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RESEARCH ARTICLE

Optimum flow rate enhances the performance of lettuce (*Lactuca sativa* L.) in hydroponic culture

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Abstract

Poor substate flow rate affects the production of crops under hydroponic systems as contact and collision times of ions (nutrients) with roots is affected deciding nutrients uptake rate and quantity required for crop growth. Keeping in view, a study was conducted under hydroponic culture to obtain optimal flow rate for higher production of lettuce, which is an important leafy vegetable. Two lettuce varieties (Boston and Lollo Bionda) were subjected to 4 different flow rates (0.5, 1.0, 1.5, 2.0 L min^{-1}) under completely randomized design (CRD) with factorial arrangement and replicated four times. The outcomes of the study suggest that performance of Lollo Bionda variety was better than Boston regarding root and shoot fresh and dry biomass, leaf number, area, length and width and head diameter and plant height. The same parameters kept on increasing with increase of flow rate and achieved maximum values at 1.5 L min^{-1}. Beyond that flow rate the values for these parameters declined which indicated that the optimal flow rate for these 2 lettuce verities is 1.5 L min^{-1}. Hence, it was concluded that for higher production of lettuce, the flow rate should be kept at 1.5 L min^{-1} in Nutrient Film Technique (NFT) using hydroponic system with environmental and substrate conditions mentioned in materials and method portion of this article.

Keywords

flow rate; hydroponic; lettuce; nutrient film technique; production

Introduction

Choice of public to reside in big cities is causing a severe pressure on cities regarding food security as availability of fresh fruits, vegetables other perishable commodities is a serious concern for urban areas. To cut this pressure short, urban farming *viz.* rooftop gardening, kitchen gardening, aeroponics, vertical farming, aquaponics, hydroponics and edible landscape are the energy saving, ensuring food availability and eco-friendly techniques for growing fruits and vegetables (1). Among these techniques, hydroponics is widely adopted technique for production of fruit, ornamental, medicinal and vegetable plants. According to a report of TechSci Research, during the year 2022, United Arab Emirates (UAE) market of hydroponics valued at 95.22 million USD and has been identified to flourish at compound annual growth rate (CAGR) of 8.66 % till forecast period of 2028. Hydroponic is system in which plants does not require soil for anchorage instead plants are supported by pebbles, clay or rocks and roots of plants are immersed in nutrient enriched water (2). Plants are grown in controlled environment as temperature, relative humidity, air circulation; characteristics of nutrients enriched water are controlled in a range (3). As the nutrients are added in the water and circulated in the channels by maintaining a specific temperature, pH and flow rate either manually or by mechanical timers. Due to controlled growing conditions, disease, insect/pest and pathogen incidence reduces (4) as well as the use of pesticides is also reduced to minimal level.

As all the growing conditions are controlled in a specific range, the range of these inputs or conditions is found at optimal level for better production of crops. It was reported that the substrate used for hydroponic cultivation circulates, in contrary to that of soil culture and its flow rate affects the crop production and he indicated this feature as key difference between these 2 production systems (5). The rate of flow determines the interaction of root system with nutrients and water for their absorption, accumulation and utilization. Plants uptake more nutrients at optimal flow rate, resulting in better crop growth and ultimately the production. The development of plants roots and shoots depends upon the nutrient uptake required for growth as higher nutrient uptake and utilization efficiency develops better root system as well as shoots biomass. Extensive root system of crops enables them to uptake more nutrients and water and results in better crop production. The crop species also have some genetic feature to develop their root system. Some plant species and even different cultivars of same species have different root system which distinguishes those regarding nutrients uptake, growth rate and production.

Although the production of lettuce is being promoted in recent years, however, the growing conditions have not been standardized yet (6). Major challenge to produce lettuce in hydroponics by limiting environmental issues and efficiently using water resources is the standardization of system for quality production at large quantity (7). It was reported the increase in higher leaf production of lettuce in green house using hydroponic system (8, 9). Production of lettuce under hydroponic system was 41 kg $m^{-2} y^{-1}$ however, under soil-grown conditions the production of the same was 3.9 kg $m^{-2} y^{-1}$ (8).

