Journal of Applied Horticulture, 12(2): 140-144, July-December, 2010

Horizontal and vertical soilless growing systems under Cyprus conditions

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Abstract

Under the impact of new cultivation and socioeconomic trends, and the aspiration for agricultural sustainability, a research study was conducted under Cyprus conditions. Lettuce (*Lactuca sativa* cvs. 'Paris island', 'Lollo rosa', and 'Oakleaf') and strawberry (*Fragaria* x *ananassa* cv. 'Camarosa') plants were used to evaluate horizontal and vertical growing setups in a 'closed' soilless system. For lettuce, the vertical system provided more marketable lettuce per system's surface area compared to the horizontal setup. However, the horizontal system provided greater lettuce mass and higher percentage marketable yield than the vertical one. The nitrate content of all lettuce cultivars was not significantly different between the two systems and remained lower than the European standards all over the experiment. For strawberry, the vertical setup offered higher yield compared to the horizontal one. The quality characteristics were not different between the two systems. These results suggest that the studied setups and the 'closed' soilless system can be used as a tool for the improvement of Cyprus greenhouse production, water use efficiency and prevention of environmental damage from regular` disposal of hydroponics solution. The possibility of an improved greenhouse production system could be considered as technique of choice under semi-arid Cyprus and E. Mediterranean conditions using such materials.

Key words: Lettuce (*Lactuca sativa*), strawberry (*Fragaria x ananassa*), horizontal system, vertical system, hydroponics

Introduction

Achieving agricultural sustainability is a major goal in many parts of the world, primarily in the developed countries. The increased environmental awareness, the need to protect the various ecosystems, as well as the ongoing effort to implement agricultural practices that are economically viable and environmentally sound, give an impulse for the use of soilless growing techniques and a new research directive. Consequently, the use of soilless systems in North America, the European Union and the Middle East is popular, not only because of the preceded trends, but as a natural consequence of the climatic conditions of these regions. Naturally, the closed hydroponic systems gain familiarity, because of the water scarcity in parts of the world, and the legislation demanding the adoption of closed hydroponic systems in many countries (Avidan, 2000; De Kreij *et al.*, 2001). However, 'closed' systems are seldom completely closed, because some ions or chemicals will eventually build up to an excessive level, and generally, it is less expensive to discard such a solution than to clean it (Schröder and Lieth, 2002).

In Cyprus, few studies have been conducted targeting the hydroponic production of cut flowers and vegetables (Chimonidou, 1999, 2003; Polycarpou *et al.*, 2005; Neocleous *et al.*, 2005, 2007). However, it is necessary to conduct further studies, because of the new cultivating and socio-economic trends, and the pollution of the surface and subsurface waters with nitrates from fertilizers. Furthermore, there is an increasing interest in soilless culture and vertical systems, because it provides better energy utilization and more efficient use of the greenhouse volume, resulting in higher yield per unit area (Paraskevopoulou-Paroussi and Paroussis, 1995). Eventually, these studies will increase the competitiveness of the Cyprus hydroponic production, and help the local agricultural community adopt the framework of the Environment Action of the European Community (EC Decision No. 1600/2002) and follow the Code of Good Agricultural Practices (Cyprus Government, Decision 407/2002).

The aim of this work was to study the feasibility of horizontal and vertical growing systems, with the subsequent minimization of nutrient solution losses to the environment, under Cyprus (E. Mediterranean) conditions. To achieve the latter, a closed hydroponic system was used and quantitative assessment of the two systems´ production was conducted.

Materials and methods

The evaluation of the horizontal and vertical systems was done in a polyethylene-coated, omega type triple-span greenhouse, 27 m long, 21 m wide and 5 m high with side and roof openings, and a 'closed' hydroponic system, at the Zygi Experimental Station of the Cyprus Agricultural Research Institute (long. 32^{o}E, lat. 35^{o}N) during late Winter - early Summer in 2006. All systems were built on a pilot-scale in order to provide the fundamental data for further investigation and future large-scale implementation.

