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GROWING LETTUCE BY A FLOAT-SUPPORT NON-CIRCULATING HYDROPONIC METHOD IN HAWAII AND PENNYSLVANIA

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Abstract: Similar experiments were conducted in high tunnels at Volcano, Hawaii and State College, Pennsylvania. Styrofoam boards (61 x 122 cm) were configured to hold 12 lettuce plants in net pots. They floated on nutrient solution in a 14 cm deep tank and came to rest on 8, 10 and 12 cm diameter plastic pipes as nutrient solution was lost by evaporation and transpiration, thus creating 3 different heights of humidified air spaces. There were also continuously floating and fixed supported treatments. There was only an initial application of water and nutrients. Electrical power and pumps were not needed for aeration and circulation. Yields from semi-head, romaine and leafy cultivars were similar for the fixed supported, continuously floating and the float-support treatments in the Pennsylvania trials. The same was true for leafy and semi-head cultivars in the Hawaii trials. However, romaine lettuce yields were significantly lower in continuously floating and 8 cm float-support treatments than fixed supported and 10 and 12 cm float-support treatments in the Hawaii trials. Heads were allowed to develop to a larger size in the Hawaii trials, because bolting was not a serious threat in the cool upper elevation climate.

Introduction

The suspended pot, non-circulating hydroponic method is a powerful technique for growing lettuce, because the entire crop can be grown with only an initial application of water and nutrients, and electrical power and pumps are not needed for aeration and circulation (5, 6, 7). Plants grow in a 5 cm net pot containing growing medium which is supported by an expanded polystyrene cover held in a fixed position on top of the growing tank. The lower portion of the net pots are originally immersed in nutrient solution at planting or transplanting time, thus automatically watering the plants by capillary wetting of the growing medium in the net pots. The liquid level drops below the net pots as the plants grow such that the roots extend into the receding nutrient solution. This creates an expanding moist air space between the nutrient solution and the tank cover. Lettuce was successfully grown on expanded polystyrene rafts which floated on aerated nutrient solution in long rectangular tanks called raceways (3, 8). This innovation allowed planting from one end of the raceway and harvesting from the other end, because floating rafts could easily be moved on the frictionless nutrient solution surface. In addition to saving labor, this method also utilized space more efficiently because interior walk aisles were not needed. Lettuce yielded 19 per cent more when grown by the suspended pot method than when grown in a floating raft on a receding shallow depth (7.6 cm) of non-circulated and non-aerated nutrient solution (4). However, head weights were only 7% lower when the expanded polystyrene boards initially floated on the nutrient solution and then rested on a 5 cm high support during the latter stage of growth, thus increasing the moist air space for the roots. Crops growing in a 7.6 cm nutrient solution depth performed less consistently than those growing in 12.7 cm or deeper nutrient solution (9).

The purpose of this study was to compare a continuously floating non-circulating hydroponic method with a fixed support method and 3 float-support levels where an expanded polystyrene board initially floats on the surface of the nutrient solution and then comes to rest on plastic pipes when nutrient solution level decreases during the growth of the crop in a 14 cm deep tank at 2 locations with semi-head, romaine and leafy head cultivars.

