 28 cm and 29 cm and for 10 L/h plant height of 24 cm, 25 cm is observed (Fig. 1, Table 1). Through this it is concluded that the higher height is achieved for flow rate 20 L/h. Moreover, Table 1 shows that the highest plant height (28 cm) was achieved at T2 (20 L/h). Thus, the highest plant height will be the highest head mass also. The relationship between plant height in Table 1 and head mass in Table 2 is positive.

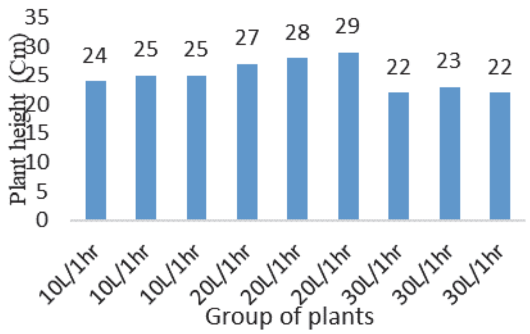

Fig. 1. Comparison of plant height (cm) with different flow rates of water (liters per hour)

Table 1
Effect of water flow rate on plant height of lettuce under NFT hydroponics system

Treatments	Plant height (cm)
10 L/h	24.67
20L/h	28.00
30 L/h	22.33
Significant	*

Means followed with columns the same letter is not significantly different at p-value 0.05 using LSD; *, **, *** – Significantly different at p-value 0.05, 0.01 and 0.001, respectively; ns – Not significantly different at p-value 0.05

Head mass and biomass yield

For 10 L/h plant head mass is at the rate of 158 g, 146 g and 154 g while for 20 L/h head mass is 233 g, 240 g and 237 g. In case of 30 L/h head mass is observed as 133 g, 136 g and 135 g (Fig. 2, Table 2). Head mass was highly influenced by the water flow effect of absorb and uptake the nutrients ($P < 0.05$). Moreover, the weight of head mass was considered as an important indicator required by lettuce growers to judge the economic value of its conditions. For this purpose, NFT system was used in this study to evaluate the effect of water flow rate on head mass under hydroponics. Moreover, optimum water flow rate was a key to achieve high quality of lettuce for increasing the marketable percent of production especially when lettuce was a high crop value nowadays around the world. Table 2 shows that T2 (20 L/h) was the ideal flow rate with highest head mass 236.67 g. T3 (30 L/h) illustrate the lowest head mass (134 g).

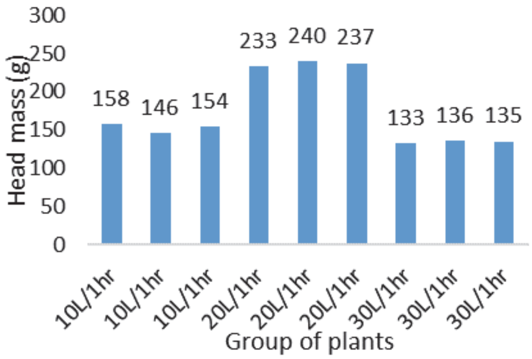

Fig. 2. Comparison of head mass (g) with different flow rates of water (liters per hour)

Table 2
Effect of water flow rate on head mass for lettuce under NFT hydroponics system

Treatments	Head mass (g)
10 L/h	152.67b
20L/h	236.67a
30 L/h	134.67c
Significant	*

Means followed with columns the same letter is not significantly different at p-value 0.05 using LSD; *, **, *** – Significantly different at p-value 0.05, 0.01 and 0.001, respectively; ns – Not significantly different at p-value 0.05

In addition, an increase in flow rate of water in NFT would influence the growth of the lettuce, possibly decrease the biomass growth because the contact time between the root surface area and flow rate it is not ideal to absorb the elements from the nutrient solution. Moreover, increase the water flow and decrease water have same effects on head mass or fresh yield of lettuce. A marketable lettuce head (biomass yield) of 236.67 g can be achieved hydroponic solution in 20 L/h water flow.

