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Yield and growth of Pak Choi and Green Oak vegetables grown in substrate plots and hydroponic systems with different plant spacing

Wiangsamut, B.* **and Koolpluksee, M.**

Department of Crop Production and Landscape Technology, Faculty of Agro-Industrial Technology, Rajamangala University of Technology Tawan-Ok Chanthaburi Campus, Chanthaburi 22210, Thailand.

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Abstract The yields of Pak Choi and Green Oak vegetables grown in deep flow technique hydroponic system with narrow plant spacing of 10 cm x 12 cm (HydroDFT10x12) were significantly higher than those vegetables grown in other planting systems with different plant spacings. The yield of Pak Choi grown in HydroDFT10x12 was the highest due to the highest plant density that compensated for the low fresh weight per plant, narrow canopy diameter, and low number of leaves per plant. Green Oak grown in HydroDFT10x12 had the second highest yield due to high plant density, high fresh weight per plant, highest canopy diameter, high number of leaves per plant, and tallest plant height. Yields of Green Oak grown in Sub20x25 (substrate plot with wide plant spacing of 20 cm x 25 cm) and HydroNFT20x25 (nutrient film technique hydroponic system with wide plant spacing of 20 cm x 25 cm) were lower than in other treatments caused by the lowest plant density. Pak Choi had significantly higher yield than Green Oak, as Pak Choi grown with higher plant density compensated for its lower canopy diameter, light fresh weight per plant, and lesser number of leaves per plant. Plant density was the main factor for the higher yield of Pak Choi. HydroDFT10x12 gave the significantly highest yield, which was higher than Sub20x25, Sub10x12 (substrate plot with narrow plant spacing of 10 cm x 12 cm), HydroNFT20x25, and HydroDFT20x25 (deep flow technique hydroponic system with wide plant spacing of 20 cm x 25 cm), due to the highest plant density, widest canopy diameter, tallest plant height, and high fresh weight per plant as indicated by positive values of the correlation coefficients. Therefore, the HydroDFT10x12 is the most suitable planting system for producing Pak Choi and Green Oak vegetables.

Keywords: Substrate culture, Deep flow technique, Plant spacing, Pak Choi, Green Oak

Introduction

The Chinese cabbage cultivar "Pak Choi" (*Brassica chinensis* L. var. *chinensis* Mansf.) and lettuce cultivar "Green Oak" (*Lactucasativa* L. var.

* **Corresponding Author:** Wiangsamut, B.; **Email:** timbancha@yahoo.com, bancha_wi@rmutto.ac.th, bancha24217@gmail.com

crispa) are the most popular vegetables in Thailand (BAC, 2014; NRCS, n.d.; AKA, 2003). The total vegetable growing area is about 0.176–0.288 million hectares per year, with the total yield of 1.8–2.8 million tonnes. Thais consume vegetables more than 45 kilograms per capita per year (Tongaram, 2004).

Some of these consumed vegetables are derived from soilless culture, particularly the substrate culture and hydroponic systems such as nutrient film technique (NFT) and deep flow technique (DFT) (Nuntagij, 2000; Khamwongsa, 2010). Substrate culture is the use of planting media substituted for soils in which plants can grow normally as they do when grown in soils. Wiangsamut *et al*. (2016) reported that the planting medium of rice husk ash: sand: cow dung (1:1:1) gave the tallest plants and highest fresh weight of new tubers of "Thao Yai Mom" (*Tacca leontopetaloides* Ktze.) compared with the other planting media. NFT and DFT are the recirculating hydroponic systems where the nutrient solution flows down to a set of gullies, and flows down to a larger growing bed containing a deep flow of solution, respectively (Wiangsamut, 2016). Yield quantity, crop duration, and labor can be managed effectively and efficiently in NFT and DFT systems (Thongket, 2001).