Production of lettuce is getting popularity across the globe and is getting attention for higher production due to its beneficial effects on human health (10). Due to its bioactive compounds such as carotenoids, phenolics and Vitamins i.e. A, B9 and Vitamin C contents and dietary fibres the nutritional value of lettuce is ascribed (11, 12). Lettuce is being elected as staple component in salad like fresh meals due to its low sodium, fats and caloric value and is being well-liked and getting popularity (13, 14). Although its nourishing quality is not considered well due to higher water contents (15), yet this tender and verdant vegetable is getting consideration in industrialized countries like USA and China (8). Keeping in view the importance of lettuce for more market demand, value, short duration, low demand for light and sensitivity to the outside environment, the contemporary study was planned to find optimal flow rate for lettuce in NFT using hydroponic system. It was hypothesized that optimal flow rate will enhance the production of lettuce by favouring root and shoot growth, higher uptake of nutrients and increasing their use efficiency.

Materials and Methods

The current study was conducted to evaluate the optimal flow rate for better production of lettuce from March 15 to May 13, 2022 in Dubai, at GEAP Farms LLC, Technology Park. The experiment was designed in CRD with factorial arrangement having 2 varieties (Boston and Lollo Bionda) and 4 flow rates (0.5, 1.0, 1.5 & 2.0 L m^{-1}) and replicated four times. The experiment was conducted under Nutrient Film Technique (NFT). The temperature, relative humidity, CO_2 concentration and temperature of circulating fluid was also maintained in specific range as described in Table 1. No pesticide was applied exogenously. Light was provided artificially using LED tubes.

Table 1. Range of fixed inputs provided to the lettuce in this experiment.

Sr. No	Input	Range
1	Air temperature	22-23°C
2	Relative humidity	70-80%
3	CO_2 level	600-800 ppm
4	Water temperature	22-23°C
5	EC of water	1.0-1.8 dSm^{-1}
6	pH of water	5.8-6.8

The nursery was prepared in Rockwool cubes with deionized/demineralized water with reverse osmosis. After 8 days, the nursery was transplanted in racks having using plastic net cups by exposing the roots of plants to the nutrient flow rate to few millimetres. The nutrient rich water flows through PVC pipes of NFT channels. The NFT channels were inclined at slope of 2.5-3.5%. Each rack has 12 shelves and 8 NFT channels having 3.2 m length. A total 16 plants were transplanted with P-P distance of 17.5 cm in each NFT channel, so the number of plants in each rack was 1536. 4 racks were used in experiment by considering each rack as replication and using half shelves of each rack for each variety. Nutrient rich water was allowed to flow through NFT channels for 9 h a day.

After 58 days, 10 plants of lettuce were harvested from each treatment and their height, head diameter, leaf length and width were measured with help of measuring scale. Root and shoot fresh weights were taken with help of digital weighing balance. The number of leaves was counted for each plant and their average leaf area was measured with help of digital leaf area meter. After recording of these parameters, each plant was subject to air dry and then transferred to drying oven to get constant dry weight of roots and shoots which was also weighed on digital weighing balance.

Statistics

The recorded parameters were analysed statistically using Fisher's Analysis of Variance technique and treatment's means were compared using Tukey's honestly significant difference test (16). The regression analysis was performed for each parameter to check the increase/decrease response for each dependent variable with per unit increase of input variable. The correlation analysis was also performed to measure the strength of association of all recorded parameters.

Results

Data in Fig. 1 shows that flow rate of media in hydroponic system significantly affected the collected parameters. Increase in flow rate increased the plant height of lettuce as minimum height was recorded with slowest flow rate and maximum with the fastest flow rate however the more increase in height was recorded in Lollo Bionda variety than Boston. According to data in Fig. 1 head diameter, number of leaves, leaf length, leaf width and leaf area of both lettuce verities increased with flow rate up to 1.5 L min^{-1} but the decreased as flow rate reached to 2 L min^{-1}. Increase in the values of all these parameters except number of leaves was more in Lollo Bionda than Boston, however the number of leaves in both varieties was statistically at par in each treatment. The regression analysis showing the response of both varieties with increasing rate of flow was also done for all these parameters and is presented in Fig. 1.