Description of the horizontal and vertical systems: Sixteen canals for substrates (Ramat Hashofet, Israel), with dimensions 0.17 x 0.20 m and length 11 m each, were placed 40 cm apart within the greenhouse, to serve as the horizontal system's growing setup. In order to prevent the formation of algae due to the presence of photosynthetic microorganisms, black nylon and black-ash wood covered the connections between the canals.

A computerized time-control irrigation unit (Macqu) controlled the electrovalve of the greenhouse, monitoring the pH and the EC of the irrigation solution. Polyvinyl chloride (PVC) 16 mm inline drip irrigation tubing, with drippers of 4 L h^{-1}, spaced 30 cm apart, was used to deliver the nutrient solution to the plants, and the drainage solution was collected in a reservoir for reuse. For the vertical system, eighty grow-bags were used (Sunsaver, Spain), with height 1.80 m, and 12 sacks (6 on each side). Each sack's dimensions were 12 x 8 cm. To support the grow-bags in two rows of forty bags, two 1.91 cm diameter galvanized steel pipes were installed at a height of 2.50 m, parallel to the ground, and spaced 1.50 m apart. The distance between each grow-bag was 10 cm, and Macqu controlled the irrigation. For the irrigation of the vertical system, a 16 mm PVC inline drip irrigation tubing (spaghetti) with pairs of 25 cm spaced emitters was used providing a total of 16 L h^{-1} for every grow-bag. With the aid of a black nylon canal, under every row of grow-bags, the drainage solution was collected for reuse. A UV lamp (Montagna) disinfested the drainage solution of both systems, prior any reuse, in order to prevent the development of any microbial pathogens.

Irrigation practices: An experimental 'closed' system using software developed in an earlier EU-project (MACQU, AIR 1603) was used. A central computer was utilized to send the desired functional and control parameters to stations (setup), and also to provide the user with an image of the greenhouse. The automatically started irrigation time program operated every day from 06:00 to 18:00. In each day we defined up to 10 time intervals during which we wanted the program to operate. Irrigation was done through a drip irrigation system. The amount of the water applied was estimated according to the amount of drainage solution (30-40%). The drainage solution from the substrates was first filtered (150 μm) and then disinfected through the UV lamp.

Definition of the hydroponics parameters: The EC and pH of the solution were regulated using Macqu as mentioned previously. The desired pH and the lower and upper pH limits were determined for the solution according to basic nutrient solution concentrations (see below). In case that the pH was under the lower limit, the program closed the irrigation valves and opened the reject valve so that fresh water entered in the mixing tank. If the pH was higher than the upper limit, the program closed the irrigation valves and tried to reduce the pH by adding acid in the mixing tank. The desired electrical conductivity (EC) and the lower and upper EC limits were specified for the solution. In case that the EC was under the lower limit, the program closed the irrigation valves and added condensed solutions in the mixing tank. If the EC was higher than the upper limit, the program closed the irrigation valves and opened the reject valve so that fresh water entered the mixing tank to lower the EC. Such a system minimizes the build up of toxic ion concentrations in the solution. As a consequence it was not necessary to discard the solution more often than 2 months. The substrate for both systems was 100% hydroponic perlite. Moreover, a greenhouse environmental control unit, Galileo Greenhouse irrigation and climate control V_2 (Eldar, Shany), controlled the automatic opening of the windows at 20°C, the closing of the windows and the start of the cooling system (cooling pad and fans) at 25°C, while maintaining a desirable range of relative humidity between 40 to 65%. The nutrient solution consisted of (ppm): N (127.6), P (36.6), K (181), Ca (89.9), Mg (42.89), S (36), Fe (0.85), Mn (0.250), Cu (0.01), B (0.25), Zn (0.125), and Mo (0.025). The iron was in the form of Fe-EDDHA chelate. The corresponding pH and EC values for the solution were 6.2 and 1.25 mS cm^{-1}, respectively.

