International Journal of Agricultural Technology 2021 Vol. 17(3): 1183-1198
Available online http//:www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Assessment of four species of vegetables grown in deep flow technique and nutrient film technique hydroponic systems

Wiangsamut, B.[1*] and Wiangsamut, M. E. L.[2]

[1]Department of Crop Production and Landscape Technology, Faculty of Agro-Industrial Technology, Thailand; [2]Department of Liberal Arts, Faculty of Social Technology, Rajamangala University of Technology Tawan-Ok at Chanthaburi Campus, Chanthaburi, Thailand.

Wiangsamut, B. and Wiangsamut, M. E. L. (2021). Assessment of four species of vegetables grown in deep flow technique and nutrient film technique hydroponic systems. International Journal of Agricultural Technology 17(3): 1183-1198.

Abstract The results showed that taller plants and higher plant density in DFT10x12 (deep flow technique hydroponic system with plant spacing of 10 cm x 12 cm) compensated to its low number of leaves per plant, low shoot dry weight per plant, and low total dry weight per plant which resulted in signicantly higher fresh yield than those in DFT20x25 and NFT20x25 (nutrient film technique hydroponic system with plant spacing of 20 cm x 25 cm) by 56% and 46%, respectively. The higher fresh yield in DFT10x12 can also be explained by the number of leaves per plant, water productivity, and plant density with 100% accuracy as established through stepwise multiple regression analysis. With less amount of water application which used to produce fresh yields in NFT20x25, there was a signicant decrease in fresh yields of Tokyo Bekana cabbage (61%), Green Cos (21%), Green Coral (25%), and Red Coral (8%) compared with DFT10x12 as explained by the values of water productivity. The highest fresh yield and plant density of Tokyo Bekana cabbage were found in DFT10x12. Moreover, the DFT10x12 is the most commercially feasible hydroponic system for investment of producing vegetables such as Tokyo Bekana Cabbage, Green Cos, and Green Coral, except Red Coral, as measured by the values of B/C ratio that are greater than 1 indicating a profit gain. All vegetables produced in NFT20x25 were not commercially feasible as indicated by the values of B/C ratio that are less than 1 indicating a loss. Green Cos grown in DFT20x25 was only feasible for making a profit. Therefore, Tokyo Bekana cabbage, Green Cos, and Green Coral grown in DFT10x12 had better growth, fresh yield, water-wise use and high economic values than in DFT20x25 and NFT20x25.

Keywords: Hydroponic system, Water productivity, Vegetable, Fresh yield, Benefit and cost ratio

Introduction

The three lettuce cultivars, “Red Coral”, “Green Coral”, and “Green Cos” (*Lactuca sativa* L.), and Tokyo Bekana cabbage cultivar (*Brassica rapa* var.

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

chinensis 'Tokyo Bekana') are popular for consumption in most countries (NRCS, n.d.; AKA, 2003). These vegetables are favorable for people who want to consume chemical-free vegetables (Thongket, 2001). Tokyo Bekana cabbage and lettuces produced in hydroponic systems in Thailand can replace the importing of foreign vegetables because of their same quality, same taste, and cheaper price (Tongaram, 2000) with their counter imported vegetables. The selling price is between USD 1.26–4.08/kg (USD 1 equals to THB 31.80) (USDA, 2019). Packaged lettuce salad was the best-selling vegetable produce with weekly sales of USD 4,017 per store (SRD, 2016). More than forty kilograms of vegetables per capita per year were consumed by Thai people while it was a hundred kilograms per capita per year for Chinese and Japanese people (Tongaram, 2004). The hydroponic vegetables can grow all year round due to its non-seasonal limitation and less labor requirement. Its products are right on the need of consumers, with no contamination (i.e. toxicity), and less diseases. With this reason, Thai farmers prefer to grow more and more of these hydroponic vegetables (Maneepong *et al.,* 2011).