According to data in Fig. 2, the economic yield of lettuce in form of head fresh weight was obtained

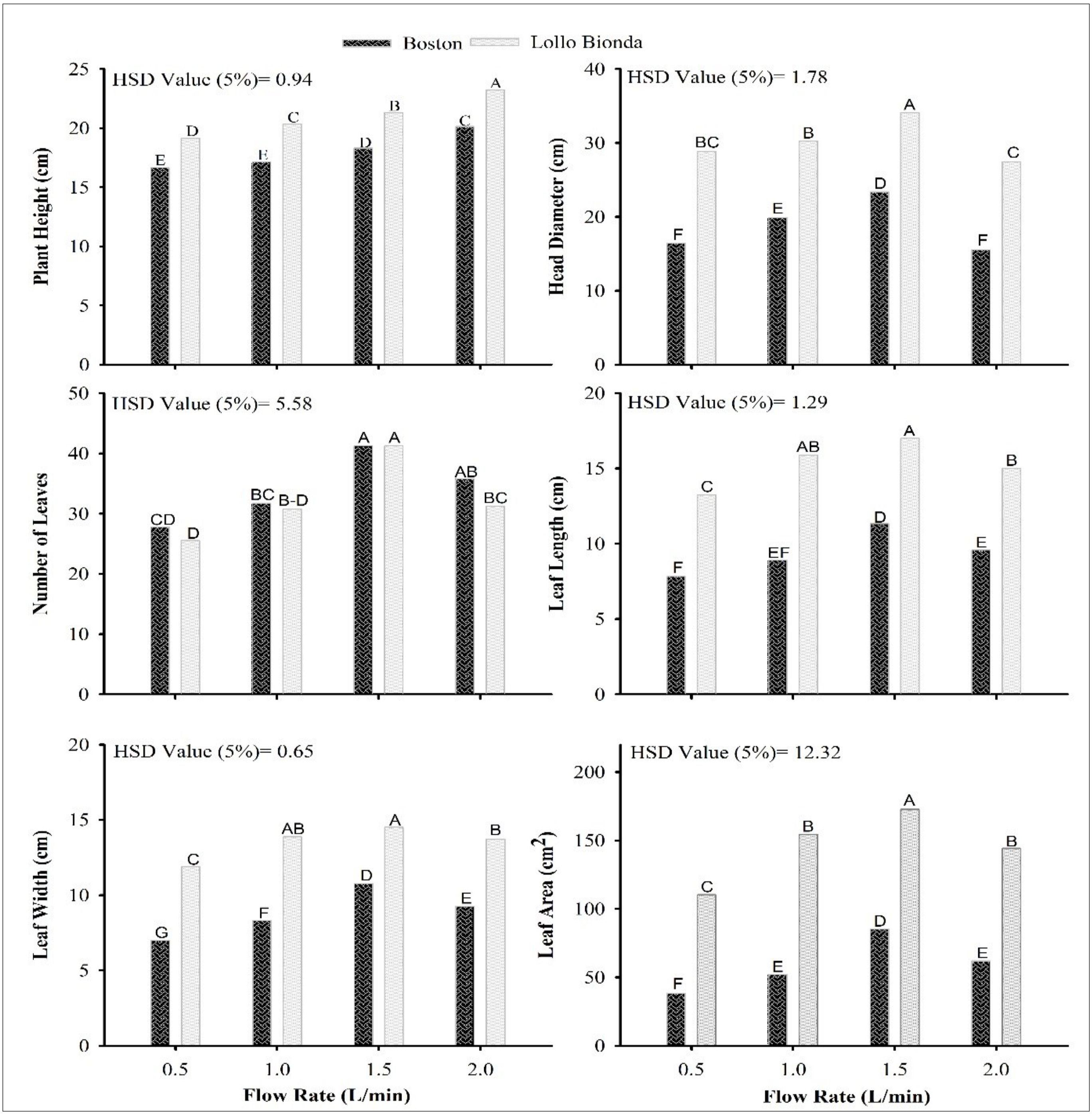

Fig. 1. Response of Plant Height, Head Diameter, Number of Leaves, Leaf Length, Leaf