Pest management: Insects and diseases were controlled using Integrated Pest Management (IPM) techniques. Pests were controlled successfully with a combination of: a) mechanical control using fine-mesh screens on the windows, a soil-cover to prevent the pupae stage of various insects, and a double door entrance hall with good insulation; b) physical control using yellow traps (chromo-attractive control) painted with glue and hung between the plants of both systems, as well as monitoring and scouting (24 plants were selected to be observed); c) biological control using beneficial insects such as the predatory bug *Orius laevigatus* and the biologically-derived insecticide Tracer (Spinosad); d) chemical control with the acaricides Pride (Fenazaquin) and Nissorun (Hexythiazox). Sulphur fumigators worked every night from 2 am to 3 am in order to prevent mycological disease and control the populations of *Tetranychus* spp.

Plant transplantation: The experimental crops were strawberry (*Fragaria x ananassa*, cv. 'Camarosa') and lettuce (*Lactuca sativa*). The lettuce variety 'Paris island' was used during the first lettuce growing season, followed by 'Lollo rosa' and 'Oakleaf'. The seedlings were raised on peat compost cubes, and were transplanted in the horizontal and vertical system when 5-7 cm tall. In twelve canals of the horizontal system, 'Paris island' plants were transplanted (6 plants/m), and strawberries were transplanted in the remaining four canals (5 plants/m). Strawberries were placed into seventy-two grow-bags (12 plants/bag), and lettuce was placed in the rest eight bags (12 plants/bag).

General methodology: Collection of the environmental data of the greenhouse was achieved using a 21X Micrologger data logger (Campbell Scientific), two MP 100A temperature – relative humidity probes (Campbell Scientific), and a CM3 Pyranometer (Kipp & Zonen). Nutrient solution supply was recalculated on a regular basis using the readings of the applied and drainage water. IPM data such as population count in the monitoring traps and monitoring plants were gathered on a weekly basis. The experiment was a completely randomised design. Analysis of variance (ANOVA) and mean separation by Duncan's multiple range tests were performed on the lettuce and strawberry datasets using the SAS statistical software, Release 8.2 (SAS Institute Inc.).

Lettuce methodology: Sampling and analysis began two weeks after the transplantation. Randomised lettuce samples were analysed to determine their: a) leaf fresh weight, root fresh weight, leaf dry weight (%), and root dry weight (%) ('Paris island'); b) leaf fresh weight, and leaf dry weight (%) ('Lollo rosa' and 'Oakleaf'); c) nitrate and chloride content ('Paris island', 'Lollo rosa', and 'Oakleaf'). Fresh weight was measured after harvesting the upper part of lettuce above the basal area. The above samples were dried at 65°C to constant weight. For the potentiometric determination of the nitrate concentration in the dry sample, a nitrate-ion electrode and the pH & Conductivity meter EC30 (HACH) were used. Furthermore, for the determination of the dry sample's chloride content a titration with $AgNO_3$ was used.

Strawberry methodology: A random selection of strawberry plants was monitored for its a) auxiliary shoot production; b) fruit fresh weight, fruits picked per surface area, and non-marketable fruit quantity; c) vitamin C, pH, soluble solids concentration, titratable acidity, and total anthocyanin content.

Analyses: For ascorbic acid (vitamin C) determination randomised strawberry samples of 16 fruits, stored overnight at 4°C, were homogenized for 5 min. 0.5 g of homogenized sample was added to 40 mL extracting solution (oxalic acid 1%), homogenized for 1 min, and filtered through Watman (No. 1) filter paper. The ascorbic acid content was measured using the instrument RQflex Plus (Merck) in combination with a standard solution of known ascorbic acid concentration (200 ppm). Ascorbic acid reduces yellow molybdo-phosphoric acid to phosphomolybdenum blue, the concentration of which is determined reflectometrically. Ascorbic acid analytical test strips, Reflectoquant, were provided by Merck (Darmstad, Germany). The test strip was inserted into the sample and transferred into the RQflex Plus adapter for the measurement result.

The pH of the pulp was recorded by a high-impedance voltmeter AGB-4001 pH Meter (Labtech Instruments). Soluble Solids Concentration (S.S.C) at 20 °C was determined in the homogenized sample using the Automatic Refractometer GPR 11-37 (Index Instruments).

