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The effects of irrigation timing on growth, yield, and physiological traits of hydroponic lettuce

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ABSTRACT

Crop-specific timing of irrigation is necessary to conserve irrigation water and improve yield of vegetables. Therefore, the experiment was conducted to identify the optimum irrigation timings for hydroponic lettuce plants. Three nutrient solution timings, T_1(once a day at 0900 hours), T_2(once on alternative days at 0900 hours), and T_3(once at two-day intervals), and three varieties, 'Legacy' (V_1), 'Red fire' (V_2), and 'Green wave' (V_3) were evaluated. Growth and yield parameters, including number of leaves, leaf length, leaf diameter, and fresh weight of leaves, and growth parameters, including leaf area (LA), leaf area ratio (LAR), leaf mass ratio (LMR), root weight ratio (RWR), relative growth rate (RGR), and net assimilation rate (NAR) were determined. The values of growth parameters were the highest for T_1. The highest and lowest NAR and RGR values were obtained for T_1 and T_3, respectively. The values of most growth traits, including fresh weight, NAR, and RGR were higher for V_1 than other varieties. T_1 provides high yield with comparatively less irrigation water and nutrient solution so it can be used to culture lettuce using aggregate hydroponics as.

INTRODUCTION

Lettuce (*Lactuca sativa* L.) is an economically important vegetable crop worldwide (Palmer et al. 2005). It is cultivated using intensive farming in open fields as well as in greenhouses (Bartzas et al. 2015). Irrigation is necessary to ensure stable yields and high quality of lettuce grown in greenhouses (Rahman et al. 2012). Crop-specific irrigation timings that save water and do not negatively affect crop productivity need to be developed for sustainable crop cultivation (Quamruzzaman et al. 2017). Deficit irrigation methods, namely regulated deficit irrigation and partial root zone drying have been successfully used to improve irrigation water use efficiency in various crop species (Kirda et al. 2004; Van Hooijdonk et al. 2004) but the timing of nutrient application timing on lettuce grown in soilless culture has not yet been studied. Research has been conducted to determine the influence of irrigation timing on field-grown sweet pepper (Russo 2011). Knowledge of the effects of irrigation timing on vegetable production in soilless culture could help to improve crop yield and quality of the products. The timing of nutrient solution delivery can affect water availability to plants, and directly affect yield, quality, and production costs. Thus, an understanding of the timing of nutrient solution is important to achieve sustainable agriculture. Sustainable agricultural development depends on sound irrigation and water management, the main aim of which is to satisfy the crop's water requirement, and to maintain good soil aeration (McNiesh and Welch 1985). Therefore, in application timing of nutrient solution could result in serious yield reduction. Furthermore, over-irrigation and prolonged soil saturation can cause root rot or disease in plant roots. However, differences in irrigation timing and volume could have an effect on the growth and yield of lettuce plants. Therefore, this experiment was conducted to determine the optimal timing and volume for nutrient solution application to lettuce plants.

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MATERIALS AND METHODS

Experimental site and plant materials

A semi-greenhouse experiment was conducted in the Horticulture Farm at the Sher-e-Bangla Agricultural University, Dhaka from September 2016 to March 2017. Three lettuce cultivars, *viz.*, 'Legacy', 'Red fire', and 'Green wave' were used in this experiment.

Experimental design and treatments

A randomized complete block design with 3 × 3 factorial treatments and three replications were used in this study. The two factors of this experiment were three nutrient solution application timings, *viz.*, T_1 (once a day at 0900 hours), T_2 (once on alternative days at 0900 hours), and T_3 (once at two days interval at 0900 hours), and three varieties, *viz.*, 'Legacy' (V_1), 'Red fire' (V_2), and 'Green wave' (V_3).