Width and Leaf Area of lettuce at different flow rates.

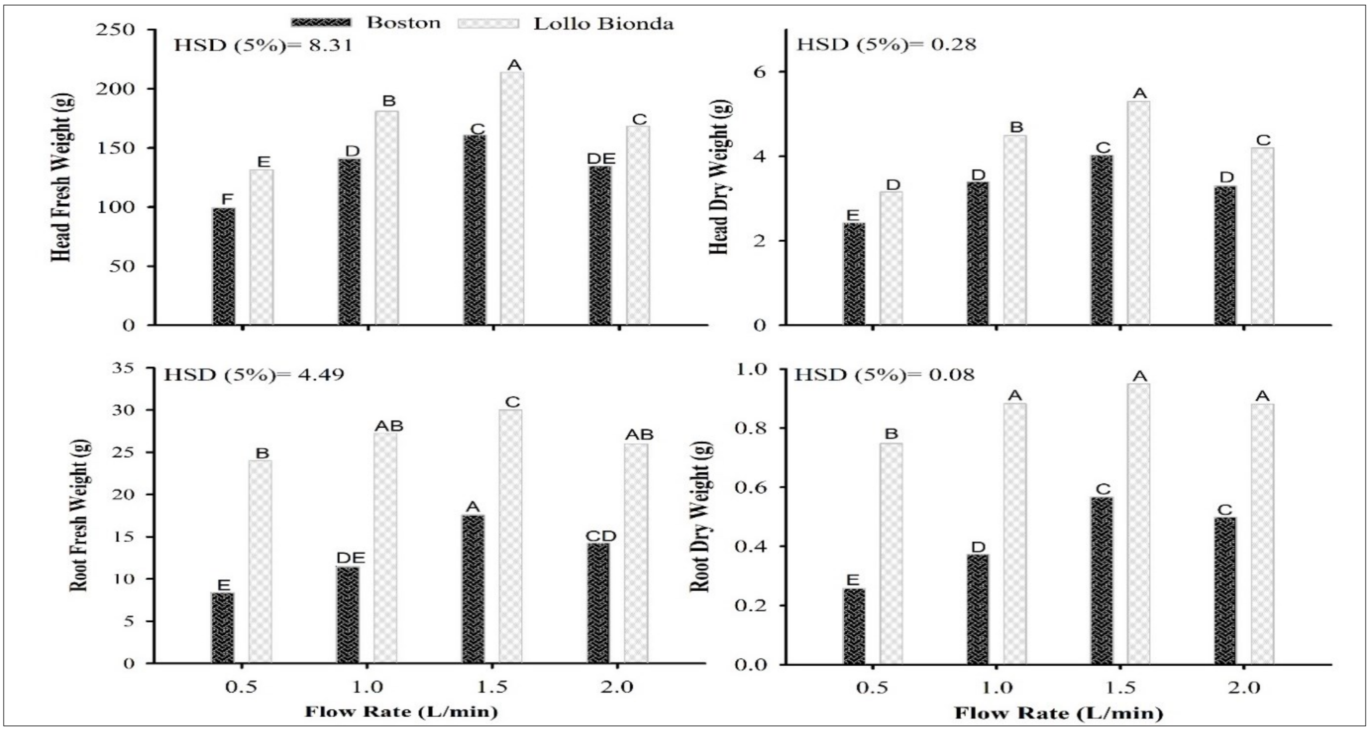

Fig. 2. Response of Head Fresh Weight, Head Dry weight, Root Fresh Weight and Root Dry Weight of lettuce at different flow rates.

