Effect of plant densities and supporting materials of the vertical hydroponic system on the growth and yields of lettuce

Nguyen Van Quy[1], Wantana Sinsiri[1*], Suphatrat Chitchamnong[1], Kriangsuk Boontiang[1] and Waranyoo Kaewduangta[1]

ABSTRACT: An appropriate vertical production system needs to be developed and it is essential to find out the best method to place the vertical hydroponic system as well as the plant density within the system to create and optimum product. The objectives of the research were to develop cultivation and management techniques for lettuce (*Lactuca sativa* L.) grown on a vertical hydroponics system. The effects and interactions of plant densities and supporting materials used on a vertical hydroponic system on the growth and yield of lettuce were investigated. Three supporting materials (mat, shoddy felt, and burlap) and 4 plant densities (10×12, 12×14, 14×16, 16×16 cm) were investigated. The different supporting materials evaluated in the vertical hydroponics system had no significant effects on lettuce growth and yield. However, when comparing the weight and cost of the system, evaporation of water/m^2, usefulness after one season, and especially durability, the mat was the best material to use for a vertical hydroponics system. Plant density was a crucial factor affecting the growth and yield of lettuce cultivars when they were grown on the vertical hydroponics system. Lettuce with plant densities of 14×16 and 16×16 cm gave the highest parameters of lettuce growth, while lettuce with plant densities at 10×12 and 12×14 cm had the highest yield because of the high number of plants/m^2. From the above results, the plant densities of 10×12 or 12×14 cm were the most suitable for growing lettuce on the vertical hydroponics system to achieve high yield. The result of this study will represent a vertical hydroponic system with simplification and low cost to people. I will increase growth and yield of lettuce.
Keywords: Vertical garden, *Lactuca sativa* L., plant population, hydroculture, cultivation

Introduction

Along with dealing with factors arising from global climate change, one of the urgent requirements facing agriculture today is to find ways of increasing both total production and crop yield per unit area in order to meet the demand for food in the future. The vertical hydroponics system is one of the ways that can be used to meet such objectives (Ozeker et al., 1999; Linsley-Noakes et al., 2006). Planting density per unit area can be increased three times by using a vertical system (Morgan, 2006)

Lettuce (*Lactuca sativa* L.) is an important commercial vegetable crop grown all over the world in different kinds of environments (Ryder, 2006) and is one vegetable crop which is currently cultivated in hydroponic systems (Stanghellini and Rasmussen, 1994; Niederweiser, 2001). Lettuce production methods have included many types of vertical hydroponic systems. However, most of these systems have been made from plastic, they have complex composes, high costs and high electricity consumption. The use of fabric or rug-like materials to make the vertical hydroponics systems are an attractive option as such systems would have lower weight and costs.

There have been many studies that have shown that vertical hydroponics systems can produce higher yields than where the same

[1] Department of Agricultural Technology, Faculty of Technology, Mahasarakham University, Thailand, 44150
* Corresponding author: wantana.sinsiri@gmail.com

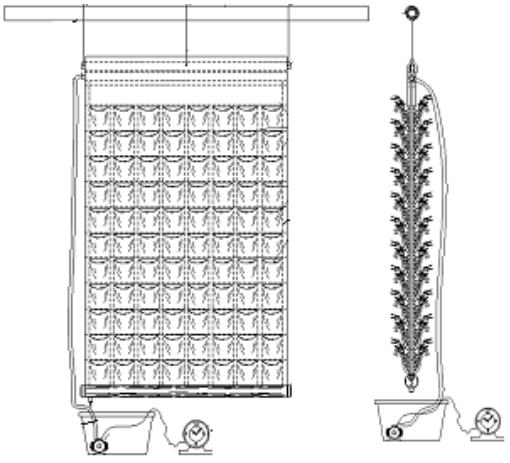
crops are cultivated on a horizontal plane (Paraskevopoulou-Paroussi and Paroussis, 1995; El-Behairy et al., 2001). However, these reports also showed that the weight of each plant on a vertical hydroponics system was lower than that compared with conventional cultivated forms (Dijkstra et al., 1993). The cause of this decrease is due to the shading between plants that was caused by plant density on vertical hydroponics systems with many of the plants (Durner, 1999). Therefore, research to find the most suitable density for growing lettuce on a vertical hydroponics system, to facilitate uniform distribution of light, would have a significant impact in improving the yield and quality of lettuce. Such gains would enable the vertical hydroponics system to be used more widely and assist farmers to choose the most effective methods for cultivating lettuce. The aim of this study was to evaluate the effect of planting densities and supporting materials of a vertical hydroponic system on the growth and yields of lettuce.