Methods and Materials

Similar experiments were conducted in screened high tunnels at Volcano, Hawaii (1300 m elevation) and State College, Pennsylvania. Seeding, transplanting and harvest dates for Pennsylvania and Hawaii lettuce trials are detailed in Table 3. Raceway tanks were constructed (inside measurements of 1.22 m x 7.32 m x 14 cm deep) on a level surface by draping 0.15 mm-thick polyethylene over a lumber frame. Similar tanks with outside width measurements of 1.2 m were also constructed. Tanks were filled with water to overflowing. Equal amounts of 2 stock nutrient solutions were added once per crop prior to transplanting such that the EC (electrical conductivity) of the nutrient solution in the raceways ranged between 1.5 to 2.0 mS. One nutrient stock solution consisted of 120 grams of soluble greenhouse grade calcium nitrate per liter of water, and the other stock solution consisted of a mixture of 72 grams of magnesium sulfate and 120 grams of Chem-Gro 8-15-36 Lettuce Formula (Hydro-Gardens, Colorado) per liter of water. The Chem-Gro formulation also contained micronutrients. Large batches of stock solutions (95 liters) were stored in 2 opaque plastic trash containers and mixed prior to use. One preparation of these stock solutions was more than adequate for these trials. Two parallel lengths (1.8 m) of 8, 10 and 12 cm diameter plastic pipes were supported by the floor of the wider tanks and placed 0.9 m apart; a control treatment with no pipes was also included. Zip-lock bags filled with rocks were placed in the pipes to prevent them from floating. Blue, 1.3-cm (Hawaii) or 2.5-cm-thick (Pennsylvania) Styrofoam boards (61 x 122 cm) were designed to hold 12 plants. Holes were cut in a staggered arrangement at spacings of 20 x 30 cm to accommodate 5-cm net pots. Lettuce seedlings (7 to 15 days old, except 2 replicates of the Hawaii trial utilized 28-day-old romaine lettuce seedlings) were transplanted into 5-cm net pots filled with peat-perlite growing medium. The net pots were placed into the openings of the Styrofoam boards. The Styrofoam boards floated on the nutrient solution in the wider tank, because the nutrient solution was deeper than the heights of all of the support pipes. As nutrient solution was lost by evaporation and transpiration, the Styrofoam boards came to rest on the pipes - thus creating 3 different heights of humidified air spaces. There was also a continuously floating treatment with no pipe supports. A fixed supported treatment consisted of Styrofoam boards resting on the sides of the narrower tanks which were additionally supported by upside-down plastic pots to prevent sagging of the middle of the board. ‘Green Mignonette’ (semi-head), ‘Jericho’ (romaine) and ‘Red Sails’ (leafy) cultivars were grown in the Hawaii trials and ‘Adriana’ (semi-head), ‘Green Forest’ (romaine) and ‘Red Sails’ were grown in the Pennsylvania trials. At harvest time, the 1.22 m raceway was filled with water to allow floatation of the boards which were collected from one end of the raceway. Heads were removed and fresh weight data were collected. Net pots were removed, the boards were washed, fertilizer was added to the tanks and the newly replanted boards were floated back onto the raceway. Likewise, the support treatment was also harvested and replanted. The experiments were arranged as a split-plot randomized complete block in time (6 replications in Pennsylvania and 4 replications in Hawaii) with 12 plants per treatment.

Results and Discussion

Yields from 'Adriana' semi-head, 'Green Forest' romaine and 'Red Sails' leafy cultivars were similar for the fixed supported, continuously floating and the 3 float-support treatments in the Pennsylvania trials (Table 1). 'Red Sails' lettuce produced the largest head size (242 g) followed by 'Green Forest' (228 g) and 'Adriana' (162 g). The average head size for all treatments, cultivars and replicates was 211 g.

Table 1. Yields of 3 lettuce cultivars grown by a non-circulating hydroponic method in a State College, Pennsylvania high tunnel where the tank top cover was continuously suspended, continuously floating or floated at transplanting time and then supported by 8, 10 or 12 cm diameter pipes as the nutrient solution level receded during the growing period of the crop.

	Cultivars		
Top Cover Treatment	Red Sails	Green Forest	Adriana
		grams/plant	
Supported	244a[zy]	209a	166a
Continuously Floated	236a	230a	160a
Float-support on 8 cm pipe	235a	234a	157a
Float-support on 10 cm pipe	243a	231a	161a
Float-support on 12 cm pipe	251a	236a	164a
Ave.	242C	228B	162A

[z] Means followed by the same lower case letter within individual columns or capital letters within the last row are not significantly different ($P \leq .05$) by Duncan's Multiple Range Test.
[y]CV for error b which tested top cover treatment means was 11.30%.

'Red Sails' leafy lettuce and 'Green Mignonette' semi-head lettuce yields were also similar for the fixed supported, continuously floating and the 3 float-support treatments in the Hawaii trials (Table 2). However, 'Jericho' romaine lettuce yields were significantly lower in the continuously floating and the 8 cm float-support treatment than the fixed supported and 10 and 12 cm float-support treatments. 'Jericho' produced the largest heads (492 g) followed by 'Red Sails (375 g) and 'Green Mignonette' (309 g). The average head size for all treatment, cultivars and replicates was 392 grams.

Table 2. Yields of 3 lettuce cultivars grown by a non-circulating hydroponic method in a Volcano, Hawaii high tunnel where the tank top cover was continuously suspended, continuously floating or floated at transplanting time and then supported by 8, 10 or 12 cm diameter pipes as the nutrient solution level receded during the growing period of the crop.