Most of vegetable producers use the technology of soilless vegetable culture, particularly the hydroponic vegetable-producing system such as the deep flow technique (DFT) and nutrient film technique (NFT) (Nuntagij, 2000; Khamwongsa, 2010). These techniques can control pests and soil-borne diseases by avoiding the contact between soil and plants. Nutrient availability at plant roots is better-manipulated, -monitored, and controlled real-time leading to higher qualitative and quantitative productions (FAO, 2014). The recirculating hydroponic systems, such as DFT and NFT, are where the nutrient solution flows down to a larger growing bed containing a deep flow of solution and flows down to a set of gullies, respectively (Wiangsamut, 2016). Moreover, DFT hydroponic system with narrow plant spacing of 10 cm x 12 cm is the most suitable planting system for producing Pak Choi and Green Oak vegetables according to Wiangsamut and Koolpluksee (2020). Presently, most of producers grow Red Coral, Green Coral, Green Cos, and Tokyo Bekana cabbage in NFT hydroponic system with recommended plant spacing of 20 cm x 25 cm with one seedling per hill. This causes the unchanging yield and insufficient quantity of vegetables to meet the world’s consumers’ demand with the increasing population. Increasing yield per unit of growing area by reducing plant spacing in DFT hydroponic system may be the way to solve the shortage of vegetables. The expensive selling price can be accounted to its being insecticide- and chemical disease-free. The hydroponic vegetables are safe for producers, consumers, as well as the environment. It is therefore important to arrange the plant spacing to match the vegetable species in hydroponic systems.

Accordingly, the study aimed to assess the plant growth, fresh yield, cost and benefit of Red Coral, Green Coral, Green Cos, and Tokyo Bekana cabbage vegetables in DFT hydroponic systems with wide plant spacing of 20 cm x 25 cm (DFT20x25), narrow plant spacing of 10 cm x 12 cm (DFT10x12), and NFT hydroponic system with wide plant spacing of 20 cm x 25 cm (NFT20x25).

Materials and methods

The experiment was performed in the hydroponic houses with 7% UV protective roofs and nets covering the sides, in December (2018) to February (2019); at Rajamangala University of Technology Tawan-Ok at Chanthaburi Campus, Chanthaburi, Thailand. The experiment was performed in a split plot design replicated 4 times. The mainplot treatments were occupied by DFT20x25, DFT10x12, and NFT20x25. The subplot treatments were the vegetable species: Red Coral, Green Coral, Green Cos, and Tokyo Bekana cabbage. There were 12 hydroponic tables used for each of the mainplot treatments.

Eighty liters of clean water contained in blue polyethylene containers filled each table in DFT20x25, DFT10x12, and NFT20x25; a day before transplanting. Nine-day old seedlings transplanted in all tables of the mainplots, with 1 seedling per hill for Red Coral, Green Coral, and Green Cos, and 2 seedlings per hill for Tokyo Bekana cabbage. Nutrient solutions A and B were prepared as cited by Wiangsamut (2016). Nutrient solution A was firstly added to polyethylene containers containing 80 L water while nutrient solution B was added after 4 hours. Then, the electrical conductivity (EC) of both nutrient solutions diluted in the 80 liters of water were adjusted to the threshold of 1.0-1.5 dS/m. Likewise, the pH was adjusted to the threshold of 5.4-6.7. The EC and pH values were monitored every day at 0700H. Both nutrient solutions diluted in water were maintained at 20-80 liters per polyethylene container for the entire growing period, except 3 days before harvesting; it was drained, and substituted with clean water to reduce nitrate accumulation in the vegetable plants. Both nutrient solutions diluted in water were electrically circulated through the root system of the plants in the larger growing bed containing a deep flow at 7 centimeters depth of DFT20x25 and DFT10x12; while 2-3 millimeters deep in a set of gullies of NFT20x25. The total nutrient solutions (A and B) used for NFT20x25 was 1.62 liter per table (L/table), and 10.58 L/table for each DFT10x12 and DFT20x25. Water use for the entire growing period of single cropping season was 983 L/table in each DFT20x25 and DFT10x12; while it was 245 L/table in NFT20x25. Neither insects nor diseases were found in DFT20x25, DFT10x12, and NFT20x25 as the vegetables grew under a protected cultivation shade house.