Materials and methods

This study was carried out in March to May, 2012 in a greenhouse at the Faculty of Agronomy, Hue University, Viet Nam.

The lettuce cultivar used was 'Rapid Red'. Seeds were germinated in polypropylene tray of 120 cells filled with coconut fiber. Two weeks after germination, the seedlings were transplanted onto the vertical hydroponics system. A hydroponic nutrient solution from Ministry of Agriculture and Fishery was used for fertilization (Tregidga et al., 1986). The EC of the solution being maintained at 1.5 to 2.0 mS/cm and the pH was maintained at 6.0 to 6.5.

A total of 12 vertical hydroponics systems were established for the experiment. These included 4 systems made from burlap that have been made from jute, 4 made of mat fabric, 4 made of shoddy felt that have been crafts produced in Vietnam with a thickness of 2 cm. These vertical hydroponics systems were divided into 4 parts each having different planting bag sizes which were: 10×12 cm, 12×14 cm, 14×16 cm, 16×16 cm. The total system was suspended 0.2 m above the ground in a north-south direction to absorb optimal sunlight. The spacing between each of the vertical hydroponic systems was 1 m. A tank of water and nutrients with a capacity of 500 L and a 150 W pump was installed to provide water and nutrients to the plants. The time of irrigation was set at 6.00 am, 12.00 am, and 6.00 pm and the period of each irrigation was 15 min.



Vertical hydroponic system design

The experiment was laid out in 3×4 split plot design with 4 replications. Analysis was done with supporting materials of the vertical hydroponic system as the main plot factor including A1: vertical hydroponic system made of burlap, A2: vertical hydroponic system made of shoddy felt,

A3: vertical hydroponic system made of mat. The planting density was treated as a subplot including B1: spacing: 10×12 cm (400 plants/m^2), B2: spacing: 12×14 cm (288 plants/m^2), B3: spacing: 14×16 cm (224 plants/m^2), B4: spacing: 16×16 cm (192 plants/m^2).

45 days after planting, each experimental unit had 10 randomly assigned plants from which to collect data. The data recorded were plant height (cm), number of leaves/plant, plant canopy diameter (cm), total fresh weight (g), chlorophyll concentration in the leaves, leaf area (LA), Leaf area index (LAI), yield/ area unit, ascorbic acid (vitamin C) concentration and nitrate concentration.

Plant canopy diameter was collected by ruler to measure the position having largest diameter. Leaf area and leaf area index were determined by Portable area meter model: LI-3000C. Chlorophyll concentration was analyzed as described by Arnon (1949). Ascorbic acid (vitamin C) concentration was analyzed as procedure of ISO 6557/2 (Anonymous, 1984). Nitrate concentration was determined by selective electrode method (Bedwell et al., 1995). Data was analyzed using STATISTIC version 8.0 (Statistic, 2007). Least Significant Difference (LSD) was calculated at 5% level to compare the treatment means.

Result and discussion

Plant height: Different supporting materials and plant densities had no significant effects on plant height (**Table 1**). These results indicate, therefore, that the supporting materials had no significant role in determining stem length of lettuce and, in practical terms, plant densities of 10×12 cm to 16×16 cm were suitable for development of plant height. Growers could, therefore, choose a planting density of 10×12 cm to get the highest number of plants per unit area. These results are not consistent with the results of Moniruzzama (2006), who found that lettuce height decreased as planting density increased. However, Firoz et al. (2009) found no significant difference in lettuce height between two planting densities of 50×30 cm and 50×45 cm.

Number of leaves: The different supporting materials had no effect on the number of leaves per plant. However, an increase in planting density tended to increase leaf number (**Table 1**) with a peak at planting densities of 12×14, 14×16 and 16×16 cm. (18.54, 18.51 and 19.01 leaves, respectively). This is similar to Moniruzzaman (2006) who found that a decline in planting density (40×20, 40×30 and 40×40 cm) resulted in an increase in the number of leaves and in the maximum length of the leaf. In our study, a planting density of 12×14 cm provided sufficient space for the development of plants. The interaction between difference supporting materials and difference plant densities at 12x14 cm,14x16 cm and 16x16 cm were significant with plant density at 10x12 cm on number of leaves.