	Cultivars		
Top Cover Treatment	Red Sails	Jericho	Green Mignonette

		grams/plant	
Supported	398a [z,y]	551b	303a
Continuously Floated	350a	398a	304a
Float-support on 8-cm pipe	353a	409a	311a
Float-support on 10-cm pipe	386a	515b	321a
Float-support on 12 cm pipe	388a	586b	307a
Ave.	375B	492C	309A

[z] Means followed by the same lower case letter within individual columns or capital letters within the last row are not significantly different ($P \leq .05$) by Duncan's Multiple Range Test.
[y] CV for error b which tested top cover treatment means was 11.95%.

Jensen and Malter (2) suggested that plants produce small fluffy roots in the air space between a polystyrene board and the nutrient solution and these roots absorb much of the required oxygen for the plant since the dissolved oxygen levels in the nutrient solution are often low. Tyson et al (10) reported that plant performance was improved by doubling 1.9-cm thick floating panels. This would provide more air space than a single layer. The Pennsylvania trials employed 2.5-cm thick Styrofoam board as compared to Hawaii's 1.3-cm boards and this increased the moist air root zone in the Pennsylvania trials. The combination of large 'Jericho' heads in the Hawaii trial with a thin floating board created a situation of large oxygen demand and an insufficient root zone in moist air with the floating treatment. The air space was increased with the fixed support and 10 and 12 cm float-support treatments and this resulted in higher yields. The current Hawaii and Pennsylvania studies utilized 14-cm deep tanks which should have improved growth consistency (10) as compared to a previous Hawaii study utilizing 7.6 cm of nutrient solution (4).

The total time from seeding to harvesting ranged between 42 and 48 days for the Pennsylvania trials and 55 and 59 days for the Hawaii trials excepting for 'Jericho' which was allowed an additional 13 days in replicates 3 and 4 (Table 3). The time in the growing tanks from transplanting to harvest ranged from 28 to 39 days in the Pennsylvania trials and 40 to 52 days in the Hawaii trials. The cooler temperatures in Hawaii greatly reduced the risk of bolting and these crops were allowed to grow for a longer time than the Pennsylvania trials. This resulted in larger head weight in the Hawaii trials. For example, 'Red Sails' leafy lettuce was grown at both locations and was 133 grams heavier at the Hawaii location. In retrospect, it would have been prudent to terminate the Hawaii trials, perhaps, a week earlier. For example, there was no tipburn a week prior to harvest in replicates 3 and 4, but there was significant tipburn in 'Green Mignonette' and 'Jericho' at harvest time. Also,'Jericho' exhibited light yellow leaves a week prior to harvest and this was exacerbated at harvest time.

Average head weights for replicates 3 and 6 in the Pennsylvania trials were lower than the other 4 replicates. Replicate 3 was harvested slightly early because warm August weather conditions increased the risk of bolting. It was prudent to terminate replicate 6 early, because lettuce (especially 'Red Sails') had developed an early aphid infestation.

Daily high ambient temperatures for the Pennsylvania trials ranged between 10 ^{o}C and 33 ^{o}C with an average high temperature of 25 ^{o}C. The ambient daily low temperatures ranged from 0 ^{o}C to 20 ^{o}C with an average low of 12 ^{o}C. Daily high ambient temperatures for the Hawaii trials ranged from 15 ^{o}C to 23 ^{o}C with an average high temperature of 19 ^{o}C. The daily low Hawaii temperatures ranged from 6 °C to 17 °C with an average daily low temperature of 11°C. The daily high Pennsylvania temperatures were more variable and the average daily high was 6 °C higher than respective Hawaii temperatures. The Pennsylvania daily low temperatures were also more variable and the average daily low temperature was 1 °C higher than the respective Hawaii temperature.

Daily high temperatures in the Pennsylvania tunnel were about 2 °C higher than ambient high temperatures. Daily high temperatures in the Hawaii tunnel were about 7 °C higher than ambient temperatures. This difference may be partially explained by more windy conditions at the Pennsylvania site. Daily low temperatures in the Pennsylvania high tunnels were similar to ambient temperatures. However, daily low temperatures in the Hawaii tunnel were 1.2 °C lower than respective ambient low temperatures.

Temperatures of nutrient solution in the Pennsylvania growing tanks ranged between 15 and 24°C from August 23 through October 16. Daily variations between high and low temperatures typically remained in a 2°C range and never exceeded 3.4°C. The Styrofoam boards greatly insulated the nutrient solution from air temperatures in the tunnel which ranged from 1°C to 35°C during this period.