Number of leaves

From the graph at Fig. 3 it is clearly observed that maximum number of leaves is grown at 20 L/h with count of 42.40 and 38. Leaves count for 10 L/h is 34, 33 and 32 and similarly for flow rate of 30 L/h count is 24.25 and 26. According to the data in Table 3, the highest total number of leaves was achieved at T2 20 L/h (40 leaves). The number of outer leaves was 21.34 and the number of inner leaves was 18.66 at the T2 20 L/h (Fig. 4, 5).

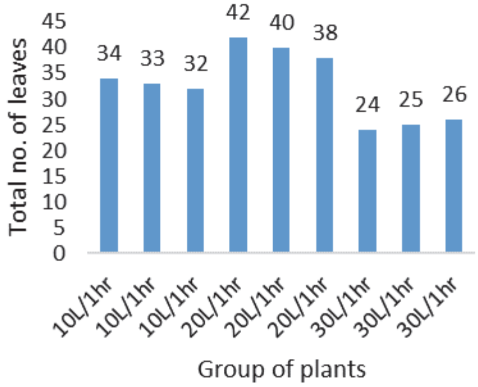

Fig. 3. Comparison of total number of leaves with different flow rates of water (liters per hour)

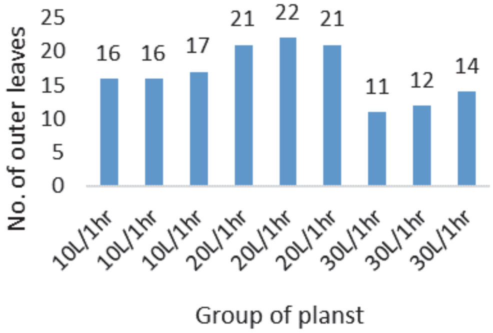

Fig. 4. Comparison of number of outer leaves with different flow rates of water (liters per hour)

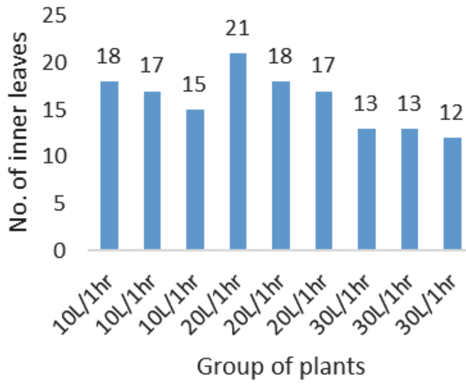

Fig. 5. Comparison of number of inner leaves with different flow rates of water (liters per hour)

The lowest total number of leaves was achieved at T3. Outer leaves count also maximum for flow rate of 20 L/h with count of 21 and 22 which is comparatively higher than 10 L/h and 30 L/h flow rate. Same as total leaves and outer leaves count inner leaves count also exhibits higher leaves count for flow rate 20 L/h. For 10 L/h inner leaves are 18, 17 and 15 in count and for 30 L/h count is 13 and 12. In order

Table 3

Effect of water flow rate on total number of leaves, number of outer leaves and number of inner leaves for lettuce under NFT hydroponics system

Treatments	Total number of leaves	Number of outer leaves	Number of inner leaves
10 L/h	33b	16.34b	16.67b
20L/h	40a	21.34a	18.66a
30 L/h	25c	12.34c	12.66c
Significant	*	*	*

Means followed with columns the same letter is not significantly different at p-value 0.05 using LSD; *, **, *** – Significantly different at p-value 0.05, 0.01 and 0.001, respectively; ns – Not significantly different at p-value 0.05

to verify the result obtained in the present study, number of outer and inner leaves has been resulted for evaluating the effect of outer and inner leaves on marketable value of lettuce. Lettuce with highest number of outer leaves have more value due the size of leaves which give more weight and more marketable for producers.

The highest outer and inner leaves were hatched under similar conditions of the water flow. Total number of leaves was significantly affected by T2 (20 L/h) and affects both outer and inner leaves ($P < 0.05$).