Somboonya (2005) and Sompituk (2005) reported that the growth of Pakchoy (*Brassica chinensis* L. var. *chinensis*) is the best in NFT system with plant spacing of 25 cm x 25 cm due to its widest and highest number of leaves, tallest plants, highest total weight, and highest edible plant parts. Thai planters prefer to grow more hydroponics vegetables (Maneepong *et al*., 2011). Most of soilless producers grow Pak Choi (or Pakchoy) and Green Oak vegetables in accordance with the recommended plant spacing of 20 cm x 25 cm with only one seedling per hill. This may be due to the unchanging yield and insufficient quantity of vegetables to meet consumers' demand with the increasing population growth. Increasing yield per unit of growing area by reducing plant spacing may be the way to solve the scarcity of vegetables. It is important to arrange the appropriate soilless culture system with plant spacing to match the different types of vegetables. This may help achieve better plant growth and obtain higher yields.

The study aimed to compare yields and growth of Pak Choi and Green Oak vegetables grown in different substrate plots, nutrient film technique (NFT) and deep flow technique (DFT) hydroponic systems with narrow and wide plant spacing.

Materials and methods

The experiment was conducted at the experiment station of the Department of Crop Production and Landscape Technology, Faculty of Agro-Industrial Technology at Rajamangala University of Technology Tawan-Ok

Chanthaburi Campus in Chanthaburi Province, Thailand from October 28, 2014 to December 30, 2014. The experiment was laid out in a split plot design with an arrangement of randomized complete block design (RCBD), replicated four times. The planting system with plant spacing was assigned to be the main plot treatments comprised of: 1) substrate plot with wide plant spacing of 20 cm x 25 cm (Sub20x25); 2) substrate plot with narrow plant spacing of 10 cm x 12 cm (Sub10x12); 3) NFT hydroponic system with wide plant spacing of 20 cm x 25 cm (HydroNFT20x25); 4) DFT hydroponic system with narrow plant spacing of 10 cm x 12 cm (HydroDFT10x12); and 5) DFT hydroponic system with wide plant spacing of 20 cm x 25 cm (HydroDFT20x25). The vegetables were assigned as the subplot treatments. The vegetables grown were Pak Choi and Green Oak.

Sixteen substrate plots were prepared by horizontally stacking two layers of bricks on top of each other (brick size of 12.5 cm x 25.0 cm x 10.0 cm) to form a plot. Each plot size was 1.20 m wide x 6.00 m long x 0.20 m tall. The prepared planting medium (mixture of sand, rice husk ash, coconut coir, and cow dung with a ratio of 1:1:1:1 by volume) was then placed on each substrate plot with a 0.15 m height, and no material was placed under planting medium to prevent the loss of water and nutrients through seepage and percolation. Planting holes were made on the substrate surface with a plant spacing of 20 cm x 25 cm for eight plots, and with a plant spacing of 10 cm x 12 cm for other eight plots. Then, a minisprinkler was installed in each plot for irrigation supply within a protected cultivation shade house (with plastic roof of 7% UV protection). Likewise, the NFT and DFT hydroponic systems were in a protected cultivation shade house (with a plastic roof of 7% UV protection) to prevent damage from the rain during the early rainy season. Eight sets of NFT hydroponic tables were prepared; each table had 1.2 m wide x 6.0 m long, plant spacing of 20 cm x 25 cm, eight gullies/table, 24 holes/gully along with 8 pieces of 35-watt submersible pumps (one submersible pump/table). Twelve sets of DFT hydroponic tables were prepared; each table had a larger bed of 1.2 m wide x 6.0 m long with plant spacing of 10 cm x 12 cm for eight tables, and plant spacing of 20 cm x 25 cm for another 8 tables, along with 16 pieces of 35-watt submersible pumps (one submersible pump/table). Nine-day old seedlings of Pak Choi and Green Oak were pulled out from the seedling medium trays then were transplanted to the prepared holed substrate plots; two seedlings of Pak Choi/hole or two seedlings/hill, and one seedling of Green Oak/hill. Nine-day old seedlings from the planting sponge were transplanted to the planting pots into the prepared NFT and DFT hydroponic tables, two seedlings of Pak Choi/hill and one seedling of Green Oak/hill.