Leaf area and leaf area index:

The different supporting materials of the vertical hydroponics system had no effect on either leaf area or leaf area index of lettuce, while the different plant densities and the interaction between supporting materials and plant densities showed significantly (table 2). Using shoddy felt with 16 x 16 cm, burlap with 16 x 16 cm, burlap with 12 x 14 cm, burlap with 14 x 16 cm, shoddy felt with 14 x16 and mat with 16 x 16 cm had the

high leaf area with the mean of 0.118, 0.117, 0.103, 0.112, 0.111 and 0.111 m2 respectively. However, the interaction between supporting materials and plant densities showed significantly on the leaf area index (table 2). Using shoddy felt with 10×12 cm, burlap with 10×12 cm and mat with 10×12 cm had high leaf area index with mean of 17.86, 16.86, 15.86 respectively.This work observed that, due to the limitations of light and development space, crops grown in high planting density usually had a lower leaf area than plants grown at a low planting density.

Plant canopy diameter: Lettuce grown in planting densities of 16×16 cm and 14×16 cm had the highest plant canopy diameter (20.64 and 19.89 cm, respectively) (**Table 3**). The different supporting materials had no effect on plant diameter. The interaction between supporting materials and plant densities showed significantly. Using burlap with 16 x 16 cm, mat with 16 x 16 cm, mat with 14×16 cm and burlap with14×16 cm had high plant canopy diameter with mean 21.52, 20.91, 20.37, 20.02 cm respectively.

Chlorophyll concentration: The different supporting materials of the vertical hydroponics system had significant effect as planting density on chlorophyll concentration in the lettuce leaves. (**Table 3**). The interaction between supporting materials and plant densities showed significantly. Using burlap with 10×12 cm, mat with 12×14 cm and 10×12 cm had high chlorophyll concentration with mean 16.3, 16.2 and 16.1 mg/100g respectively. Beneragama and Goto (2010) reported that chlorophyll content in leaves was higher in low light conditions than in strong light conditions.

Ascorbic acid concentration (vitamin C) The different supporting materials of the vertical hydroponics system had significant effect as planting density on ascorbic acid concentration in the lettuce leaves (**Table 4**). The interaction between supporting materials and plant densities showed significantly. Using mat with 16x16 cm, and 14×16 cm had high ascorbic acid concentration with mean18.4 and 18.1 mg/100g respectively. This might be related to the higher light intensities on the leaves at the wider spacing as ascorbic acid content in lettuce leaves increases under strong light conditions and decreases under weak light or shaded conditions (Hulewicz and Kalbarczyk, 1976; Shinohara and Suzuki, 1981).

Nitrate accumulation: The high nitrate accumulation in lettuce heads was found significantly with lettuce grown in planting densities of 10×12 and 12×14 cm (**Table 4**). The interaction between supporting materials and plant densities showed significantly. Using burlap with 10×12 cm and shoddy felt with 10×12 cm had high nitrate accumulation with mean 903.6 and 856.4 mg/kg respectively. This might be related to the light competition effect amongst the plants growing in the denser populations. This result agrees with those of Al-Bahash et al. (1985) who also reported that higher planting densities gave the highest nitrate accumulation compared to lower densities. Nitrate concentrations in this study ranged from 684.9 to 903.6 mg/kg, this is the safe level for people when compared with the European standards for nitrate concentration under Belgian and Dutch climatologically conditions (from 1/1/98) is 2500 mg $N0_3$ per kg fresh head lettuce (Benoit & Ceusterrnans, 1995).

Total fresh weight and yield: The different supporting materials used on the vertical