Plant samplings were done weekly obtaining 25 plants per experimental unit per time at 17, 24, 31, 38, and 45 days after sowing. Then, plant height stretched and measured from the stem base to the highest plant tip by a ruler in centimeters (cm). The number of leaves per plant (only fully-opened leaves except cotyledon) was counted in a unit of number per plant. The shoot dry weight per plant was the whole plant dry weight, except root dry weight, recorded in a unit of gram per plant. The total dry weight per plant was the sum of shoot dry weight and root dry weight, recorded in a unit of gram per plant. Note that the plant samples were air-dried at room temperature under gentle ventilation for 2 hours, and were then oven-dried at 70^{o}C for 48 hours.

Vegetable samples from the growing area of 1 square meter were taken to determine their plant density, in a unit of number per square meter, and fresh yield, unit of gram per square meter and then adjusted into the unit of ton per hectare per single growing season (t/ha/single growing season) basis, at the maturity stage–45 days after sowing or 36 days after transplanting. Water productivity (WP) was calculated by computing the ratio of the total plant dry weight per table to the total water use per table in a unit of gram per liter (g/L). Note that the total water use is the volume of water applied to the vegetables from the day of seed sowing to maturity stage.

The costs and benefits of vegetable production from DFT20x25, DFT10x12, and NFT20x25 were collected and recorded for a single growing season (1 year = 8 times of growing seasons). Then, the gross benefits and gross costs were computed in the unit of USD/ha/year (fresh yields in each of DFT20x25, DFT10x12, and NFT20x25 were assumed to be stable and that could produce for 8 times all year round within 188 tables per hectare for each hydroponic system with planting spacing and vegetable species tested). Note that it is calculated for the initial investment for vegetable crop production for the first year only. The benefit and cost ratio (B/C ratio) were also computed. Statistical analysis system (SAS) program was used to analyse all plant data. Duncan's multiple range test was used for mean comparisons at 0.05 and 0.01 probability levels. A simple benefit and cost analysis was employed for the data on cost and benefit of vegetable production. Relationships among all plant parameters were established through correlation analysis. To determine the relationships of fresh yield with plant parameters, stepwise multiple regression was used.

Results

Plant height, number of leaves per plant, shoot dry weight per plant, and total dry weight per plant

The plant height of Tokyo Bekana cabbage (or Tokyo) was the tallest, Red Coral (or Red) was the shortest, while Green Cos (or Cos) and Green Coral (or Green) were intermediate between the two former species. At vegetative stage (38 days after sowing), only the plant height of Tokyo Bekana cabbage was affected by the hydroponic system with plant spacing—it was appreciably taller in DFT10x12 than that in DFT20x25 and NFT20x25. While the plant heights of Green Coral, Green Cos, and Red Coral were not significantly affected (Figure 1). The number of leaves per plant for the Green Cos and Tokyo Bekana cabbage was overall higher than Green Coral (Figure 2). The growth of number of leaves per plant, shoot dry weight per plant, and total dry weight per plant were affected by the hydroponic system with plant spacing as the vegetables grown in DFT10x12 significantly reduced their number of leaves per plant, shoot dry weight per plant, and total dry weight per plant compared with those in DFT20x25 and NFT20x25 (Figures 2, 3, and 4). The number of leaves per plant, shoot dry weight per plant, and total dry weight per plant for Red Coral were substantially the lowest in DFT20x25, DFT10x12, and NFT20x25 hydroponic systems. At 38 and 45 days after sowing in DFT10x12, the shoot dry weight per plant and total dry weight per plant for Tokyo Bekana cabbage were appreciably the highest while it was the lowest for Red Coral. At maturity stage (45 days after sowing) in DFT10x12, it was found intermediate for Green Coral and Green Cos (Figures 3 and 4).