Water was applied twice a day, from 0600H to 0630H and from 1700H to 1730H in the substrate culture plots, until the plants reached their physiological maturity stage. Urea [CO $(NH_2)_2$] (46% N) and 16-16-16 chemical fertilizer (16%N, 16%P_2O_5, and 16%K_2O) were mixed at a ratio of 1:1 by weight, then the mixture was applied to the vegetables at the rate of 250 kg/ha (159 kg N/ha, 256 kg P_2O_5/ha, and 40 kg K_2O/ha). This was equally applied in five splits (50 kg/split) at 14, 19, 24, 29, and 34 days after sowing or 5, 10, 15, 20, and 25 days after transplanting.

The nutrient solutions A and B were pumped within a holding container through PVC pipes at the top of every sloping gully and the runoff from the bottom of the gullies was returned to the container. The nutrient solution A was applied in a container a day after transplanting; then after 4 hours, the solution B was also added. The electrical conductivity (EC) of the mixed nutrient solutions (A and B) diluted in water was adjusted to the threshold of 0.91–1.53 dS/m using an EC meter, and the pH was adjusted to the threshold of 5.4–6.9 with a pH meter for the entire growing crop duration, except 3 days before harvesting. These mixed nutrient solutions were drained and substituted with clean water to reduce the nitrate accumulation in the vegetables. The total nutrient solution used for the entire growing period of cropping season for NFT was 0.77 L/table for each solution, and 5.34 L for each solution in DFT. Hand weeding was done in substrate culture plots when required. No insects were found and no diseases occurred in substrate culture plots, NFT and DFT hydroponic systems, as the vegetables were grown under the protected cultivation shade house.

Vegetable samples were taken to determine their yields and growth parameters (plant height, number of leaves per plant, canopy diameter and fresh weight per plant) at the maturity stage, 46 days after sowing or 37 days after transplanting. With these, 40 plant samples of Pak Choi and 20 plant samples of Green Oak were taken to determine the yield and fresh weight per plant; whereas for plant height, number of leaves per plant, and canopy diameter, 8 plant samples of Pak Choi and 4 plant samples of Green Oak were taken. Yield was measured by weighing all the taken plant samples in a unit of kilogram per square meter, then the unit was converted to a unit of kilogram per hectare (kg/ha). For plant height, first, the plant leaves, were stretched, then measured from the stem base to the highest plant tip by a ruler in centimeters (cm). Number of leaves per plant was counted for all fully expanded leaves per plant (leaves/plant). Canopy diameter was measured by a vernier caliper through the widest vegetable canopy diameter position from a canopy edge on one side to the edge of the other side in centimeters (cm). Plant density was measured by counting the number of plants in one square meter and expressed as number of plants per square meter (plants/m^2). Fresh weight was weighed on each plant and computed for average fresh weight per plant in grams per plant (g/plant).

All plant parameters were statistically analyzed through the software Statistix 7 (SXW) except plant density since it is fixed. Means comparisons were done using the Duncan's Multiple Range Test (DMRT) at the 0.05 probability level. Relationships among all plant parameters were established through correlation analysis.

Results

Yield

The significantly highest yield was in HydroDFT10x12 (52,582 kg/ha), followed by the yields of Sub10x12 (27,244 kg/ha), HydroNFT20x25 (18,547 kg/ha), HydroDFT20x25 (15,144 kg/ha), and Sub20x25 (13,763 kg/ha) (Table 1). Yield of Pak Choi (30,042 kg/ha) was significantly higher than that of Green Oak (20,870 kg/ha). Yield was influenced by the planting system with plant spacing as the yields of Pak Choi (55,825 kg/ha) and Green Oak (49,338 kg/ha) in HydroDFT10x12 were significantly higher than those in other planting systems with narrow and wide plant spacings.