Growth Environment

Twenty-seven plastic crates of 25L pots were used for culturing the plants. Each pot was filled with a mixture of coco peat, broken bricks, and vermiculite in a ratio of 60:30:10 (v/v), respectively. Coco peat was soaked in a big bowl for 24 h. It was washed with water and spread in a polythene sheet for 3 h and mixed with broken bricks and vermiculite. The experiment was conducted in a semi-greenhouse (not controlled environment, i.e. temperature, humidity etc) under intensive care. Half strength of Rahman and Inden (Rahman and Inden, 2012) solution was used in this experiment. The concentrations of the nutrients, *viz.*, NO_3-N, P, K, Ca, Mg, and S were 17.05, 7.86, 8.94, 9.95, 6.0, and 6.0 meq•L^{-1}, respectively. The concentrations of the micronutrients, *viz.*, Fe, B, Zn, Cu, Mo, and Mn were 3.0, 0.5, 0.1, 0.03, 0.025, and 1.0 mg•L^{-1}, respectively. The timing of the nutrient solution's application depended on the treatment and the same volume of nutrient solution was applied. An ultra-drip irrigation tube and electric timers were used for maintaining the volume and time of nutrient application. The pH and electrical conductivity (EC) were maintained at approximately 6.0 and 2.5 dS/cm, respectively in the nutrient solutions. Two-week-old lettuce seedlings were transplanted in the pots. Three plants were considered as an experimental unit in each crate.

Harvesting

The crop was harvested at 42 days after transplanting (DAT). Crop was harvested from each crate by carefully uprooting the plants with hands. The growth media and fibrous roots adhering to the roots were removed and cleaned.

Data collection

Growth and yield parameters, *viz.,* number of leaves, leaf length, leaf diameter, and fresh weight of leaves of lettuce were measured from 0 to 42 DAT at 7-day intervals. The physiological growth parameters *viz.,* leaf area (LA), leaf area ratio (LAR), leaf mass ratio (LMR), root weight ratio (RWR), relative growth rate (RGR), and net assimilation rate (NAR) were also determined. The parameters were measured according to Rahman and Inden (2012b), as described below.

$$\mathrm{LAR} = \frac{\mathrm{LA}}{\mathrm{PDW}} \quad (1),$$

Where LAR = leaf area ratio, LA = Leaf area (cm^2), PDW = plant dry weight (g).

$$\mathrm{LMR} = \frac{\mathrm{LDW}}{\mathrm{PDW}} \quad (2),$$

Where LMR = leaf mass ratio, LDW = leaf dry weight (g).

$$\mathrm{RWR} = \frac{\mathrm{RDW}}{\mathrm{PDW}} \quad (3),$$

Where RWR = root weight ratio, RDW = root dry weight (g).

$$\mathrm{RGR} = \frac{\mathrm{PDW_1} - \mathrm{PDW_0}}{(\mathrm{t_1} - \mathrm{t_0}) \times \mathrm{PDW_0}} \quad (4),$$

Where t = time, subscripts 0 and 1 refer to the transplanting and final harvest (days), respectively.

$$\mathrm{NAR} = \frac{\mathrm{RGR}}{\mathrm{LAR}} \quad (5)$$

Statistical analysis of data

Data from the two trials were combined and analyzed by one-way analysis of variance (ANOVA) using SPSS version 19.0, and differences among the means were determined by Tukey's test at $P \leq 0.05$.

RESULTS AND DISCUSSIONS

Vegetative growth of lettuce

Significant differences were observed in the plants' heights as a result of irrigation at 7, 14, 21, 28, 35, and 42 DAT (Table 1). Results showed that T_1 treatment produced the tallest plants and the heights were statistically similar to those obtained for T_2 at 7, 14, 21, 28, 35, and 42 DAT, while T_3 produced the shortest plants at all time of irrigation. This might be because of treatment T_1 resulting in the maximum vegetative growth, because irrigation helped in higher vegetative growth (Rahman et al. 2012). Niu et al. (2006) reported that photosynthesis, transpiration (E), and stomatal conductance (gs) of some bedding plants were reduced when the moisture content in the growth substrate was decreased. Furthermore, Bozkurt et al. (2009) found that the irrigation level influenced the height of the lettuce plant. The lettuce plant's height was also significantly affected by water

