COMPARISON BETWEEN OPEN AND CLOSED HYDROPONIC SYSTEMS ON LETTUCE YIELD

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Abstract

In the present study, lettuce production under the closed and open hydroponic systems was investigated. The tested substrates were perlite : peat (4 : 1, v/v), sand : peat (4 : 1, v/v) and sand: peat : perlite (3 : 1 : 1, v/v/v) under different shading treatments control, i.e. (without shading), medium shading (40 % shade) and heavy shading (80 % shade). The current study was conducted with lettuce (*Lactuca sativa*).

The total yield was higher with the closed systems compared with open ones. Perlite and perlite + peat mixture gave the highest yields among the tested substrates. The highest nutrient consumptions were obtained from perlite and perlite + peat (4 : 1. v/v). On the other hand, medium shading (40 % shade) gave the highest yield compared with other treatments. Also, the results obtained indicated that in the closed system could save both water and nutrient consumption.

INTRODUCTION

Hydroponics is cultivating crops in nutrient solution or media without soil. There are several advantages to hydroponic culture. Some of the problems associated with conventional soil culture such as poor soil structure, poor drainage, salinity, lack of fertile soil and water shortage, as well as weeds and soil-borne pathogens, are eliminated. With hydroponics, there is no need for soil, and only about one twenty-fifth as much water is needed as in conventional farming. In areas where fresh water is not available as the desert regions the hydroponics may be the only system that can be used to grow successfully vegetable crops. So, the desert regions of the world may be such places, where hydroponics has important application.

Lettuce prefers cool temperatures and is considered to be a spring crop. However, unless when summers are extremely hot or when winters are incredibly cold, there are fairly simple ways to extend the lettuce season. Leaf lettuce can tolerate much warmer temperatures than heading lettuce, and because it is also nutritious and fast-growing (Pacher, 1989). Heading types require rather exacting temperatures between 50 – 70° F (10 - 20° C). Optimum growth occurs between 60 – 70° F (15 - 20° C). Heading is prevented and sled stalks form between 70 - 80° F (20 - 27° C). As the weather warms up, make new lettuce plantings in shadier locations (shade cloth can work wonders), and utilize some of the newer heat-resistant summer varieties that are less likely to bolt, particularly if given plenty of water (Whitaker *et al.*, 1974).

There are many classifications for hydroponic systems, the closed and open systems. The open system seems to be more promising due to its high adaptability to the farmers' conditions (Benoit and Ceustermans, 1995).

In countries where hydroponics is applied commercially, open hydroponics cultivation systems have created pollution problems resulting in a consequent transition to closed systems. Closed systems increase water, nutrient and pesticide use efficiency and decrease their impact on the environment but a specific system needs to be developed for each crop (Bohme, 1996 and Van Os, 1995).

This study was conducted to compare water and nutrient consumption of lettuce yield grown in open and closed hydroponic systems under different mixture substrates.

MATERIALS AND METHODS

This research was conducted in the greenhouses locations of Faculty of Agriculture, Ain Shams Univirsty, Shobra El-Khima, Cairo, Egypt, College of Food and Agricultural Sciences, King Saud University, Al-Riyadh and Central Laboratory for Agriculture Climate (CLAC), ARC, Giza, Egypt, in two successive growing seasons of 2005 at the summer season in order to compare lettuce yield and water and nutrient consumption grown in both open and closed systems under different mixture substrates. The study consists of two experiments. The first one, in the first season, was to study the effect of hydroponics systems and shading on lettuce yield and water consumption by plant. The shading treatments were control (without shading), medium shading (40 % shade) and heavy shading (80 % shade). In the second season, and based on the first season results, the second experiment was conducted to study the effect of different substrates on nutrient consumption by lettuce plant under both open and closed systems with medium shading (40 %).