Table 1. Yield (kg/ha)

Planting System and Plant Spacing (PS)	Vegetable (V)		Mean[/2]
	Pak Choi	Green Oak	
Sub20x25	18,763d[/1]	8,763e	13,763c
Sub10x12	33,888b	20,600cd	27,244b
HydroNFT20x25	29,369bc	7,725e	18,547c
HydroDFT10x12	55,825a	49,338a	52,582a
HydroDFT20x25	12,363de	17,925de	15,144c
Mean[/3]	30,042a	20,870b	

[1/] In the table of PS X V means with the same letter is not significantly different at the 0.05 probability level (DMRT).

[2/] In the column of PS means with the same letter is not significantly different at the 0.05 probability level (DMRT).

[3/] In the row of V means with the same letter is not significantly different at the 0.05 probability level (DMRT).

The second highest yield was Pak Choi in Sub10x12 (33,888 kg/ha), followed by Pak Choi in HydroNFT20x25 (29,369 kg/ha), Green Oak in Sub10x12 (20,600 kg/ha), Pak Choi in Sub20x25 (18,763 kg/ha), Green Oak in HydroDFT20x25 (17,925 kg/ha), Pak Choi in HydroDFT20x25 (12,363 kg/ha), Green Oak in Sub20x25 (8,763 kg/ha), and Green Oak in HydroNFT20x25 (7,725 kg/ha) (Table 1).

Plant height

Plants in HydroDFT10x12 (29.6 cm) were significantly taller than those in Sub20x25 (20.6 cm), Sub10x12 (20.5 cm), HydroNFT20x25 (22.3 cm), and HydroDFT20x25 (20.7 cm) while plant heights in the latter four plant systems together with different plant spacings were not significantly different (Table 2). Plant height of Pak Choi (23.0 cm) did not differ significantly with that of Green Oak (22.4 cm) (Table 2). Plant height was influenced by the planting system with plant spacing and vegetable as Green Oak grown in HydroDFT10x12 had the significantly tallest plants (34.3 cm), followed by Pak Choi in HydroNFT20x25 (26.8 cm), Pak Choi in HydroDFT10x12 (24.9 cm), Pak Choi in 10x12 (22.3 cm), Green Oak in HydroDFT20x25 (21.5 cm), Pak Choi in Sub20x25 (21.1 cm), Green Oak in Sub20x25 (20.1 cm), Pak Choi in HydroDFT20x25 (19.9 cm), and Green Oak in Sub10x12 (18.6 cm), and Green Oak in HydroNFT20x25 (17.7 cm).

Table 2. Plant height (cm)

Planting System and Plant Spacing (PS)	**Vegetable (V)**		**Mean[/2]**
	Pak Choi	**Green Oak**	
Sub20x25	21.1bcd[/1]	20.1cd	20.6b
Sub10x12	22.3bcd	18.6d	20.5b
HydroNFT20x25	26.8b	17.7d	22.3b
HydroDFT10x12	24.9bc	34.3a	29.6a
HydroDFT20x25	19.9cd	21.5bcd	20.7b
Mean[/3]	23.0a	22.4a	

[1/] In the table of PS X V means with the same letter is not significantly different at the 0.05 probability level (DMRT).
[2/] In the column of PS means with the same letter is not significantly different at the 0.05 probability level (DMRT).
[3/] In the row of V means with the same letter is not significantly different at the 0.05 probability level (DMRT).