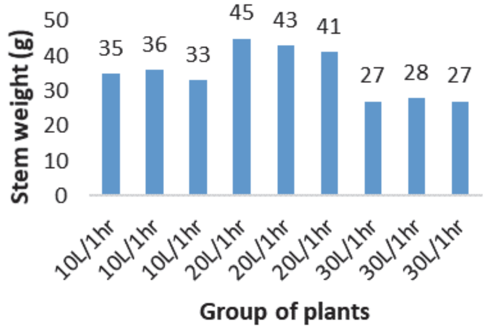

Fig. 6. Comparison of stem weight (g) with different flow rates of water (liters per hour)

Table 4

Effect of water flow rate on stem weight for lettuce under NFT hydroponics system

Treatments	Stem weight (g)
10 L/h	34.66b
20L/h	43a
30 L/h	27.34c
Significant	*

Means followed with columns the same letter is not significantly different at p-value 0.05 using LSD; *, **, *** – Significantly different at p-value 0.05, 0.01 and 0.001, respectively; ns – Not significantly different at p-value 0.05

Stem weight

Stem weight observed for flow rate 10 L/h is 35 g, 36 g and 33 g while for 30 L/h stem weight is 27 g and 28 g. In case of flow rate of 20 L/h stem weight is 45 g, 43 g and 41 g (Fig. 6, Table 4).

Dry weight

On the other hand, dry weight of the plant was also higher for flow rate of 20 L/h compared with 10 L/h and 30 L/h (Fig. 7, Table 5). The dry weight obtained for 20 L/h is 21 g, 22 g and 23 g.

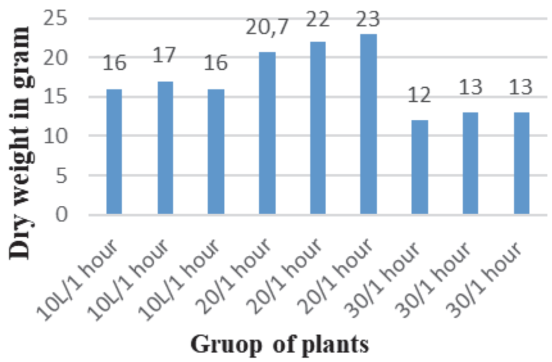

Fig. 7. Comparison of dry weight (g) with different flow rates of water (liters per hour)

Table 5

Effect of water flow rate on dry weight for lettuce under NFT hydroponics system

Treatments	Dry weight(cm)
10 L/h	16.33b
20L/h	21.9a
30 L/h	12.66c
Significant	*

Means followed with columns the same letter is not significantly different at p-value 0.05 using LSD; *, **, *** – Significantly different at p-value 0.05, 0.01 and 0.001, respectively; ns – Not significantly different at p-value 0.05

Table 6

Descriptive statistics

Variables	Mean	SD	Max	Min
Plant height	25.00	2.55	29	22
Head mass (g)	174.67	47.29	240	133
Total number of leaves	32.67	6.61	42	24
Number of outer leaves	16.67	4.00	22	11
Number of inner leaves	16.00	2.96	21	12
Stem weight (g)	35.00	6.91	45	27
Dry weight (g)	15.30	6.73	23	1

The variables considered for analyzing hydroponics process are presented in Table 6. There are 7 variables considered such as plant height, head mass, number of leaves, number of outer leaves, number of inner leaves, stem weight and dry weight. The results obtained during this study revealed clear variation of quantity dry yields at different flow water rate, which influence on dry herbage yields of lettuce under NFT hydroponics system (Table 6).

The results presented in Table 6 showed that for dry yields under T2 (20 L/h) mean and standard deviation of 35.00, 15.30, 6.91 and 6.73 was significantly higher than that of other treatments (T1 and T2) at (P > 0.05). It is observed that plant height average mean of 25.00 with standard deviation of 2.55 with range of 22-29 (Table 6). Mean value obtained for head mass, total number of leaves, number of outer and inner leaves are 174.67, 32.67, 16.67 and 16.00, respectively. These variables have standard deviation of 47.29, 6.61, 4.00 and 2.96. Stem weight and dry weight have mean and standard deviation of 35.00, 15.30, 6.91 and 6.73.