Table 1. Effects of irrigation timing and variety on plant height of lettuce

Treatment	Pant height at different days after transplanting (DAT) (cm)					
	7 DAT	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT
Timing (T)						
T_1	6.63a[z]	10.33 a	13.83 a	16.75 a	18.63 a	22.04 a
T_2	6.13ab	9.03 b	13.88 a	15.79 ab	17.71 b	19.92 a
T_3	5.79b	9.24 b	12.42 b	14.50 b	16.13 c	18.79 b
Variety (V)						
V_1	6.39a[z]	10.71 a	16.00 a	19.33 a	22.28 a	22.78 a
V_2	5.89	7.58 c	8.67 c	9.00 c	10.39 c	13.11 c
V_3	6.17	8.88 b	12.11 b	14.39 b	16.72 b	20.72 b
Level of significance (*P*)						
T	0.008	<0.001	0.002	0.003	<0.001	<0.001
V	0.342	<0.001	<0.001	<0.001	<0.001	<0.001
T × V	0.999	0.033	0.001	<0.001	<0.001	<0.001

[z]Means with different letter is significantly different by Tukey's test at $P \leq 0.05$. *P* represents the level of significance of two-way ANOVA. T_2 = once a day at 0900 HR; T_2 = Once at alternative days at 0900 HR and; and T_3 = Once at two days interval at 0900 HR. V_1 = 'Legacy', V_2 = 'Red fire', andV_3= 'Green wave'.

deficiency (Acar et al. 2008). The results are consistent with these findings.

The vegetative growth observed for T_2 was statistically similar to that observed for treatment T_1 with less water and nutrient supply. This could reduce the volume of irrigation water as well as nutrient solution, thereby reducing the cost of lettuce production.

There were differences among the heights of the lettuce plants of different varieties (Table 1). The heights of lettuce plants tended to increase with increasing the days of planting. V_1 plants were the highest, while V_2 plants were the smallest at 7, 14, 21, 28, 35, and 42 DAT. This might be because of genetic composition of V_1.

In the case of interaction effect of time and variety (TV), significant differences of plant height were observed at all dates except at 7 DAT (Table 1).

Irrigation timing had a significant effect on the leaf length (Table 2). Treatment of T_1 resulted in the longest leaves at all sampling dates, except at 21 DAT and 28 DAT. At 21 DAT and 28 DAT, leaves from T_2 were the longest. Furthermore, T_3 resulted in the shortest lettuce leaves at all time-points. These results indicate that a considerable reduction in water and nutrient supply has an adverse effect on leaf length in T_3. Rahman et al. (2012) observed that three times of nutrient supply resultant the higher photosynthetic rates in sweet pepper ultimately affected yield. Our results are consistent with their findings.

Leaf lengths of V_1 were significantly higher

Table 2. Effects of irrigation timing and variety on leaf length of lettuce

Treatment	Leaf length at different days after transplanting (DAT) (cm)					
	7 DAT	14DAT	21DAT	28DAT	35DAT	42DAT
Timing (T)						
T_1	6.62a[z]	10.33a	13.83a	15.79ab	19.92a	19.42a
T_2	6.12ab	9.24b	13.88a	16.75a	17.63b	18.71ab
T_3	5.79b	8.02c	10.42c	12.50c	14.01c	16.08c
Variety (V)						
V_1	6.39a[z]	11.00a	16.72a	20.00a	22.94a	20.72a
V_2	6.28	7.58c	8.67c	9.00c	10.39c	10.94c
V_3	6.17	8.86b	12.11b	14.39b	16.72b	18.56b
Level of significance(p)						
T	0.008	<0.001	0.002	0.003	<0.001	<0.001
V	0.342	<0.001	<0.001	<0.001	<0.001	<0.001
T x V	0.999	0.001	0.001	<0.001	<0.001	0.001

[z]Means with different letter is significantly different by Tukey's test at $P \leq 0.05$. *P* represents the level of significance of two-way ANOVA. T_2 = once a day at 0900 HR; T_2 = Once at alternative days at 0900 HR and; and T_3 = Once at two days interval at 0900 HR. V_1 = 'Legacy', V_2 = 'Red fire', andV_3= 'Green wave'.