Number of leaves per plant

The highest number of leaves per plant was in HydroDFT20x25 (20.7), followed by those in HydroNFT20x25 (18.9), HydroDFT10x12 (17.7), Sub20x25 (14.8) and Sub10x12 (12.1) (Table 3). Green Oak had the significant highest number of leaves (21), higher than that of Pak Choi (12.6) (Table 3). Number of leaves was influenced by the planting system with plant spacing and vegetable, as indicated by the number of leaves for Green Oak in any planting system with narrow and wide plant spacings being higher than that for Pak Choi in the same planting system with same plant spacings. The number of leaves for Green Oak in HydroDFT20x25 was the highest (28.5) while it was the lowest (9.5) for Pak Choi in Sub10x12.

Table 3. Number of leaves per plant (leaves/plant)

Planting System and Plant Spacing (PS)	Vegetable (V)		Mean[2]
	Pak Choi	Green Oak	
Sub20x25	11.6ef[1]	18.0bcd	14.8c
Sub10x12	9.5f	14.7def	12.1d
HydroNFT20x25	16.7cde	21.1bc	18.9ab
HydroDFT10x12	12.4ef	22.9b	17.7b
HydroDFT20x25	12.9def	28.5a	20.7a
Mean[3]	12.6b	21.0a	

[1/] In the table of PS X V means with the same letter is not significantly different at the 0.05 probability level (DMRT).
[2/] In the column of PS means with the same letter is not significantly different at the 0.05 probability level (DMRT).
[3/] In the row of V means with the same letter is not significantly different at the 0.05 probability level (DMRT).

Canopy diameter

Canopy diameter was not significantly different among planting systems with different plant spacings, ranging from 19.2 cm to 21.3 cm, except in Sub10x12 as it obtained the significantly narrowest canopy diameter at 15.5 cm (Table 4). Canopy diameter for Green Oak was, 21.4 cm, significantly wider than that for Pak Choi, 17.5 cm. Canopy diameter was influenced by the interaction between planting system with plant spacing and vegetable, as shown by Green Oak grown in HydroDFT10x12 had the significant widest canopy diameter at 25.3 cm, followed by Pak Choi in HydroNFT20x25 (22.9 cm), Green Oak in HydroDFT20x25 (22.8 cm), Green Oak in Sub20x25 (21.4 cm), Green Oak in HydroNFT20x25 (18.9 cm), Green Oak in Sub10x12 (18.5 cm), Pak Choi in HydroDFT20x25 (18.0 cm), Pak Choi in HydroDFT10x12 (17.3 cm), Pak Choi in Sub20x25 (16.9 cm), and Pak Choi in Sub10x12 (12.5 cm).

Table 4. Canopy diameter (cm)

Planting System and Plant Spacing (PS)	Vegetable (V)		Mean[2]
	Pak Choi	Green Oak	
Sub20x25	16.9ef[1]	21.4abcd	19.2a
Sub10x12	12.5f	18.5cde	15.5b
HydroNFT20x25	22.9ab	18.9bcde	20.9a
HydroDFT10x12	17.3de	25.3a	21.3a
HydroDFT20x25	18.0de	22.8abc	20.4a
Mean[3]	17.5b	21.4a	

[1/] In the table of PS X V means with the same letter is not significantly different at the 0.05 probability level (DMRT).
[2/] In the column of PS means with the same letter is not significantly different at the 0.05 probability level (DMRT).
[3/] In the row of V means with the same letter is not significantly different at the 0.05 probability level (DMRT).

Plant density

Plant density in the planting systems with the narrow plant spacings (Sub10x12 and HydroDFT10x12) was noticeably higher at 125 plants/m^2 than those in the planting systems with the wide plant spacings (Sub20x25, HydroNFT20x25, and HydroDFT20x25) at 30 plant/m^2 (Table 5). Plant density for Pak Choi (91 plant/m^2) was appreciably higher than that for Green Oak (45 plant/m^2) as Pak Choi were transplanted in the plots with two seedlings/hill while it was only one seedling/hill for Green Oak (Table 5). Plant density for Pak Choi in Sub10x12 and HydroDFT10x12 was both the highest at 167 plants/m^2; followed by Green Oak in Sub10x12 and HydroDFT10x12 at 83 plants/m^2; Pak Choi in Sub20x25, HydroNFT20x25 and HydroDFT20x25 with 40 plants/m^2; and Green Oak in Sub20x25, HydroNFT20x25, and HydroDFT20x25 with 20 plants/m^2.