The tested substrates were perlite : peat (4 : 1, v/v), sand : peat (4 : 1, v/v) and sand : peat : perlite (3 : 1 : 1, v/v/v). The current study was conducted with lettuce (*Lactuca sativa*). Substrates were filled into horizontal containers as 5 liters per plant. Seedlings were transferred to the substrate (perlite) in the first experiment on June 2 and to the other substrates on August 10 for the second experiment. Plants are planted at a density of 2 plants per square foot. Yield was harvested after 35 to 40 days after transplanting.

Water and nutrient requirements of the plants were supplied with the nutrient solution having the following composition (mg/l): Ca $(NO_3)_2$, 0.575; KNO_3, 0.331; Mg $(NO_3)_2$. $7H_2O$, 0.219; $KH_2 PO_4$, 0.0828 and K_2SO_4, 0.1466 (g/l). The micro nutrients were supplied to this solution as Fe - EDDHA 16; $MnSO_4$. $7H_2O$, 2.44; H_3BO_3, 0.68; $ZnSO_4$. $7H_2O$, 0.176; $CuSO_4$. $5H_2O$, 0.156 and (NH_4) 6 MO_7O_{24}, 0.148 (mg/l) (Cooper, 1979). Nutrient solution was applied via drip irrigation system. The daily applied solution was calculated using the following equation:

$$ETc = Kc \times ETo$$

Where, Kc is the crop coefficient, ETc is the actual measured rate of evapotranspiration for non-stressed lettuce. ETo is reference evapotranspiration was calculated from actual temperature, humidity, sunshine/radiation and wind-speed data, according to the FAO Penman-Monteith method (FAO, 1998). The meteorological data were collected by the Central Laboratory for Agriculture Climate (CLAC), ARC, Giza, Egypt. Crop coefficient values were taken from FAO 1998, where the Food and Agriculture Organization (FAO) have published guidelines for crop factors (including lettuce) and some work has also been completed to estimate crop factors for specific regions.

In the open system, plants in different substrates were fed from the same tank, but drained water was collected into separate tanks from each container and their volumes were recorded. In the closed system, each substrate had its own tank and make-up solution was added to maintain original volume after checking EC and pH values. Nutrient solution was completely changed in cases where EC exceeded 2.5 dS/m.

Water consumption was calculated by subtracting the amount of drainage solution from the applied amount on a daily basis.

At harvest, three plants were randomly chosen from each plot and plant fresh weight was determined. Total yield was also recorded. The plant samples were oven dried at 70° C then ground in a blender and stored in glass vials for elemental analysis. In digested solution, nitrogen was determined by steam distillation procedure using devarda, phosphorus was measured colorimetrically with ammonium molybdate, while, potassium was determined with a flame photometer and Ca and Mg were measured by atomic absorption spectrophotometer (Chapman and Pratt, 1961).

The experiment design was a split plot design with three replicates for each treatment. The data were statistically analyzed by the analysis of variance using SAS package. Comparison of treatment means was done using LSD at 5 % level of significance (Snedecor and Cochran, 1980).

RESULTS AND DISCUSSION

In respect to yield, Table 1 shows that there were no significant differences between the tested hydroponics systems. However, the yield of the closed system increased by almost 5 % as compared with the closed one. Previous researches results mentioned that the recirculating systems did not differ from the open system in terms of yield (Van Os, 1995 and Bohme, 1996). Dhakal *et al.* (2005) reported that the total crop yield of the closed system of fertigated greenhouse was almost similar to that of the open system greenhouse.

In term of environment, one of the serious problems of the open system is the effluence of overdosed nutrient solution from the system into the soil resulting in euterophication of soil and groundwater (Benoit and Ceustermans, 1995). Therefore, closed system, has great importance, in which drain solution is recirculated to reduce environmental pollution.

Table 1. Effect of the hydroponic systems and shading on lettuce yield (g/plant).