Table 7
Kruskal Wallis test for studied variables

Ranks			Kruskal Wallis chi-square	p-value
Treatments	Group	Mean rank		
Plant height (cm)	10 L/h	5.00	7.322	0.026*
	20 L/h	8.00		
	30 L/h	2.00		
	Total			
Head mass (g)	10 L/h	5.00	7.200	0.027*
	20 L/h	8.00		
	30 L/h	2.00		
	Total			
Total number of leaves	10 L/h	5.00	7.200	0.027*
	20 L/h	8.00		
	30 L/h	2.00		
	Total			
Number of outer leaves	10 L/h	5.00	7.322	0.026*
	20 L/h	8.00		
	30 L/h	2.00		
	Total			
Number of inner leaves	10 L/h	5.67	6.108	0.047*
	20 L/h	7.33		
	30 L/h	2.00		
	Total			
Stem weight (g)	10 L/h	5.00	7.261	0.027*
	20 L/h	8.00		
	30 L/h	2.00		
	Total			
Dry weight (g)	10 L/h	4.00	5.647	0.059
	20 L/h	8.00		
	30 L/h	3.00		
	Total			

*p < 0.05

The Kruskal Wallis chi-square value is 7.322 and p-value is less than 0.05 (p=0.026) for plant height, hence there is significant difference in the mean rank between 10 L/h, 20 L/h and 30 L/h (Table 7). Mean rank is high (8) in 20 L/h compared to 10 L/h (5) and 30 L/h (2).

The Kruskal Wallis chi-square value is 7.200 and p-value is less than 0.05 (p=0.027) for head mass, hence there is significant difference in the mean rank between 10 L/h, 20 L/h and 30 L/h. In which mean rank is high (8) in 20 L/h compared to 10 L/h (5) and 30 L/h (2). The Kruskal Wallis chi-square value is 7.200 and p-value is less than 0.05 for (p=0.027) for total number of leaves, hence there is significant difference in the mean rank between 10 L/h, 20 L/h and 30 L/h. In which mean rank is high (8) in 20 L/h compared to 10 L/h (5) and 30 L/h (2). The Kruskal Wallis chi-square value is 7.322 and p-value is less than 0.05 for (p=0.026) for number of outer leaves, hence there is significant difference in the mean rank between 10 L/h, 20 L/h and 30 L/h. In which mean rank is high (8) in 20 L/h compared to 10 L/h (5) and 30 L/h (2). The Kruskal Wallis chi-square value is 6.108 and p-value is less than 0.05 for (p=0.047) for number of inner leaves, hence there is significant difference in the mean rank between 10 L/h, 20 L/h and 30 L/h. In which mean rank is high (7.33) in 20 L/h compared to 10 L/h (5.67) and 30 L/h (2). The Kruskal Wallis chi-square value is 7.261 and p-value is less than 0.05 for (p=0.027) for stem weight, hence there is significant difference in the mean rank between 10 L/h, 20 L/h and 30 L/h. In which mean rank is high (8) in 20 L/h compared to 10 L/h (4) and 30 L/h (3).

Discussion

Kruskal Wallis chi-square analysis of lettuce hydroponics variables are evaluated through ranking, chi-square and p-value. The first variable plant height provides mean rank of 5.00, 8.00 and 2.00 for flow rate 10 L/h, 20 L/h and 30 L/h, respectively. Kruskal Wallis chi-square value for plant height is obtained as 7.322 with p-value 0.026 which is in acceptable range. Through this it is concluded that flow rate of 20L/1hr provides higher mean value of 8.00. Head mass, number of leaves, number of inner leaves and number outer leaves mean rank is same as that of plant height. Chi-square value for head mass and number of leaves is 7.200 with p-value 0.027 which is also in acceptable range. For variable number of outer leaves chi-square value is 7.322 with p-value 0.026 hence this variable is also in accepted range.