Fresh weight per plant

The significantly highest fresh weight per plant was found in HydroDFT20x25 at 97.5 g/plant; followed by HydroNFT20x25 (90.7 g/plant), HydroDFT10x12 (75.0 g/plant), Sub20x25 (73.4 g/plant), and Sub10x12 (36.5 g/plant) (Table 6). Fresh weight per plant of Green Oak at 82.8 g/plant was significantly higher than that of Pak Choi with 66.4 g/plant (Table 6). Fresh weight per plant was influenced by the planting system with plant spacing and vegetable as Green Oak in HydroDFT20x25 was the heaviest (145 g/plant), followed by Pak Choi in HydroNFT20x25 (118.8 g/plant), Green Oak in HydroDFT10x12 (95.8 g/plant), Pak Choi in Sub20x25 (75.9 g/plant), Green Oak in Sub20x25 (70.9 g/plant), Green Oak in HydroNFT20x25 (62.5 g/plant), Pak Choi in HydroDFT10x12 (54.2 g/plant), Pak Choi in HydroDFT20x25 (50.0 g/plant), Green Oak in Sub10x12 (40.0 g/plant), and Pak Choi in Sub10x12 (32.9 g/plant) (Table 6).

Table 5. Plant density (plants/m^2)

Planting System and Plant Spacing (PS)	Vegetable (V)		Mean
	Pak Choi	**Green Oak**	
Sub20x25	40	20	30
Sub10x12	167	83	125
HydroNFT20x25	40	20	30
HydroDFT10x12	167	83	125
HydroDFT20x25	40	20	30
Mean	91	45	

Table 6. Fresh weight per plant (g/plant)

Planting System and Plant Spacing (PS)	Vegetable (V)		Mean[/2]
	Pak Choi	Green Oak	
Sub20x25	75.9cd[/1]	70.9cd	73.4c
Sub10x12	32.9f	40.0ef	36.5d
HydroNFT20x25	118.8ab	62.5de	90.7ab
HydroDFT10x12	54.2def	95.8bc	75.0bc
HydroDFT20x25	50.0def	145.0a	97.5a
Mean[/3]	66.4b	82.8a	

[1/] In the table of PS X V means with the same letter is not significantly different at the 0.05 probability level (DMRT).
[2/] In the column of PS means with the same letter is not significantly different at the 0.05 probability level (DMRT).
[3/] In the row of V means with the same letter is not significantly different at the 0.05 probability level (DMRT).

Relationships of number of leaves per plant, plant density, canopy diameter, plant height, fresh weight per plant, and yield

Plant density was negatively associated with number of leaves per plant, canopy diameter, and fresh weight per plant as indicated by the negative values of correlation coefficients with r=−0.52, r=−0.51 and r=−0.50 (Table 7). This means that as plant density increased, the number of leaves, canopy diameter, and fresh weight per plant declined. Canopy diameter was positively associated with the number of leaves (r=0.73) and plant height (r=0.42). This means that as canopy diameter increased, the number of leaves and plant height also increased.

Table 7. Relationships of number of leaves per plant, plant density, canopy diameter, plant height, fresh weight per plant, and yield

	Number of leaves per plant	Plant density	Canopy diameter	Plant height	Fresh weight per plant
Plant density	r =−0.52				
Canopy diameter	r =0.73	r =−0.51			
Plant height	r =0.15	r =0.26	r =0.42		
Fresh weight per plant	r =0.70	r =−0.50	r =0.67	r =0.34	
Yield	r =−0.15	r =0.77	r =0.03	r =0.70	r =0.03

Note: r is correlation coefficient

Plant density was positively associated with plant height (r=0.26) and yield (r=0.77), which means that as plant density increased, plant height and yield also increased. Plant height was positively associated with number of leaves per plant (r=0.15), and fresh weight per plant (0.34), which indicated that as plant height increased, the number of leaves and fresh weight per plant also increased. In addition, as the number of leaves per plant and canopy diameter increased, fresh weight per plant also increased, as indicated by the positive values of correlation coefficient with r=0.70 and r=0.67, respectively.