Hydroponic systems	Type of shading			LSD
	Control, without shading	40 % Shade	80 % Shade	
Closed	80.2	370	169	19.0
Open	75.9	353	160	15.3
	n.s.	n.s.	n.s.	

n.s. : Non significant

On the other hand, concerning the effect of shading on the yield, it was positively responded with medium shading (40 % shade) as compared with other treatments. Thermal shade screens reduces plant stress during the summer when outside temperatures are typically in the high 30's° C, and sometimes up to 35° C inside the sheds. The thermal shade screens make a huge difference in summer. In case the control (without shading), the plants suffer with high night temperatures and lettuce becomes bitter. Tip burning also occurs at high temperatures while, with heavy shading treatment (80 % shade), the plants growth was disturbed and the yield was low. In fact, Light is vital for photosynthesis, but is also necessary to direct plant growth and development. Light acts as a signal to initiate and regulate *photoperiodism* and *photomorphogenesis* (Smith, 1992). So, with high density of the shading, plants growth display greater stem elongation and develop smaller leaves and less branching.

Regarding water consumption by lettuce plants as a function of the tested hydroponic systems and shading treatments, Table 2 shows that the average water consumption of the plants grown in the open system was 15 to 17 % higher compared to the closed systems. This result coincide with those obtained by Tuzel *et al.* (1999) and Van Os (1995) who reported that an average water saving in closed systems being 21 , 29 and 19 % in production of cucumber, rose and chrysanthemum, respectively. Generally, the open system results in higher evapotranspiration than the closed one (Bohme, 1996).

Apparently, the water consumption by lettuce plants was sharply decreased with shading. The absolute values of water consumption were 68.5 and 80.5 l/plant in control treatment for closed and open systems, respectively. While with medium shading (40 %) the values were 38.6 and 45 l/plant for closed and open systems, respectively. But, with extreme shading (80 % shade) the values of water consumption were 26 and 30.5 l/plant. The shading has a capacity to reduce light reaching to the substrates or plants surface and consequently decline the water evaporation-evapotranspiration (Whitaker *et al.*, 1974).

Table 2. Effect of the hydroponics systems and shading on water consumption by lettuce plant (l/plant).

Hydroponic system	Type of shading			LSD
	Control (without shading)	40 % Shade	80 % Shade	
Closed	68.5	38.6	26.0	3.7
Open	80.5	45.0	30.5	2.4
LSD	4.20	2.10	2.30	

Table 3 shows the effect of hydroponic systems and different substrates on lettuce yield. In closed system, among the tested substrates perlite and peat mixture with perlite gave the highest yield which reached 350 and 332 g/plant, respectively. Similar results were obtained with open system. The highest yield, i.e., 341 and 344 g/plant was recoded with perlite and peat mixture with perlite, respectively. On the contrary, the lowest yield was found with sand in both systems. Sand are the oldest hydroponic media, they are heavy when wet and tends to dry out quickly.

Table 3. Effect of the hydroponic systems and substrate type on lettuce yield (g/plant).

Substrates	Hydroponic system		LSD
	Closed	Open	
Perlite	350	341	n.s.
Sand	311	300	7.5
Perlite + Peat	332	344	n.s.
Sand + Peat	332	330	n.s.
Sand + Peat + Perlite	339	332	n.s.
LSD	6.1	7.3	

n.s. : Not significant

However, the sand media gave positive response when mixed with peat. Substrates mixed with peat showed a higher performance throughout the harvest period. Abou-Hadid *et al.* (1995) tested different media to be used as substrates in Egypt for cucumber production. They found that the peat-based mixture gave the best results for cucumber production comparing with the other substrates.

The consumed nutrients in open and closed systems are given in Table 4. It was clear that in the open system the amount of consumed nutrients were higher than those in the closed system. In accordance with the closed system, Vernooij (1992) noted that recirculation of drainwater can reduce the consumption of fertilizers by more than 50 %.

Table 4. Effect of the hydroponic systems and substrate type on nutrient uptake lettuce plant (g/plant).