Table 3. Effects of irrigation timing and variety on leaf breadth of lettuce

Treatment	Leaf breath at different days after transplanting (DAT) (cm)					
	7DAT	14DAT	21DAT	28DAT	35DAT	42DAT
Irrigation Timing (T)						
T_1	3.13a[z]	5.09 a	7.79 a	9.83 a	11.08a	12.25a
T_2	3.02	5.67 a	7.48 a	9.42 a	10.21a	11.70a
T_3	3.02	4.93 b	6.32 b	7.58 b	9.41b	10.50b
Variety (V)						
V_1	3.24a[z]	4.18b	8.76a	11.33a	12.67a	14.78a
V_2	3.13	4.39b	4.46 c	4.50c	4.94 c	6.94c
V_3	2.90	5.93a	7.89b	9.94b	10.36 b	11.39b
Level of significance (p)						
V	0.700	<0.001	<0.001	<0.001	<0.001	<0.001
T	0.895	<0.001	<0.001	<0.001	0.101	0.195
T x V	0.704	<0.001	<0.001	<0.001	0.001	0.601

[z]Means with different letter is significantly different by Tukey's test at $P \leq 0.05$. *P* represents the level of significance of two-way ANOVA. T_2 = once a day at 0900 HR; T_2 = Once at alternative days at 0900 HR and; and T_3 = Once at two days interval at 0900 HR. V_1 = 'Legacy', V_2 = 'Red fire', andV_3= 'Green wave'.

than other varieties except at 7 DAT (Table 2). Moreover, V_2 produced the shortest leaves at all time of irrigation except 7 DAT. This result could be attributed to the genetic variations among the varieties.

In the case of combined effect of TV, significant variation of leaf length was observed at all times except 7 DAT (Table 2).

Treatment T_1 resulted in the broadest leaves at all sampling times except at 14 DAT (Table 3), the results were statistically similar to those obtained from T_2. Appropriate irrigation and nutrient supply from treatment T_1 could have resulted in broader lettuce leaves.

A significantly broadest leaf breath was recorded from different varieties at all time-points except at 7 DAT (Table 3). V_3 produced the broadest leaf at 14 DAT, while for the rest of the time of irrigation V_1 produced the broadest leaf. This might be because of the genetic variations among the varieties.

In the case of interaction effect of TV, significant variation of leaf breadth was observed at all times except at 7 DAT and 42 DAT (Table 3).

Statistically significant differences were observed in the total number of leaves per plant after different irrigation timings (Table 4). T_1 produced the highest number of leaves at all sampling times; the results were statistically similar to those obtained for treatment T_2. This might be because of the optimal supply of irrigation water containing the required nutrient solution. T_3 produced the minimum number of leaves as a result of a reduction in irrigation timing as well as nutrient solution (Table 4). Acar et al. (2009) and Bozkurt and Mansuroglu (2011) found that the volume of water significantly affected the number of lettuce leaves. Our results are consistent with their findings.

There were significant differences in the number of leaves of different varieties at all time of irrigation except at 7 DAT (Table 4). The highest leaf number was recorded for V_1 at all time of irrigation except at 14DAT; V_3 produced the highest leaf number at 14 DAT. This might be

Table 4. Effects of irrigation timing and variety on number of leaf of lettuce

Treatment	Number of leaf at different days after transplanting (DAT) (cm)					
	7DAT	14DAT	21DAT	28DAT	35DAT	42DAT
Irrigation Timing (T)						
T_1	5.50a[z]	6.75a[z]	8.92a	11.58a	12.83a	16.66a
T_2	5.17	6.17b	8.75a	10.92a	12.08a	16.33a
T_3	5.25	6.00b	6.92b	8.75b	10.17b	14.75b
Variety (V)						
V_1	5.56a[z]	6.11b[z]	9.22a	12.89a	14.11a	18.44 a
V_2	5.00	6.33ab	7.33ab	8.56b	10.11b	13.11 b
V_3	5.33	6.89a	8.78b	9.00b	10.33b	15.67 b
Level of significance (p)						
T	0.256	0.002	<0.001	<0.001	0.005	<0.001
V	0.158	0.001	<0.001	<0.001	<0.001	<0.001
T x V	0.448	0.336	0.001	<0.001	0.001	<0.001

[z]Means with different letter is significantly different by Tukey's test at $P \leq 0.05$. *P* represents the level of significance of two-way ANOVA. T_2 = once a day at 0900 HR; T_2 = Once at alternative days at 0900 HR and; and T_3 = Once at two days interval at 0900 HR. V_1 = 'Legacy', V_2 = 'Red fire', andV_3= 'Green wave'.