Yield was positively associated with plant density, canopy diameter, plant height, and fresh weight per plant, but it was negatively associated with the number of leaves per plant as indicated by the values of correlation coefficient with r=0.77, r=0.03, r=0.70, r=0.03, and r=−0.15 (Table 7). This means that as plant density, canopy diameter, plant height, and fresh weight per plant increased, yield also increased, but as number of leaves declined, yield increased.

Discussion

Plants grown in deep flow technique (DFT) hydroponic system with narrow spacing of 10 cm x 12 cm (HydroDFT10x12) were taller than those in other planting systems with different plant spacings. In general, plant height was directly related to canopy height. According to Wiangsamut *et al.* (2006), the two rice hybrids had higher canopy height than the other three rice genotypes; this led to more favorable light penetration and better air circulation leading to higher CO_2 concentration inside the canopy, which was due to the wider space between the leaves of the rice plants. The taller plant height with the higher plant density could have an optimum leaf area index (LAI) to capture better light for photosynthesis to produce more assimilates partitioning to all the sink parts of the plant communities and consequently obtained the higher yield in HydroDFT10x12 and Sub10x12 as compared with other planting systems with different plant spacings which was indicated by the positive values of the correlation coefficients.

With these results, plant density and plant height are shown to be the important keys for the higher yields of vegetables. The results correspond with those of Muranyi and Pepo (2013) who reported that by increasing plant density, plant height of the individual plant also increases. The number of leaves per plant in DFT hydroponic system with wide plant spacing of 20 cm x 25 cm (HydroDFT20x25) was found to be the highest while in substrate culture with narrow plant spacing of 10 cm x 12 cm (Sub10x12) was the lowest. Wide plant spacings contributed to having more number of leaves per plant resulting in a wider leaf area to intercept the sunlight for photosynthesis and consequently more assimilates produced and accumulated into the plant, resulting in a heavier weight per plant compared with those vegetables in narrow plant spacings (Decoteau and Graham, 1994).

Higher fresh weight per plant with wide plant spacings in HydroDFT20x25 and HydroNFT20x25 could not compensate with their lower plant densities and consequently lower yields. Fresh weight per plant was the lowest in substrate culture with narrow plant spacing of 10 cm x 12 cm (Sub10x12) but it obtained the second highest yield as it had also high plant density. Detpiratmongkol *et al*. (2008) similarly reported that the narrowest plant spacing of 50 cm x 50 cm decreased stem dry weight, corm, and total dry weight per plant of Chinese water chestnut compared with other wide plant spacings; however its corm yield of 50 cm x 50 cm spacing was the highest while the 100 cm x 100 cm spacing was the lowest.