For the determination of the total anthocyanin content a modification of the Torre and Barrit method (1977) was used. 1 g of homogenized sample was added to 50 mL of extracting solution (ethanol 80% + HCl 2%). The mixture was stored for 24 h at 4°C and then filtered through Watman (No. 1) filter paper. Absorbance readings were determined at the maximum absorbance peak of 534 nm, after scanning the samples from 400 to 600 nm for maximum absorbance wavelength, using a M350 Double-beam UV-Visible spectrophotometer (Camspec) and quartz cuvettes with 5 cm optical path. The absorbance values were expressed as units of optical density per gram fresh weight [units OD (g fresh wt)$^{-1}$].

The titratable acidity was measured by mixing 2 g of the pulp and 50 mL distilled water with few drops of phenolphthalein indicator and titrating the mixture with 0.1 N NaOH. The titratable acidity was expressed as % citric acid equivalent to the quantity of NaOH used for the titration (Ryan and Dupant, 1973).

Results and discussion

Greenhouse data: The daytime temperature varied from 21.1 to 34.9°C, having a mean value of 26.8°C throughout the experiment. The average nighttime temperature had a mean value of 15.5°C, fluctuating from 8.3 to 19.7°C. During the daytime the average relative humidity was 52.4%, varying within the range of 21.5 and 65.9%, whereas the nighttime average relative humidity was 76.3%, with minimum and maximum values at 53.5 and 82.2%, respectively. The above measurements indicate the proper functioning of the climate control system, since all values were within an acceptable range, considering the warm climatic conditions of Cyprus during spring and summer. During the experiment, the intensity of the solar radiation varied from 355 to 1110 W m^{-2}, with a mean value of 867 W m^{-2}.

Generally, the nutrient solution was within the desirable working parameters as mentioned earlier, although sometimes the drainage pH increased significantly reaching a non-favourable pH mean value of 7.7 for strawberry cultivation. This increase could be justifiable because of the accumulation of catabolites/bicarbonates in the root environment, which washed out during leaching. Consequently, treating the drainage solution was essential, before reusing for the plants.

Pest management observations: Pest and diseases were controlled successfully by the means presented previously. Briefly, throughout the experiment, the major pests found were thrips and whiteflies. Their population rose up during May and this may be due to the higher temperature and humidity in the greenhouse. Thrips, whiteflies and leafminers were found on the lettuce of the horizontal setup, whereas on that of the vertical setup only thrips were detected. Thrips and mites were found on the strawberries of both systems.

Lettuce data: The leaf fresh weight of the horizontal system was much higher compared to that of the vertical setup, for all three lettuce cultivars (Table 1). However, this was not the case regarding leaf dry weight (%), where the vertical setup provided higher values. This may indicate the lower water intake and higher concentration of solutes by the vertical system's plants. On the vertical system, the fresh weight of the varieties 'Lollo rosa' and 'Oakleaf' diminished by ~45% whereas that of 'Paris island's' by 64%, possibly due to the excessive foliage and the bigger water needs. Comparing the root weight of 'Paris island', although there was no statistical difference in the root fresh weight, there was an increase in the root dry weight (%) similarly to the leaf dry weight.

The fresh leaf weight distribution along the grow-bag (Fig. 1A) for 'Lollo rosa' and 'Oakleaf' provided additional evidence for the water intake capability of the plants as a factor of their position. Therefore, the plants on the upper part of the bag with probably more nutrient solution availability had higher weights than the ones of the lower part. Although, also this trend hold for the leaf dry weight (%) of 'Oakleaf' (Fig. 1B), with the upper parts having more moisture content than the lower ones, there was no statistical difference in the leaf dry weight (%) of 'Lollo rosa'.

