Hydroponics for Food Production: Comparison of Open and Closed Systems on Yield and Consumption of Water and Nutrient

Essam M. Abd-Elmoniem[1], M. A. Abdrabbo[2], A.A. Farag[2] and M. A. Medany[2]

[1]Soil Sci. Dept. Fac.of Agric., Ain Shams Univ., Cairo, Egypt
[2]Agric. Res. Center, Giza, Egypt

Abstract

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.

There are many classifications for hydroponic system. In the present study, the closed and open systems were used. The tested substrates were perlite, sand, perlite + peat (4: I. v/v), sand + peat (4: I. v/v) and sand+ peat + perlite (3:1:1, v/v/v). The current study was conducted with lettuce, Lactuca sativa.

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

Keywords: Substrate, lettuce, shading, hydroponics

Introduction

Lettuce prefers cool temperatures and is considered to be a spring crop. However, unless your summers are extremely hot or your winters 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's also nutritious and fast-growing (Sara Pacher, 1989). Heading types require rather exacting temperatures between 50-70F (10-20C). Optimum growth occurs between 60-70F (15-20C). Heading is prevented and sled stalks form between 70-80F (20-27C). 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 hydroponics system, the closed and open systems. The open substrate culture seems to be more promising due to its high adaptability to the farmers' conditions **(**Benoit and Ceustermans, 1995 and Lapez et al., 1998).

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, 1995, 1996 and Van Os et al., 1995).

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

Materials and Methods

This research was conducted at Faculty of Agric., Ain Shams Univ., Shobra El-Khima, Cairo, Egypt and Central Laboratory for Agriculture Climate (CLAC) El Dokki, greenhouses location in two successive seasons of 2005 at the summer season in order to compare lettuce yield, water and nutrient consumptions 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 depending on the previously results, the second experiment was 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, sand, perlite + peat (4: I. v/v), sand + peat (4: I. 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, on June 2 for the first experiment and to other substrates on Aug 10 for the second experiment. Plants are planted at a density of 2 plants per square foot. As well as, the yield is ready in 35 to 40 days after transplanting.

Water and nutrient requirements of the plants were supplied with the nutrient solution having the following composition (mg/I): Ca $(NO_3)_2$, 0.575; KNO_3, 0.331; Mg $(NO_3)_2$. $7H_2O$, 0.219; KH_2PO_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 equation :

$$ETc = Kc \times ETo$$

Where, Kc is the crop coefficient, ETc is the actual measured rate of evapotranspiration for nonstressed lettuce. ETo, reference evapotranspiration can be calculated from actual temperature, humidity, sunshine/radiation and wind-speed data, according to the FAO Penman-Monteith method (FAO, 1998). 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. Also, Mete-orological data were collected by Central Laboratory for Agriculture Climate (CLAC), El-Giza, Egypt.

In open system, plants in different substrates were fed from the same tank, but drained water was collected into separate tanks from each plot and their volumes were recorded. EC and pH values of nutrient solution were checked daily and maintained between 1.5-2.5 dS/m and 5.5 and 6.5, respectively. In 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 weights were determined. Total yields were also recorded. Also, the 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 calorimetrically with ammonium molybdate, while, potassium was detriment with a flame photometer and Ca and Mg were measured by atomic absorption spectrophotometer.

The experiment design was split plot design with three replicates of 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. Data were statistically analyzed according to Snedecor and Cochran (1980).

Results and Discussion

In respect to yield, table 1 show that there were no significant differences between the tested hydroponics systems. However, the yield of closed system increased by almost 5 % as compared for closed one. The previously researches results stated that the recirculating systems did not differ from the open system in terms of yield (Van Os et al., 1991, Van Os, 1995, Bohme, 1996 and Gul et al., 1999). Dhakal et al. (2005) reported that the total crop yield of the closed system of fertigated greenhouse was almost similar to that of 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 hydroponics systems and shading on lettuce yield (g/plant).