Total fertilizer application to the Pennsylvania trial was 26.65 liters each of stock solutions “A” and “B”. Stock solution and water were added to the remainder of the previous crops; this might be referred to as ‘topping off’. Electrical conductivity readings were used to calculate stock solution application rates in subsequent crops. The stock solution applications contained 752 g N (or 0.70 g N/plant) plus all of the accompanying nutrients. This is equivalent to an application rate of 3.3 g N/kg of lettuce which is an efficient use of N and the accompanying nutrients. In addition, the EC of the nutrient solutions remaining after the final harvest in each tank ranged from 1.7 to 2.5 mS. Thus, approximately one-sixth of the total applied nutrients remained unused. At some point, tanks should be drained and refilled with fresh nutrient solution, but it appeared that topping off from the previous crop was acceptable at least for the 3 consecutive crops in each tank for these trials.

Water consumption was very efficient with this growing method and ranged from 18 to 32 liters of water/kg of lettuce in the Pennsylvania trials and only 11 to 14 liters/kg of lettuce from the Hawaii trials (Table 3). The Pennsylvania location had warmer and windier conditions than the upper elevation Hawaii site. The lowest water efficiency occurred during the July 31 to Aug 28 cropping period in Pennsylvania. Replicates 1, 3 and 5, located on the left side of the Pennsylvania high tunnel, which were more proximate to the predominating winds, consumed more moisture than replicates 2, 4 and 6 on the calmer, right side of the structure. The highest moisture loss occurred from transpiration in the last 2 weeks of the cropping period when the plants had the most foliage. Evaporation losses were minimal from the small surface area contained by the net pots and uncovered perimeters of the tank cover.

Net pots from the continuously floating and 8 cm float-support treatments pots were more difficult to remove from the board than the other treatments, because roots tended to adhere to the bottom of the Styrofoam boards. Growing lettuce in a high tunnel can extend the growing season in a cool climate and produce cleaner, high quality heads (9). Disease pressure is minimized, because the foliage is kept dry and sterile growing medium is employed. For example, there were no instances of botyritis, rhizoctonia, sclerotinia or nematode damage in trials at both locations. Older plants have more potential for developing aphid, thrips and other insect populations. Thus, it is advisable to start seedlings in a location other than the seedling house and to harvest crops sooner rather than later.

Mosquitoes can breed in non-circulating nutrient solution and become both a health menace and a nuisance to workers. Mosquitoes were not a problem at the cool, high elevation Hawaii location or the relatively dry and windy Pennsylvania location. Mosquitoes can be controlled by *Bacillus thuringiensis subspecies israelensis* toxins, pesticides (1) or by salt-tolerant fish.

A beginning grower who wishes to use a floating production method on receding, non-circulated and non-aerated nutrient solution would be advised that: 14 cm deep tanks should be filled with nutrient solution (1.5 to 2.0 mS) prior to transplanting and no additional water or fertilizer should be applied to the crop, 7 to 15 day-old seedlings should be transplanted into 5-cm net pots which are supported by Styrofoam boards (2.5 cm thick) either continuously floating or preferably coming to rest on a 10-cm support prior to harvesting and it is preferable to harvest smaller heads (150 to 250 grams) rather than overly large heads. The continuing grower will find benefits from refinement of production methodology with particular emphasis given to cultivars, climate, daylength and season.

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Table 3. Seeding, transplanting and harvest dates, days from transplanting to harvest, average lettuce head weight and water consumption by replicate (averaged over all treatments and cultivars) in non-circulating hydroponic trials conducted in high tunnels at State College, Pennsylvania and Volcano, Hawaii.

Replicate	Seeded	Transplanted	Harvested	Transpl-Harvest	Avg Hd Wt.	Water Consumption
	-------------date (2007)-------------			days	grams	liters/kg
State College, PA						
1	June 13	June 22	July 31	39	228	23
2	June 26	July 9	August 7	29	245	20
3	July 17	July 31	August 28	28	169	32
4	July 30	August 7	September 11	35	232	18
5	August 17	August 28	October 2	35	236	23
6	September 2	September 11	October 16	35	154	19
Volcano, HI						
1&2	March 27	April 3	May 25	52	367	13
					394	13
3&4	August 3[z]	August 31	October 10		397	14
	August 16[y]	August 31	October 10	40	405	11

[z] (Jericho only)

[y] Green Mignonette and Red Sails