For lettuce, a crop with large water needs, the horizontal system provided bigger size and higher percentage of marketable yield than the vertical one in all the three cultivars (Table 1 and 2). Comparing the marketable lettuce (unit) per system's surface area, it was evident (Table 2) that although in horizontal system the percentage of the marketable quantity was higher; the vertical

Table 1. Lettuce plant fresh and dry weight in horizontal and vertical growing system for three cultivars

Cultivar	System	Leaf fresh weight (g)	Leaf dry weight (%)	Root fresh weight (g)	Root dry weight (%)
'Paris Island'	Horizontal	600a	3.40b	55.5a	9.62b
	Vertical	216b	5.71a	55.8a	11.6a
'Lollo rosa'	Horizontal	462a	3.86a	ND	ND
	Vertical	245b	3.90a	ND	ND
'Oakleaf'	Horizontal	428a	4.35b	ND	ND
	Vertical	241b	6.24a	ND	ND

ND: no data available. Means followed by the same letters within each cultivar in the same column are not significantly different, (Duncan's multiple range test $P \leq 0.05$)

Table 2. Marketable yield of lettuce cultivars in horizontal and vertical growing system (unit corresponds to one lettuce head)

Cultivar	System	Marketable quantity (%)	Yield (units m^{-2})
'Paris Island'	Horizontal	91.5	7.5a
	Vertical	64.6	31.0b
'Lollo rosa'	Horizontal	95.5	7.6a
	Vertical	77.9	37.0b
'Oakleaf'	Horizontal	92.7	7.34a
	Vertical	73.9	35.5b

Means followed by the same letters within each cultivar in the same column are not significantly different (Duncan's multiple range test $P \leq 0.05$).

Table 3. Nitrate and chloride concentrations of lettuce cultivars in horizontal and vertical growing system

Cultivar	System	NO_3 [mg (kg FW)$^{-1}$]	Cl (%)
'Paris Island'	Horizontal	445a	1.09a
	Vertical	375a	0.95a
'Lollo rosa'	Horizontal	2 277a	0.91a
	Vertical	2 033a	0.94a
'Oakleaf'	Horizontal	2 361a	0.97a
	Vertical	2 212a	0.69b

Means followed by the same letters within each cultivar in the same column are not significantly different (Duncan's multiple range test $P \leq 0.05$)

Table 4. Strawberry production characteristics in horizontal and vertical growing system

System	Fruit mass (g)	Fruits picked (units m^{-2})	Non-marketable fruits (units)	Auxiliary shoots (units)
Horizontal	15.3a	9.37a	0.53a	10a
Vertical	12.3a	21.8b	0.93b	4.25b

Means followed by the same letters in the same column are not significantly different (Duncan's multiple range test $P \leq 0.05$)

Table 5. Strawberry quality characteristics in horizontal and vertical growing system

System	pH	Ascorbic acid (vitamin C) (mg/100g FW)	Total anthocyanins [units OD (g FW)$^{-1}$]	Titratable acidity (% citric acid)	Soluble solids (% brix)
Horizontal	3.77a	39.7a	1.22a	0.79a	10.3a
Vertical	3.70a	44.2a	1.32a	0.82a	9.8a

Means followed by the same letters in the same column are not significantly different (Duncan's multiple range test $P \leq 0.05$)

Table 6. Strawberry flavour evaluation* in horizontal and vertical growing system

System	Size	Appearance	Firmness	Colour	Flavour	Aroma
Horizontal	4.3a	4.2a	3.8a	4.4a	4.3a	4.1a
Vertical	4a	4.3a	4.1a	4.3a	3.9a	4a

*Scale 1 (low) - 5 (high). Means followed by the same letters in the same column are not significantly different (Duncan's multiple range test $P \leq 0.05$)

system provided finally more marketable units m^{-2} for all cultivars, due to the better space utilization and compact setup.

Determination of the nitrate and chloride content of the lettuce cultivars from both systems indicated no differences in the NO_3 content (Table 3). For the chloride concentration, there were no differences, apart from 'Oakleaf', where the vertical plants had 0.69% Cl content compared to 0.97% of the horizontal system.