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

n.s. : Non significant

On the other hand, concerning of the effect of the shading on the yield, it was positively response with medium shading (40% shade) compared with other treatments. Thermal shade screens reduces plant stress during the height of summer when outside temperatures are typically in the high 30's (degrees C), and sometimes up to 35 degrees C inside the sheds. The thermal shade screens make a huge difference in summer. In case the control (without shading), the plants suffer where, with high night temperatures, lettuce becomes bitter. Tip burning also occurs at high temperatures while, with heavy shading treatment (80% shade), the plants growth disturbed, where 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 the water consumption by lettuce plants as function for the tested hydroponics systems and shading treatments, table 2 show 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 (1999) who reported that an average water saving in closed systems being 21 % in cucumber, 29 % in rose and 19 % in chrysanthemum production. Generally, the open system results in higher evapotranspiration than closed one (Bohme, 1996).

Apparently, the water consumption by lettuce plants shapely 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 extremely shading in particularly with 80% shade the values of water consumption were 26 and 30.5 l / plant. The shading has capacity to reduce light reaching to the substrates or plants surface and consequently decline the water evaporation-evapotranspiration (Carruthers, 1997).

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

Hydroponics systems	Control, without shading	40% Shade	80% Shade	LSD
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	

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

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

Substrates	Closed	Open	LSD
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	6.10	7.30	

n.s. : Non significant

However, the sand media appeared positive response when mixture with peat. Substrates mixed with peat showed higher performance throughout the harvest period. Abou-Hadid *et al.* (1995) tested different media to be used as substrates in Egypt for cucumber production as follows: peat moss-sand-vermiculite (1:1:1 v/v/v), peat moss-vermiculite (1:1 v/v), peat-sand (1:1 v/v) and rockwool in comparison with soil. They found that the peat-based mixture gave the best results for cucumber production comparing with the other substrates.

The amount consumed nutrients in open and closed system, are given in table 4 according to the substrates. It was clear that in the open system the amount consumed nutrients were higher than those in closed system. In accordance with the closed system, Van Os et al. (1991) and Vernooij (1992) noted that recirculation of drainwater can reduce the consumption of fertilizers by more than 50 %.

In the open and closed system, the highest uptake was recorded in perlite and peat mixtures, while the lowest values of nutrient uptake were recorded with sand media. These differences may be due to the variations in properties of substrates. Perlite is very porous, 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, 1 992). Also, high cation exchange capacity is an important advantage of peat (Verdonck, 1991).

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

Table (4): Effect of the hydroponics systems and substrate type on nutrient consumed by lettuce plant (g/plant).

	Closed system				
Substrates	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
			Open system		
Substrates	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

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 land and may be used as a substrate in hydroponics cultures with some mixtures. Also, under arid land conditions the shading is an important process to decrease the evapotranspiration.

References

Abou-Hadid, A.F., A.S. El-Beltagy, M. Medany and M.M. Hafez. 1995. Performance of soilless media on greenhouse production of cucumber (*Cucumis sativus* L.). J. Veg. Crop. Prod. l1: 93-98.

Benoit, F., N. Ceustermans. 1995. Horticultural aspects of ecological soilless growing methods. Acta Hort. 396: 11-24.

Bohme, M. 1995. Effects of closed systems in substrate culture for vegetable production
in greenhouses. Acta Hort. 396:45-54.

Bohme, M. 1996. Influence of closed systems on the development of cucumber. ISOSC, Proceedings.75-87.

Carruthers, S. 1997. Booyong Hydroponics: Repots on hydroponic lettuce and flower facility that use bacteria and fungal organisms to control plant disease. Partical Hydroponics & Greenhouses Magazine, First Publication, November/ December, Issues 37.

Dhakal, U., V. M. Salokhe, H. J. Tatau and J. Max. 2005. Development of a green nutrient recycling system for tomato production in humid tropics. Agriculture Engineering International.Vol. VII, October. http// www.cigr-ejournal.tamu.edu/s.

FAO. 1998. Crop Evapotranspiration . R. Allen, L.A. Pereira, D. Raes & M. Smith. FAO Irrigation and Drainage Paper No. 56. FAO, Rome.

Gul, A., I.H. Tuzel, O. Tuneay, R.Z. Eltez and E. Zencirklran. 1999. Soilless culture of cucumber in glasshouse: I. A comparison of open and closed systems on growth, yield and quality. Acta hort. 491: 389-394.