Chi-square value for inner leaves count is 6.108 with p-value 0.047 with average rank of 3 and its mean rank for flow rate 10 L/h is 5.67, for 20 L/h is 7.33 and for 30 L/h is 2.00. Another variable stem weight provides mean rank of 5.00 for flow rate 10 L/h, 8.00 for 20 L/h and 2.00 for 30 L/h and from this it is concluded that for 20 L/h it has higher mean value. Even p-value for this variable is also in acceptable range of 0.027 with chi-square value 7.261. Final variable dry weight has chi-square value of 5.674 with p-value 0.059 which is not accepted in this analysis. In dry weight maximum mean rank is observed for 20 L/h with 8.00. Through the chi-square analysis it is clearly observed that all variables exhibit high mean rank for 20 L/h. Further among all seven variables dry weight alone not comes under acceptable range of chi-square analysis hence that alone rejected and remaining variables are accepted. Kruskal Wallis chi-square value is maximum for plant height and number of outer leaves.

Khater and Ali (2015) reported that the ideal flow rate has positive effect on lettuce production under hydroponics. They also reported that the nutrients' uptake got decreased with increased flow rate and this negatively affected the fresh weight of shoots and roots. The other finding of Khater and Ali (2015) is that increase of flow rate lead to decrease of accumulation of nutrients particularly NO_3- in the root zone of hydroponic system and it is the major element for lettuce.

Conclusions

From the study, it was concluded that all the flow rates were found to be effective in terms of plant growth, but flow rate of 20 L/h was observed as more effective for better growth of lettuce head mass and growth characteristics. Moreover, marketable yield and dry weight were found best in 20 L/h treatments as compared to the other two treatments for lettuce plants and effectively utilized the nutrients and maintained water quality, which is ideal for lettuce production. The analysis of lettuce hydroponics variable reveals that flow rate at 20 L/h provides higher mean rank rather than other flow rates 10 L/h and 30 L/h. The variables considered in this research also exhibits that for flow rate of 20 L/h growth rate of lettuce in hydroponics is higher. Analysis of variables implicates that other than dry weight of lettuce hydroponics remaining variables is provided with acceptable p-value. The findings of this research stated that if flow rate is increased to 30 L/h plant height, number of leaves, number of outer and inner leaves, head mass and stem mass decreases. In flow rate 20 L/h there are comparatively better results than 30 L/h flow rate which means that growth rate is increased but minimal than 20 L/h. On the whole from the analysis it is concluded that flow rate 20 L/h enhances the growth rate of lettuce in hydroponics hence it is stated that flow rate of 20 L/h is good flow rate rather than 10 L/h and 30 L/h.

Water flow and drip irrigation (Altunlu et al., 2017) in NFT and all other systems in HP or soil culture is essential to be ideal through allow the plants root to absorb all elements needed. Thus, water movement in the system and the rate of turnover should be designed to ensure good contact time for roots and water flow in the system. Water flow in NFT should be optimized to be adequately absorbed to sure plant take the compounds/nutrients that are needed to growth because the lettuce has short life period 4-5 weeks only to harvest and the nutrient solution flow NFT is one of the major factors for uptake of elements towards optimal growth and development as well as yield. NFT system can be highly successful if it is balanced and managed the water flow correctly with other factors such as temperature, PH and EC, slop of PVC as well as the concentration of nitrogen, potassium and calcium. NFT is more sensitive to water flow rate that the other hydroponics type such as media bed base and deep-water culture (DWC). In media bed base there is substrate (Al-Tawaha et al., 2016) which has water holding capacity and can save the nutrients to all the roots for absorbing and uptaking the nutrients from drip irrigation. While, DWC is less dependent on water flow due it floating system and is highly dependent on dissolved oxygen. Finally, the selected ideal flow rate of water will increase the water use efficiency (WUE) for small and commercial scale through optimization the contact time between the root and water flow rate. The nutrients balance through uptake and accumulation of essential elements in nutrient solution have a role for increasing the growth of lettuce and this can increase the yield of biomass under NFT and this changes at different water flow rates in hydroponics.

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