Substrates	Closed system				
	N	P	K	Ca	Mg
Perlite	0.56	0.09	0.80	0.2	0.07
Sand	0.45	0.07	0.73	0.16	0.05
Perlite + Peat	0.63	0.10	1.10	0.22	0.07
Sand + Peat	0.52	0.08	0.90	0.18	0.06
Sand + Peat + Perlite	0.56	0.08	0.86	0.19	0.06
LSD	0.07	0.01	0.13	0.02	0.008
Substrates	Open system				
	N	P	K	Ca	Mg
Perlite	0.61	0.11	1.20	0.22	0.09
Sand	0.45	0.08	0.87	0.17	0.07
Perlite + Peat	0.71	0.12	1.32	0.25	0.1
Sand + Peat	0.55	0.09	0.98	0.21	0.08
Sand + Peat + Perlite	0.61	0.09	1.01	0.21	0.09
LSD	0.09	0.01	0.14	0.03	0.01

The highest nutrient uptake was recorded in perlite and peat mixtures, while the lowest values nutrient of nutrient uptake were recorded with sand media in both open and closed systems. These differences may be due to the variations in properties of substrates. Perlite is very porous, which has a strong capillary action and can hold 3-4 times more water than its weight. Roots in perlite are always well aerated and well watered (Olympios, 1992). Also, high cation exchange capacity is an important advantage of peat (Verdonck, 1991).

It may be worth to mention that the nutrient uptake by lettuce plants as a function of the different substrates agree with results of the obtained yield.

Finally, According to the results obtained, less water and fertilizers were consumed when using the closed system in spite of there were no significant differences between open and closed systems in respect to yield. Sand is a local inert material in arid areas and may be mixed with other substrate in hydroponics cultures. Also, under arid conditions the shading is an important process to decrease the evapotranspiration.

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مقارنة النظم المفتوحة و المغلقة للمزارع المائية
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المزارع المائية هي زراعة المحاصيل في المحاليل الغذائية أوفى بيئات بدون تربة وهناك فوائد للمزارع المائية منها أن بعض المشاكل المرتبطة بالزراعة التقليدية في الأرض مثل الأراضي الفقيرة في البناء والصرف أو التي بها ملوحة أو نقص في الخصوبة أو عند نقص الماء بالإضافة إلى الأمراض التي تولد في التربة والحشائش ، فان كل هذه المشاكل تؤدى الى إهمال تلك الاراضى. ومع المزارع المائية ليس هناك حاجة للتربة ويكفيها فقط ٢٥ % من الاحتياجات المائية المطلوبة في المزارع التقليدية.

في المناطق التي لا يتوفر الماء العذب بها مثل المناطق الصحراوية فإن المزارع المائية يمكن ان تكون هي النظام الوحيد الذي يستخدم بنجاح في زراعة محاصيل الخضر. لذا فإن المناطق الصحراوية في العالم هي الأماكن المهمة لتطبيق المزارع المائية. وهناك للمزارع المائية أقسام عديدة استخدم منها النظام المفتوح والنظام المغلق في هذه الدراسة. والبيئات المستخدمة هي البرليت : البيتموس (٤ : ١ حجما)، الرمل : البيتموس (٤ : ١ حجما)، الرمل : البيتموس : البرليت (٣ : ١ : ١ حجما) وذلك تحت مستويات تظليل مختلفة (بدون تظليل (كنترول)، ٤٠ % تظليل و ٨٠ % تظليل) و ذلك باستخدام شبك التظليل.

وقد تمت هذه الدراسة على نبات الخس، وكان الإنتاج الكلى في النظام المغلق أكبر مقارنة بالمفتوح. والبرليت + البيتموس أعطى أعلى محصول بين البيئات المستخدمة. و على الجانب الاخر اعطت معاملة التظليل ٤٠ % اعلى محصول مقارنة بباقي معاملات التظليل كما أن أعلى استهلاك للماء والمغذيات كان مع البرليت + البيتموس. وتؤكد النتائج أيضا أن النظام المغلق يوفر في استهلاك الماء والمغذيات.