hydroponics system had no significant effect on total fresh weight or on total yield of lettuce. Hence, the supporting materials were not an important factor impacting the performance of lettuce (**Table 5**). However, different plant densities had a significant effect on total fresh weight/plant and total yield. The interaction between supporting materials and plant densities showed significantly. Using burlap with 14×16 cm, burlap with 16×16 cm, shoddy felt with 16×16 cm, shoddy felt with 14×16 cm, mat with 16×16 cm, mat with14×16 cm, and mat with12×14 cm had high total fresh weight/plant with mean 16.04, 15.84, 14.83, 14.53, 14.48, 14.11, 13.66 g/plant respectively. This is consistent with Moniruzzaman (2006) who reported that when the density increased from 40×20 to 40×30 cm and 40×40 cm, the fresh weight of lettuce increased from 200.5, 288.5 and 315.2 g/plant, respectively, and the dry weight from 5.33, 7.48 to 8.24 g/plant, respectively. Fatma et al. (2010) carried out experiments on different planting densities for strawberries, and also showed that fresh weight and dry weight of plants with low planting density were higher than those at high density planting. This experiment found that interaction between supporting materials and plant densities showed significantly on total yield. Using mat, shoddy felt and burlap at plant density 10×12 cm had hightotal yield with mean 5.27, 4.95 and 4.83 kg/m^2 respectively. Contrary to total fresh weight/plant, the treatments with high planting density gave a higher total yield than those at low planting density. In our study, the treatment achieving the highest total yield was a planting density of 10×12 cm, with total yield of 50.2 tons/ha. These results are consistent with the findings of Moniruzzaman (2006) who found that a low planting density of lettuce resulted in higher total weight/plant, but that overall yield was lower in treatments having a high planting density.

Characteristic and production cost of vertical hydroponics system: The results showed that the mat substrate material had the lowest weight and the lowest evaporation rate of water/m^2. The cost of that system was 16.6 USD per system (**Table 6**). After one growing season, the product had good stability. Burlap had the lowest cost of all of the supporting materials (15.5 USD/system). However, it had the highest weight and the highest evaporation of water/m^2, and this material had rotted and was unable after only one season of use. Shoddy felt had an average weight and water evaporation rate, but its cost was very high (21.4 USD/system). This material was usable after one growing season.

Table 1 Effects of different plant densities and supporting materials of a vertical hydroponics system on plant height and leaf number of lettuce.

Plant densities	Plant height (cm)				Number of leaves			
	Mat	Burlap	Shoddy Felt	Mean	Mat	Burlap	Shoddy Felt	Mean
10 x 12 cm	21.06	19.68	19.72	*20.15*	17.24^{b}	17.29^{b}	17.26^{b}	17.26^{B}
12 x 14 cm	19.30	20.61	19.19	*19.70*	18.34^{ab}	18.59^{a}	18.66^{a}	18.54^{A}
14 x 16 cm	19.71	19.68	19.14	*19.51*	19.13^{a}	18.17^{ab}	18.25^{ab}	18.51^{A}
16 x 16 cm	18.64	20.74	19.89	*19.76*	19.25^{a}	18.80^{a}	18.96^{a}	19.01^{A}
Mean	*19.68*	*20.18*	*19.49*		*18.49*	*18.21*	*18.28*	

* Similar letters are not significantly different ($P \leq 0.05$)

Table 2 Effects of different plant densities and supporting materials of vertical hydroponics system on leaf area and leaf area index of lettuce.

Plant densities	Leaf area (m^2)				Leaf area index			
	Mat	Burlap	Shoddy Felt	Mean	Mat	Burlap	Shoddy Felt	Mean
10 x 12 cm	0.079^{e}	0.084^{de}	0.089^{cde}	*0.084^{C}*	15.86^{abc}	16.86^{ab}	17.86^{a}	*16.87^{A}*
12 x 14 cm	0.098^{bcd}	0.103^{abc}	0.102^{bc}	*0.101^{B}*	14.21^{c}	14.88^{bc}	14.64^{c}	*14.58^{B}*
14 x 16 cm	0.101^{bc}	0.112^{ab}	0.111^{ab}	*0.108^{AB}*	11.31^{e}	12.58^{de}	12.43^{de}	*12.11^{C}*
16 x 16 cm	0.111^{ab}	0.117^{a}	0.118^{a}	*0.116^{A}*	10.68^{e}	11.29^{e}	11.39^{e}	*11.12^{C}*
Mean	*0.097*	*0.104*	*0.105*		*13.02*	*13.91*	*14.08*	

* Similar letters are not significantly different (*P≤0.05*)

Table 3 Effects of different plant densities and supporting materials of vertical hydroponics system on plant diameter and chlorophyll content of lettuce.