Lapez, 1., M. Dorais, N. Tremblay, A. Gosselin, and R. Munuz-Carpena. 1998. Effects of varying sulfate concentrations and vapor pressure deficits (VPD) on greenhouse tomato fruit quality, foliar nutrient concentrations and amino acid components. Acta Hort.458: 303-310.

Olympios, C.M. 1992. Soilless media under protected cultivation rock wool, peat, perlite and other substrates. Acta Hort. 323: 215-234.

Pacher, S. 1989. Mather earth news. Issue # 115 - January/February 1989. http://www.motherearthnews.com/

Smith, H. 1992. Light quality, photoperception and plant strategy. Annual Review of Plant Physiology 33:481-518.

Snedecor, G. W. and W. G. Cochran. 1980. Statistical Methods. Sixth Edition, Iowa state university press, Ames, Iowa.

Tuzel, I.H., M.E. Irget, A. Gul., O. Tuncay and R.Z. Eltez. 1999. Soilless culture of cucumber in glasshouses: II A Comparison of open and closed systems on water and nutrient consumptions. Acta Hort. 491:395-400.

Van Os, E.A., N.A. Ruijs, P.A. Van WeeI. 1991. Closed business systems for less pollution from greenhouses. Acta Hort. 294: 49-57.

Van Os, E.A. 1995. Engineering and environmental aspects of soilless growing systems. Acta Hort. 396: 25-32.

Van Os, E.A. 1999. Closed Soilless Growing Systems: A Sustainable Solution for Dutch, Greenhouse Horticulture.

Verdonck, O.1991. Horticultural substrates. 21st 1nt. Course on Vegetable Production.

Vernooij, C. J. M. 1992. Reduction of environmental pollution by recirculation of drainwater in substrate cultures. Acta Hort. 303: 9-13.

Whitaker, T.W., E.J. Ryder, V.E. Rubatzky, and P.V. Vail. 1974. Lettuce production in the United States. USDA Agr. Handbook No. 221.

المزارع المائية لإنتاج الغذاء: مقارنة النظم المفتوحة والمغلقة من حيث المحصول واستهلاك الماء والمغذيات

عصام محمد عبد المنعم[1]، محمد عبد ربه[2]، احمد عوني فرج[2] و محمود عبدالله مدني[2]

قسم الاراضى– كلية الزراعة – جامعة عين شمس– القاهرة– مصر [1]
المعمل المركزى للمناخ الزراعى– مركز البحوث الزراعية– الجيزة– مصر[2]

المزارع المائية هي زراعة المحاصيل في المحاليل الغذائية أوفى بيئات بدون تربة، هناك فوائد للمزارع المائية وآلتي منها أن بعض مشاكل التربة المرتبطة بالزراعة التقليدية في الأرض مثل الأراضي الفقيرة في البناء والصرف أو آلتي بها ملوحة أو نقص في الخصوبة أو عند نقص الماء بالإضافة آلي الأمراض آلتي تولد في التربة والحشائش ، فأن كل هذه المشاكل تؤدى الى اهمال تلك الاراضى. ومع المزارع المائية ليس هناك حاجة للتربة ويكفيها فقد من 5 – 20 % من الاحتياجات المائية المطلوبة في المزارع التقليدية. وفى المناطق آلتي لا يتوفر الماء العذب بها مثل المناطق الصحراوية فأن المزارع المائية يمكن آن 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 – الرمل – البرليت + البيتموس(4 : 1 حجما)– الرمل + البيتموس (4 : 1 حجما) الرمل + البيتموس + البرليت(3 : 1: 1 حجما).

وقد تمت هذه الدراسة على نبات الخس. وكان الإنتاج الكلى في النظام المغلق اكبر مقارنة بالمفتوح.والبرليت + البيتموس أعطى أعلى محصول بين البيئات المستخدمة. وأعلى استهلاك للماء والمغذيات كان مع البرليت + البيتموس. وأيضا النتائج تؤكد آن النظام المغلق يوفر في استهلاك الماء والمغذيات.