The highest yield was in HydroDFT10x12, whereas it was the lowest in Sub20x25. The highest yield obtained in HydroDFT10x12 was due to the higher amount of nutrient solution applied in the larger growing beds (channels), which indicated that vegetables with high plant density could uptake adequate nutrients for plant growth and as a result, higher yield. Canopy diameter in Sub10x12 significantly declined compared with the rest due to having high plant density and inadequate nutrient uptake by the plants caused by the loss of nutrients through seepage and percolation during the irrigation supplied by the minisprinkler. This evidently did not take place in NFT and DFT hydroponic systems as the plants were grown in the hydroponic channels. Gardner *et al.* (1985) reported that narrow plant spacing reduced the plant's branches, which resulted in narrower canopy diameter compared with wide plant spacing. Tabngoen *et al.* (2004) mentioned that the cassava variety Huay Bong 60 can be planted in all spacings employed; whereas the narrowest plant spacing of 80 cm x 80 cm tended to give the maximum yield compared to those having wider plant spacings. Poothong (1997) stated that the yields of Tabasco chili plant in different plant spacings differed significantly as the yield increased with reduced plant spacing. Stoffella and Bryan (1988) found similar results as yield of Early Calwanderchili increased with reduced plant spacing. Likewise, the narrow plant spacings of 100 cm x 50 cm, 80 cm x 50 cm, 80 cm x 80 cm, and 50 cm x 50 cm for cassava contributed to having better growth, rapidly planting area coverage, weed growth suppression resulting in a higher yield per unit of area compared to the wide plant spacing of 100 cm x 100 cm (standardized plant spacing) (Kathong, 1994).

Canopy diameter, fresh weight per plant, and the number of leaves per plant of Green Oak were higher than those of Pak Choi. Significantly higher yield of Pak Choi than Green Oak was noted due to its higher plant density that compensated for its low canopy diameter, light fresh weight per plant, and less number of leaves per plant. Higher plant density was the main factor for higher yield of Pak Choi. The result differed with those of Wiangsamut *et al.* (2006) who reported that significantly higher yield was obtained in low seedling at 25 kg/ha than in broadcast seedling at 50 kg/ha. High biomass production translating into higher grain yield depends on numerous factors which include cultural practices and genotype (Dingkuhn *et al.*, 1990).

Plant height, number of leaves per plant, canopy diameter, fresh weight per plant, and yield were influenced by the planting system with plant spacing and vegetable. The significantly high yield of Pak Choi was noted in HydroDFT10x12; its yield, however, did not significantly differ with that of Green Oak in the same planting system with the same plant spacing. The highest yield of Pak Choi in HydroDFT10x12 was mainly due to the highest plant density that compensated for its low fresh weight per plant, narrow canopy diameter, and low number of leaves per plant. The second highest yield of Green Oak in HydroDFT10x12 was mainly due to its high plant density, high fresh weight per plant, highest canopy diameter, high number of leaves per plant, and tallest plant height. Lower yields of Green Oak in Sub20x25 and HydroNFT20x25 were mainly due to having had the lowest plant densities.

In conclusion, the yields of Pak Choi and Green Oak vegetables grown in deep flow technique (DFT) hydroponic system with narrow plant spacing of 10 cm x 12 cm (HydroDFT10x12) were significantly higher than those vegetables grown in other planting systems with different plant spacings. The yield of Pak Choi grown in HydroDFT10x12 was the highest due to having the highest plant density that compensated for the low fresh weight per plant, narrow canopy diameter, and low number of leaves per plant. Green Oak grown in HydroDFT10x12 had the second highest yield due to having high plant density, high fresh weight per plant, highest canopy diameter, high number of leaves per plant, and tallest plant height. Yields of Green Oak grown in Sub20x25 and HydroNFT20x25 were lower than in other treatments caused by the lowest plant density. Pak Choi had significantly higher yield than Green Oak, as Pak Choi grown with higher plant density compensated for its lower canopy diameter, lighter fresh weight per plant, and lesser number of leaves per plant. Plant density was the main factor for the higher yield of Pak Choi. HydroDFT10x12 gave the significantly highest yield due to the high plant density, widest canopy diameter, tallest plant height, and high fresh weight per plant as indicated by positive values of the correlation coefficients. As indicated in the results, the HydroDFT10x12 (deep flow technique hydroponic system with narrow plant spacing of 10 cm x 12 cm) is, therefore, the most suitable planting system for producing vegetables such as Pak Choi and Green Oak. In addition, comparative follow-up trials should also be conducted using 1 seedling/hill for Pak Choi and 2 seedlings/hill for Green Oak.

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