Table 5. Effects of irrigation timing and variety on fresh weight of lettuce

Treatment	Fresh weight (FW) per pant of lettuce (g) at transplanting time	Fresh weight (FW) per pant of lettuce at harvesting time			
		Total FW	FW of leaf	FW of stem	FW of root
Irrigation Timing (T)					
T_1	0.9312 a^z	64.08 a	52.42 a	6.54 a	5.12 a
T_2	0.7124 b	57.40 b	46.54 b	5.97 b	4.89 b
T_3	0.8502 a	45.57 c	35.99 c	5.41 b	4.48 b
Varieties (V)					
V_1	1.5422 a^z	69.88 a	56.27 a	8.33 a	5.28 a
V_2	0.4060 b	45.69 c	36.89 c	5.58 b	3.22 b
V_3	0.3433 c	56.56 b	45.33 b	7.09 c	4.14 b
Level of significance (p)					
T	<0.001	<0.001	0.008	<0.001	<0.001
V	<0.001	<0.001	<0.001	<0.001	<0.001
T x V	<0.001	<0.001	0.0043	0.001	<0.001

^{z}Means with different letter is significantly different by Tukey's test at $P \leq 0.05$. *P* represents the level of significance of two-way ANOVA. T_2 = once a day at 0900 HR; T_2 = Once at alternative days at 0900 HR and; and T_3 = Once at two days interval at 0900 HR. V_1 = 'Legacy', V_2 = 'Red fire', andV_3= 'Green wave'.

because of the genetic variations among the varieties.

In the case of combined effect of TV, significant variation of number of leaf was observed at all time of irrigation except at 7 DAT and 14DAT (Table 4).

Fresh weight

Fresh weight was recorded at the end of the experiment at 42 DAT. The fresh weight of lettuce is considered to constitute its marketable yield. The total fresh weight and fresh weights of leaf, stem, and root per plant obtained for the different irrigation timings were significantly different (Table 5). The fresh weights of seedlings from T_1 were statistically similar to those of seedlings from T_3, but were higher than fresh weights of seedlings from T_2. The values of total fresh weigh and fresh weights of leaf, stem, and root per plant were the highest for T_1, and were statistically similar to those obtained for T_2; the lowest values were obtained for T_3. The reason for this could be that the vegetative growth of the plants was higher in T_1 than the other treatments. This finding also showed that the plant's fresh weight decreased when there was a reduction in the rate of irrigation and nutrient solution. Mansuroglu et al. (2010) reported that a full irrigation treatment resulted in the highest yields, while the lowest volume of water applied to lettuce plants resulted in minimal yields.

The highest and the lowest values of fresh weight were obtained for V_1 and V_2, respectively

Table 6. Main effects of irrigation timing and variety on dry weight of lettuce

Treatment	Dry weight (DW) per pant of lettuce (g) at transplanting time	Dry weight (DW) per pant of lettuce at harvesting time			
		Total DW	DW of leaf	DW of stem	DW of root
Irrigation Timing (T)					
T_1	0.04656a^z	3.204 a	2.621 a	0.327 a	0.256 a
T_2	0.02849 b	2.296 b	1.861 b	0.238 b	0.195 b
T_3	0.03400 a	1.822 c	1.439 c	0.216 c	0.179 c
Variety (V)					
V_1	0.07711 a^z	3.494 a	2.8135 a	0.416 a	0.264 a
V_2	0.01624 b	1.827 c	1.4756 c	0.223 c	0.128 c
V_3	0.01373 c	2.262 b	1.8132 b	0.283 b	0.165 b
Level of significance (p)					
T	<0.001	<0.001	<0.001	<0.001	0.001
V	<0.001	<0.001	<0.001	<0.001	<0.001
T× V	<0.001	<0.001	<0.001	0.001	<0.001

^{z}Means with different letter is significantly different by Tukey's test at $P \leq 0.05$. *P* represents the level of significance of two-way ANOVA. T_2 = once a day at 0900 HR; T_2 = Once at alternative days at 0900 HR and; and T_3 = Once at two days interval at 0900 HR. V_1 = 'Legacy', V_2 = 'Red fire', andV_3= 'Green wave'.