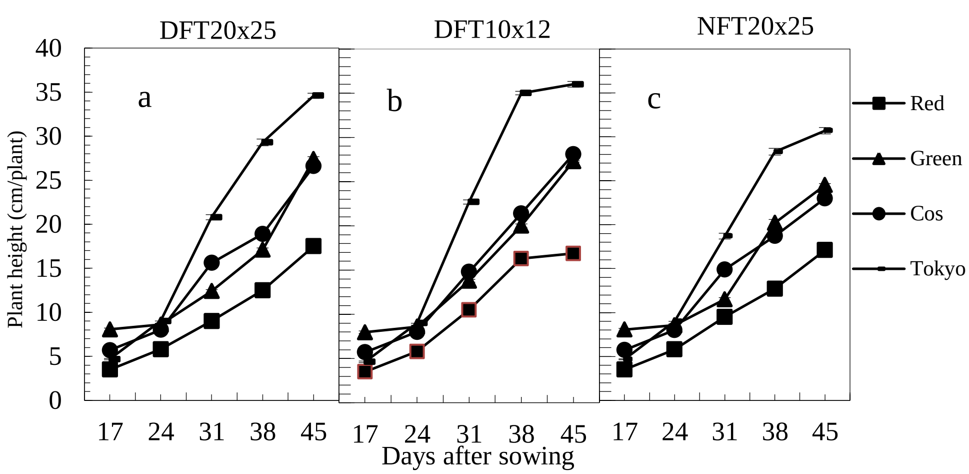

Figure 1. Plant height (cm/plant)

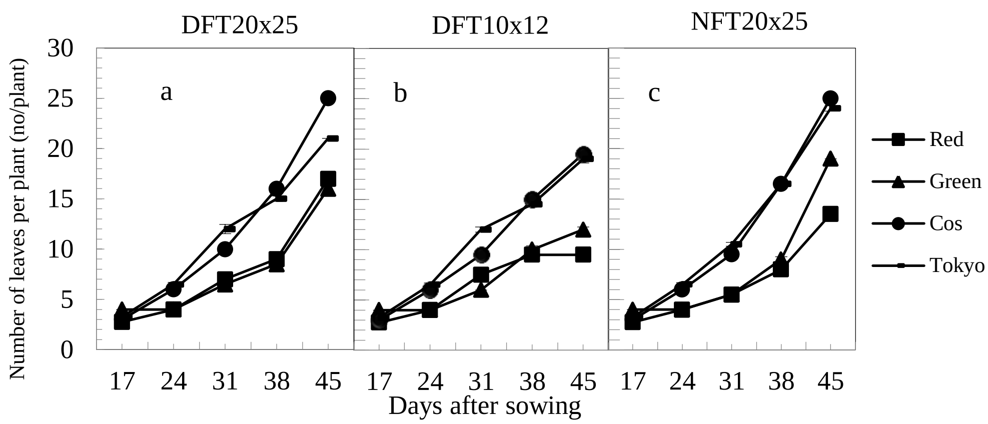

Figure 2. Number of leaves per plant (no/plant)

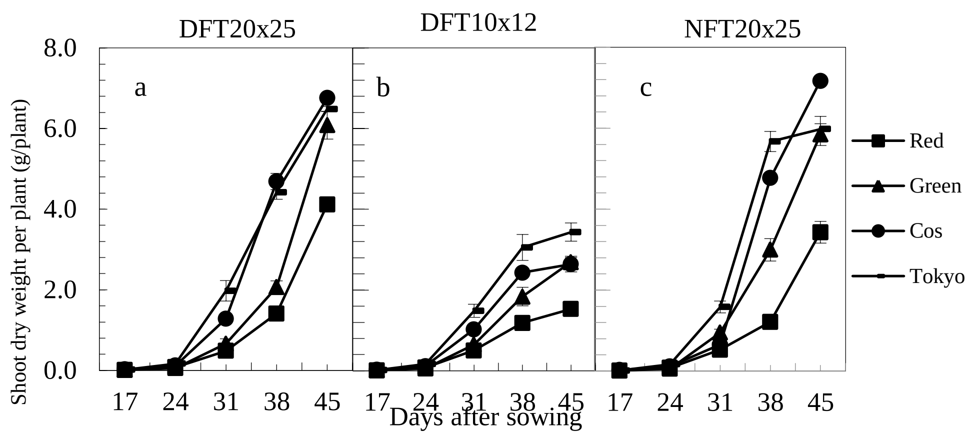

Figure 3. Shoot dry weight per plant (g/plant)