Plant densities	Plant canopy diameter (cm)				Chlorophyll concentration (mg/100 g)			
	Mat	Burlap	Shoddy Felt	Mean	Mat	Burlap	Shoddy Felt	Mean
10 x 12 cm	16.55^{g}	17.06^{g}	17.34^{fg}	*16.99^{B}*	16.1^{ab}	16.3^{a}	15.9^{bc}	*16.1^{A}*
12 x 14 cm	18.62^{defg}	18.04^{efg}	17.74^{efg}	*18.14^{B}*	16.2^{a}	15.9^{bc}	15.4^{c}	*15.8^{A}*
14 x 16 cm	20.37^{abc}	20.02^{abcd}	19.28^{bcde}	*19.89^{A}*	15.6^{b}	15.7^{bc}	14.7^{dc}	*15.3^{B}*
16 x 16 cm	20.91^{ab}	21.52^{a}	19.48^{bcde}	*20.64^{A}*	14.7^{dc}	15.2^{c}	14.2^{d}	*14.7^{C}*
Mean	*19.11*	*19.16*	*18.46*		*15.7^{A}*	*15.8^{A}*	*15.1^{B}*	

* Similar letters are not significantly different (*P≤0.05*)

Table 4 Effects of different plant densities and supporting materials of vertical hydroponics system on vitamin C and nitrate accumulation of lettuce.

Plant densities	Vitamin C concentration (mg/100 g)				Nitrate concentration (mg/kg)			
	Mat	Burlap	Shoddy Felt	Mean	Mat	Burlap	Shoddy Felt	Mean
10 x 12 cm	15.3^{e}	14.7^{f}	14.3^{f}	*14.8^{D}*	805.6^{c}	903.6^{a}	856.4^{ab}	*855.2^{A}*
12 x 14 cm	16.5^{d}	16.4^{d}	15.6^{e}	*16.2^{C}*	797.4^{cd}	834.8^{bc}	821.6^{bc}	*817.9^{A}*
14 x 16 cm	18.1^{ab}	17.4^{c}	17.2^{c}	*17.6^{B}*	738.8^{de}	746.7^{d}	753.6^{d}	*746.4^{B}*
16 x 16 cm	18.4^{a}	17.8^{bc}	17.8^{bc}	*18.0^{A}*	684.9^{f}	721.6^{def}	703.6^{ef}	*703.4^{B}*
Mean	*17.1^{A}*	*16.6^{AB}*	*16.2^{B}*		*756.7*	*801.7*	*783.8*	

* Similar letters are not significantly different (*P≤0.05*)

Table 5 Effects of different plant densities and supporting materials of vertical hydroponics system on total fresh weight and yield of lettuce.

Plant densities	Total fresh weight (g/plant)				Total yield /m^2 (kg)**			
	Mat	Burlap	Shoddy Felt	Mean	Mat	Burlap	Shoddy Felt	Mean
10 x 12 cm	12.19^{cde}	11.41^{e}	12.06^{de}	*11.88^{C}*	5.27^{a}	4.83^{ab}	4.95^{a}	*5.02^{A}*
12 x 14 cm	13.66^{abcde}	13.53^{bcde}	13.60^{bcde}	*13.60^{B}*	4.32^{cd}	4.28^{cd}	4.39^{bc}	*4.33^{B}*
14 x 16 cm	14.11^{abcd}	16.04^{a}	14.53^{abc}	*14.89^{AB}*	3.61^{ef}	3.89^{de}	3.63^{ef}	*3.71^{C}*
16 x 16 cm	14.48^{abc}	15.84^{ab}	14.83^{ab}	*15.05^{A}*	3.35^{f}	3.49^{ef}	3.42^{f}	*3.42^{D}*
Mean	*13.61*	*14.21*	*13.75*		*4.14*	*4.12*	*4.10*	

* Similar letters are not significantly different (*P≤0.05*)

** Total yield: was determined by the head of lettuce, not including roots

Table 6 Characteristics and production cost of different supporting materials of vertical hydroponics system.

Treatments	Weight of system (kg)	Evaporate water /m^2 system/hour (ml)	Usable after one season	Cost of system (USD)
Mat	32	70.8	Good	16.6
Burlap	56	160.8	Rotten	15.0
Shoddy Felt	47	139.2	Good	21.4

Conclusions

The different supporting materials used on the vertical hydroponics system had no significant effect on the parameters of lettuce growth and yield in this study. This indicates that all three kinds of material can be used to build vertical hydroponics systems for growing lettuce. However, the mat material was the best material to use due to its light weight, low cost, low surface evaporation, and especially its durability. Different planting densities had a significant effect on lettuce growth and yield. Lettuce with planting densities at 14×16 cm and 16×16 cm gave great total fresh weight, while lettuce at planting densities at 10×12 cm had the highest total yield, especially using mat with this spacing gave the highest mean 5.27 kg/m^2 because of large number of plants/m^2.

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