maximum in Lollo Bionda than in Boston. Maximum values for head fresh weight were recorded when flow rate was 1.5 L min^{-1} while minimum head fresh weight was obtained at slowest flow rate of 0.5 L min^{-1}. Maximum head dry weight, root fresh weight and root dry weight was also recorded with flow rate of 1.5 L min^{-1}. The increase in flow rate beyond 1.5 L min^{-1} reduced all the recorded parameters. The minimum values for these parameters were also recorded with flow rate of 0.5 L min^{-1}. The regression analysis showing the response of both varieties with increasing rate of flow was also done for these parameters and is presented in Fig. 3 and 4.

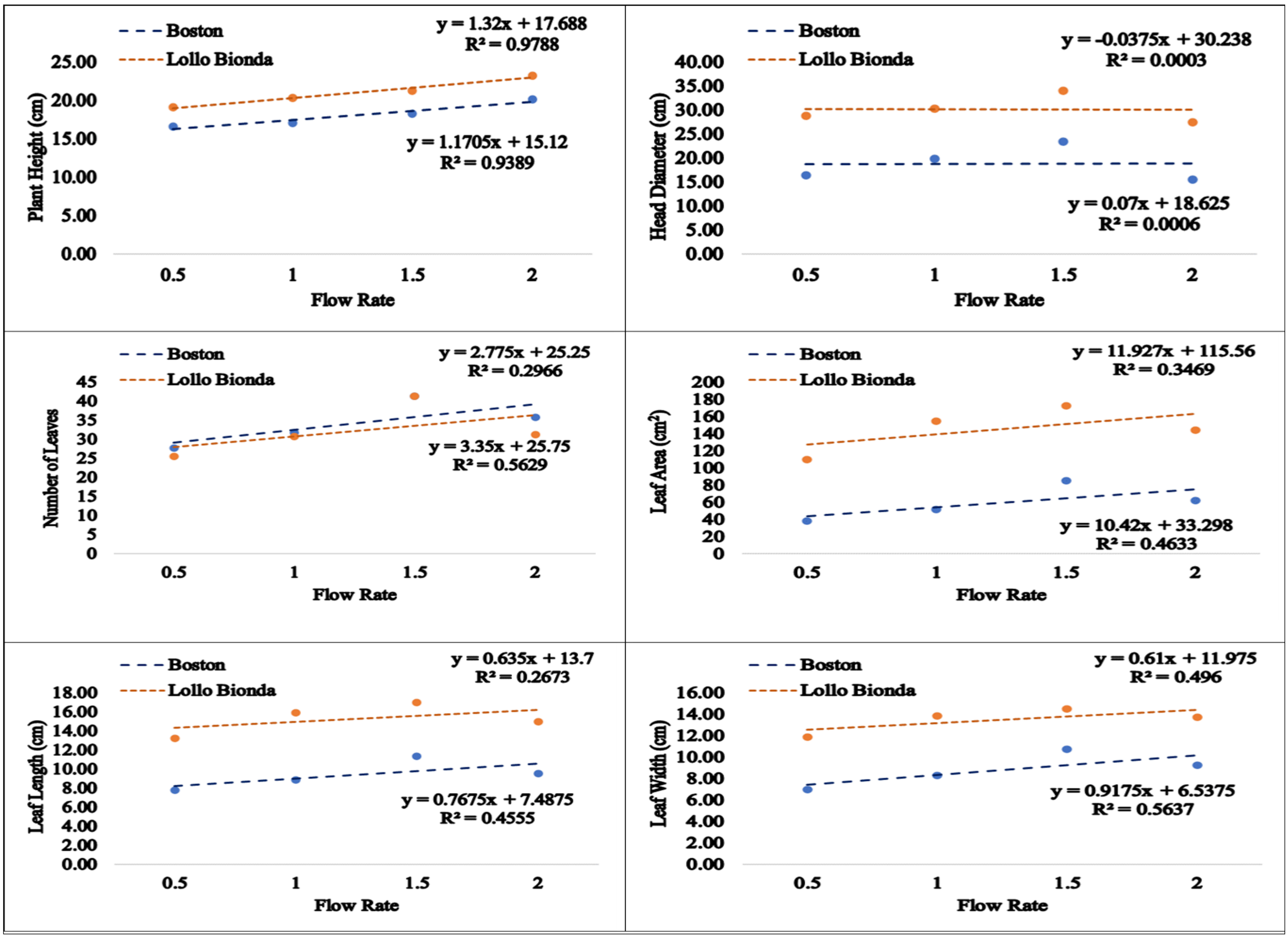

Fig. 3. Regression analysis of Plant Height, Head Diameter, Number of Leaves, Leaf Length, Leaf Width and Leaf Area of lettuce.