Table 7. Maine effects of irrigation timing and variety on physiological traits of lettuce

Treatment	LA (cm^2)	LMR ($g\ g^{-1}$)	LAR ($cm^2\ g^{-1}$)	RWR ($g\ g^{-1}$)	NAR ($g\ cm^{-2}\ d^{-1}$)	RGR ($g\ g^{-1}\ d^{-1}$)
Irrigation Timing (T)						
T_1	345.01a[z]	0.82a	107.681 a	0.07990012 c	0.0000085 a	0.00091 a
T_2	329.45 b	0.81a	121.711 a	0.08493031 b	0.0000065 a	0.00065 b
T_3	145.91	0.78b	80.0823b	0.09824369 a	0.0000054 b	0.00052 c
Variety (V)						
V_1	305.01a[z]	0.90 a	87.29536 c	0.075558 a	0.00001140 a	0.00099 a
V_2	249.55c	0.81 b	136.59 a	0.070060 b	0.00000380 c	0.00052 c
V_3	281.61 b	0.80 b	124.496 b	0.072944 c	0.00000516 b	0.00064 b
Level of significance (p)						
T	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
V	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
T× V	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

[z]Means with different letter is significantly different by Tukey's test at $P \leq 0.05$. P represents the level of significance of two-way ANOVA. T_2 = once a day at 0900 HR; T_2 = Once at alternative days at 0900 HR and; and T_3 = Once at two days interval at 0900 HR. V_1 = 'Legacy', V_2 = 'Red fire', and V_3= 'Green wave'.LA = leaf area, LAR = leaf area ratio, LMR = leaf mass ratio, RWR = root weight ratio, RGR = relative growth rate, and NAR = net assimilation rate

(Table 5); these differences could have resulted from the genetic variations among the varieties.

In the case of combined effect of TV, significant variation of fresh weight was observed at all time of irrigation (Table 5).

Dry weight

Irrigation timing had a significant impact on the dry weight of lettuce. The maximum dry weight was recorded for T_1 (Table 6). The highest values of total dry weight, and dry weights of leaf, stem and root per plant were obtained for T_1, which were statistically similar to those obtained for T_2, while the lowest were obtained for T_3. An optimal supply of irrigation water and nutrient in T_1 resulted in the maximum vegetative growth.

V_1 had the highest dry weight (Table 6); this might be because of the genetic variations among the varieties.

In the case of combined effect of TV, significant variation of dry weight was observed at all time of irrigation (Table 6).

Physiological growth traits

The growth parameters of lettuce were significantly influenced by irrigation timing and volume (Table 7). The results showed that the values of LA, LMR, NAR, and RGR were the highest for T_1, while the values of the traits were the lowest for T_3, except for RWR. The highest values of LAR and RWR were obtained for T_2 and T_3, respectively. Higher LA accelerates the production of metabolites. Prieto et al. (2007) stated that higher LA resulted in an increase in the plant's ability to intercept light. The values of LA and LMR were higher in the T_1, which decreased upon the reduction in irrigation timing and volume in treatments of T_2 and T_3. Results indicated that along with the decrease in irrigation timing and volume, the production of metabolites also decreased. In contrast, RWR increased in the reduction in irrigation water and nutrient supply.

The growth parameters of the different varieties differed significantly (Table 7). The values of LA, RWR, NAR, and RGR were the highest in V_1 compared to other varieties. Moreover, V_1 had the lowest LMR and LAR, while V_2 had the highest LMR and LAR; this might be because of the genetic variations among the varieties.

In the case of combined effect of TV, significant variation of physiological growth traits was observed at all time-points (Table 7).

CONCLUSION

In conclusion, the values obtained for all the growth parameters, including fresh weight, NAR, and RGR of lettuce for treatment of T_1 were higher than those obtained for the other treatments; results from T_1 were statistically similar to those obtained for treatment T_2. Moreover, result obtained for most growth traits, including fresh weight, NAR, and RGR were higher in V_1 than other varieties. Since T_1 provides high yield with comparatively less irrigation water and nutrient solution so it can be used to culture lettuce using aggregate hydroponics as.

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