Strawberry data: Although the horizontal system produced slightly larger fruits (15.3 g) than the vertical system, however the difference was not significant (Table 4). However, the difference was significant regarding fruits picked, non-marketable fruits and auxiliary shoot formation between the two setups. There was a large difference in the number of fruits picked m^{-2} between the two systems (21.8 for the vertical and 9.37 for the horizontal), because of the larger population of strawberry plants in the vertical system (Table 4). This indicates that the vertical setup's produced higher yield due to better space utilization. Auxiliary shoot production was more than two times higher in the horizontal system (10 shoots per plant) compared to the plants in the vertical (4.25 shoots per plant) (Table 4). The lower auxiliary shoot production in the vertical system can be interpreted as fewer man-hours for the maintenance of the vertical setup's plants, compared to the pruning time needed for the horizontal plants.

There was no difference in fruit pH, ascorbic acid content, S.S.C. and titratable acidity between the two systems (Table 5). In accordance, strawberry flavour evaluation indicated no significant differences between the two systems (Table 6). Hence, no differences in flavour, aroma, colour, firmness, appearance, and size were found, indicating no consumer preference towards a specific cultivating system.

The vertical system under investigation performed well without any difficulties, providing higher marketable yield per system's surface area and proved to be suitable for the growth of crops like lettuce and strawberry. However, the horizontal system provided higher product fresh weight particularly in lettuce. The lower strawberry auxiliary shoot production in the vertical system can be interpreted as fewer man-hours for the maintenance of the

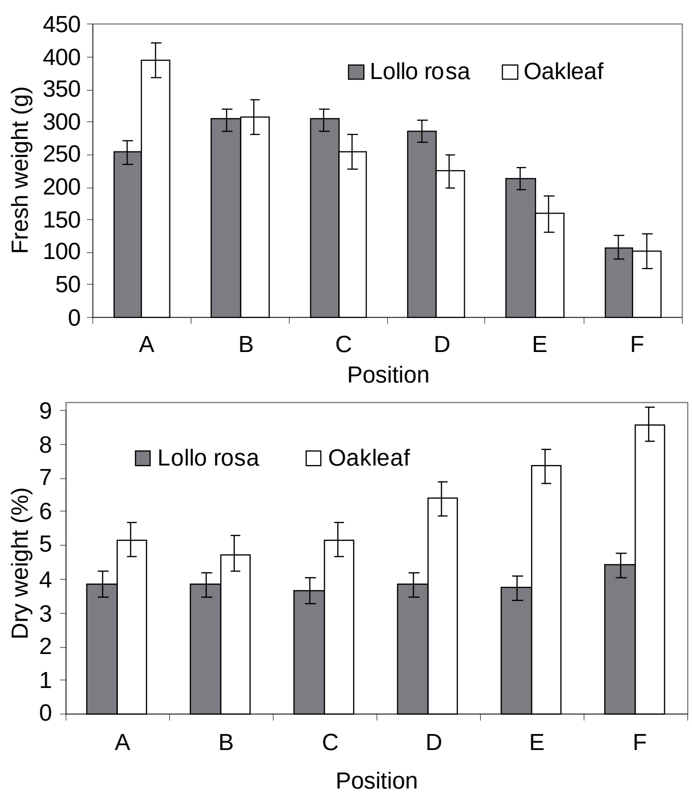

Fig. 1. (A) Fresh leaf weight distribution, and (B) dry leaf weight (%) distribution of 'Lollo rosa' and 'Oakleaf' along the grow-bag. Letters A through F indicate the sack's position, where A is the top sack and F the bottom one. SE bars are shown.

vertical setup's plants. For the strawberry, there was not any significant difference between qualitative characteristics for the two growing systems.

The obtained results suggest that the studied setups and the closed hydroponic system can be used as a sustainable system for the improvement of Cyprus greenhouse production, efficient water management and prevention of environmental damage from the frequent disposal of nutrient solution. Particularly, this system could be suitable for farmers with small greenhouse facilities. Moreover, it can be used in existing or future hydroponic facilities, particularly in areas proximal to vulnerable ecosystems, such as the rivers and coastline. Nevertheless, further studies should be conducted with other plants and substrates exploiting the system's capabilities for better adaptation by the agricultural community in the E. Mediterranean region.

Acknowledgement

This study was partially sponsored by the Cyprus Research Promoting Foundation (PENEK/ENTA 0509).

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Received: October, 2009; Revised: June, 2010; Accepted: October, 2010