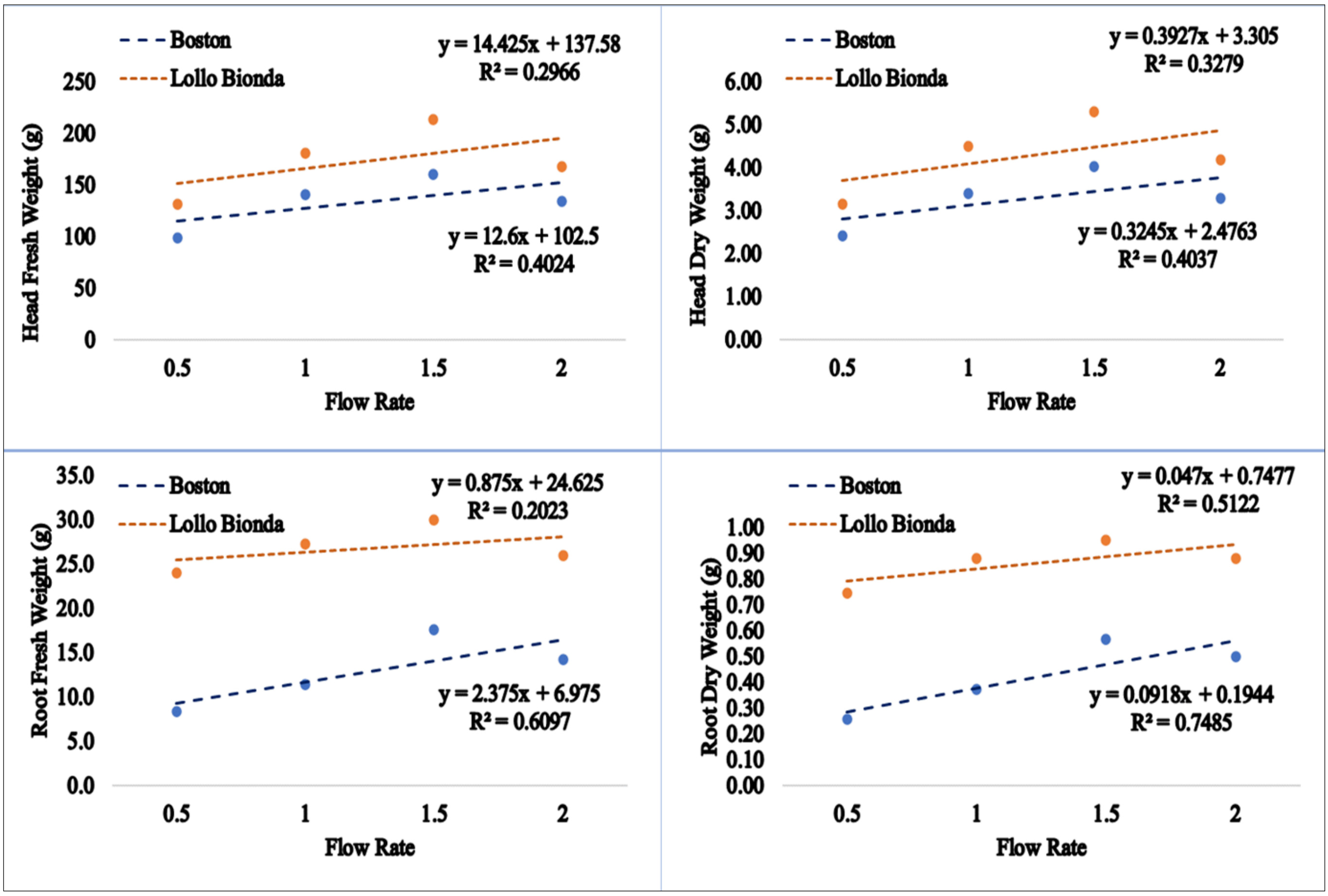

Fig. 4. Regression analysis Head Fresh Weight, Head Dry weight, Root Fresh Weight and Root Dry Weight of lettuce.

Correlation of the recorded parameters (Table 2) shows that a strong correlation exists in all other parameters except number of leaves with all other parameters and correlation of plant height with shoot fresh and dry weight and with head diameter. The strength of association is also indicated (Table 2).

Table 2. Correlation Analysis of different parameters of Lettuce grown in Hydroponic culture.

	HD	LA	LL	LW	NL	PH	RDW	RFW	SDW
LA	0.94**	*							
LL	0.95**	0.99*	*						
LW	0.92**	0.99**	0.99**	*					
NL	0.15 ^{NS}	0.23 ^{NS}	0.22 ^{NS}	0.25 ^{NS}	*				
PH	0.59 ^{NS}	0.80*	0.78*	0.83*	0.22 ^{NS}	*			
RDW	0.92**	0.98**	0.99**	0.99**	0.20 ^{NS}	0.84**	*		
RFW	0.95**	0.99**	0.99**	0.99**	0.19 ^{NS}	0.79*	0.99**	*	
SDW	0.80*	0.87*	0.86**	0.86**	0.63 ^{NS}	0.68 ^{NS}	0.83*	0.82*	*
SFW	0.80*	0.87*	0.86**	0.86**	0.62 ^{NS}	0.66 ^{NS}	0.82*	0.83*	0.99**

HD= head diameter, **LA**= leaf area, **LL**= leaf length, **LW**= leaf width, **NL**= Number of leaves, **PH**= plant height, **RDW**= root dry weight, **RFW**= root fresh weight, **SFW**= shoot fresh weight, **SDW**= shoot dry weight, ***** = Significant at $p \leq 0.05$, ****** = Significant at $p \leq 0.01$, **NS**= non-significant.

Discussion

Higher plant biomass is required when yield of any crop plant is based on fresh or dry biomass (17). As plant growth depends upon photosynthetic capability and leaf area (18) therefore for photosynthetic process the leaf is most important component for energy synthesis. The results of the study show that flow rate affects the performance of lettuce in terms of growth and yield (Fig. 1, 2). Both the varieties showed different response to flow rate. Lollo Bionda performed better than Boston. That might be due to fact that different cultivars of same species have shown different behaviours to the environment. Root characteristics vary for each plant species (19). Moreover, for each plant species the interaction of flow and plant differs depending upon structure-fluid interaction (20). More root and shoot biomass (fresh and dry), leaf length, width, area, head diameter and plant height of Lollo Bionda in our study further verify the fact (Fig. 1, 2). The differing root morphological characteristics of plants lead to difference in nutrient uptake (21), due to which plant shows different growth and biomass production.

Data in Fig. 1 and 2 indicates that increase in flow rate increases the head diameter, fresh and dry biomass, plant height, leaf area, leaf length and width, fresh and dry biomass of roots to a certain flow rate (1.5 L min^{-1}) however, the further increase in flow (2 L min^{-1}) significantly suppressed the values of all these parameters. Optimum flow rate is required for the better performance of crops in hydroponic system as it determines the availability and uptake of nutrients by root system of crop. It was found that root length and area increased with increasing flow rate to an extent but beyond the optimum flow rate the same parameters reduced (5). Slower flow rate will not affect plant growth obviously and in contrast the faster flow rate will affect the growth negatively.

Uptake of nutrients depends upon surface area and length of roots (21, 22) as roots are the main organ for uptake of nutrients in plants. More root surface area and length lead to better nutrient absorption resulting in higher biomass production with increasing flow rate. For better absorption of nutrients ideal flow rate/pattern offers optimal collision rate and interaction time to ions with roots. The elongation of roots occurs due to optimal physical stimulation leading to better growth (5). The difference in root biomass (Fig. 1, 2) might be due to varying kinetic energy due to varying flow rate, as kinetic energy is regarded as physical stimuli and growth promoter (23). The faster flow rate provides excessive physical stimuli to roots resulting in reduced contact time (24) and ultimately reducing nutrient absorption for better crop growth and biomass production. Stress theory of plants also verifies the outcomes of the study (Fig. 1, 2) as it describes that ideal mechanical/physical stimulus causes eustress resulting in enhanced root growth, nutrient absorption and biomass production, however excessive mechanical/physical stimulus causes distress leading plants to lower nutrients absorption, reduced root growth and biomass production (25). It was reported that regulated flow rate control thigmomorphogensis in plants resulting in better growth, nutrient absorption and biomass production (26). It was also reported that increasing flow rate to an optimal level enhances nutrient absorption and their use efficiency resulting in better growth however, the increase in flow rate beyond that optimal level exceeds physical stimulation resulting in limited plant growth (27).

Each plant species needs different flow rate depending upon environmental factors, substrate structure and inputs composition. As the previous studies in Table 3 show the following results.

Table 3. Findings of previous studies about optimal flow rate determination

Year	Plant	Authors	Flow Rates / Optimum Flow rate (L/min)	Recorded Parameters
2021	Swiss chard	5, 26, 27	2, 4, 6, 8 / 6	Fresh and dry root biomass, fresh and dry shoot biomass, root cellulose & hemicellulose contents, root morphology, Flow pattern, nutrient uptake, and their use efficiency
2020	Cauliflower	28	1.5, 2.5 / 1.5	Shoot diameter, plant height, leaf number and area,
2020	Lettuce	29	0.5, 1, 2, 4 / 1	Nutrient uptake, fresh and dry biomass
2018	Lettuce	24	10, 20, 30 / 20 L/ha	Number of leaves, fresh and dry weight, and plant height
2016	Spinach	30	0.8, 2.4, 4 / 0.8	Leaf length, plant height and gain%, yield
2015	Lettuce	31	1, 1.5, 2 / 1	Fresh and dry weight, N uptake, nutrient uptake

The study is only limited to the flow rate only, however the Hydroponic culture needs extensive studies on flow rate in combination with several other environmental factors such as salinity, wavelength and intensity of light, temperature and nutrient concentration as well as composition because the growth of plants depends upon interaction of several environmental factors at a time. This NFT system under hydroponic culture also has the limitations as it has high installation cost. Moreover, the attack of fungus is significant in this system.

Conclusion

Keeping in view the outcomes of contemporary study it is concluded that optimal flow rate (1.5 L min^{-1}) should be kept in hydroponic system to obtain higher yields of lettuce and suitable varieties regarding yield performance should be grown. Among varieties, Lollo Bionda should be preferred over Boston variety and among flow rates, 1.5 L min^{-1} should be adopted in NFT under Hydroponic systems for higher lettuce production which will not only meet the market demand but will also enhance the growth of the industry related to hydroponic culture.

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Authors' contributions

SA, MF, MUR, AKS planned and conducted the research trial and collected Data, SA, MQI, MA, MY analysed the data statistically and wrote results, MKM, NZ & SH wrote introduction, discussion and provided technical guidance. All the authors have read the manuscript and approved for submission.

Compliance with ethical standards

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

Ethical issues: None.

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