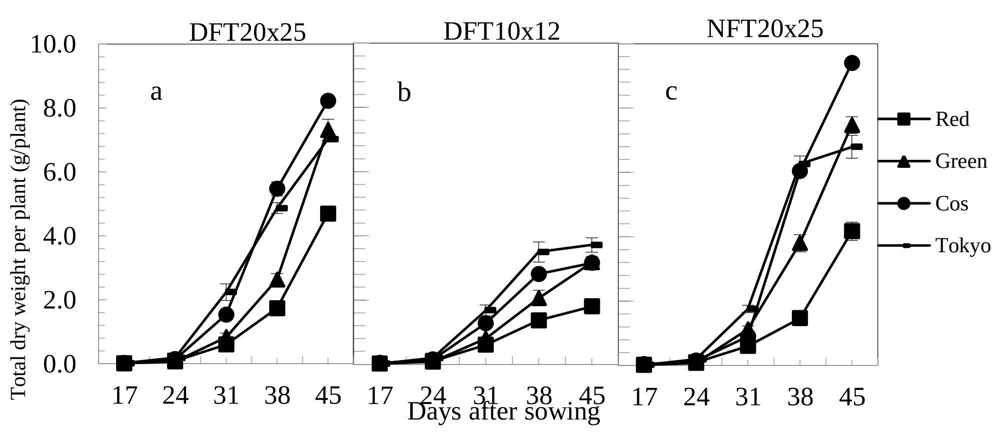

Figure 4. Total dry weight per plant (g/plant)

Plant density, fresh yield, and water productivity

The plant density in DFT10x12 was significantly higher by 76% than those in DFT20x25 and NFT20x25. Likewise, fresh yield in DFT10x12 was appreciably higher than those in DFT20x25 and NFT20x25 by 56% and 46%, respectively. The plant density and fresh yield in DFT20x25 and NFT20x25 were not significantly different (Tables 1 and 2). The plant density and fresh yield for Tokyo Bekana cabbage were significantly the highest followed by the Green Cos, Green Coral, and Red Coral, respectively. Plant densities for Green Cos, Green Coral, and Red Coral did not differ significantly. Fresh yields for Green Cos and Green Coral were not significantly different; while it was the lowest for Red Coral. There was an interaction between vegetable species and hydroponic system with plant spacing on plant density and fresh yield as Tokyo Bekana cabbage had significantly the highest in DFT10x12, while it was the lowest for Red Coral in DFT20x25 (Tables 1 and 2).

Table 1. Plant density (no/m^2)

Hydroponic system with plant spacing (HSPS)	**Vegetable species (VS)**				**Mean**
	Red[1/]	**Green**	**Cos**	**Tokyo**	
DFT20x25	20.0d	20.0d	20.0d	39.5c	24.9b[2/]
DFT10x12	83.3b	83.3b	83.3b	166.7a	104.2a
NFT20x25	20.0d	20.0d	20.0d	39.8c	25.0b
Mean	[3/]41.1b	41.1b	41.1b	82.0a	

[1/]in the table of HSPSxVS means with the same letter is not significantly different at 0.05 and 0.01 probability levels (DMRT); [2/]in the column of HSPS means with the same letter is not significantly different at 0.05 and 0.01 probability levels (DMRT); [3/]in the row of VS means with the same letter is not significantly different at 0.05 and 0.01 probability levels (DMRT)

Table 2. Yield (t/ha/single growing season)

Hydroponic system with plant spacing (HSPS)	**Vegetable species (VS)**				**Mean**
	Red[1/]	**Green**	**Cos**	**Tokyo**	
DFT20x25	2.98f	4.45def	6.70cdef	9.25bc	5.85b[2/]
DFT10x12	3.46ef	7.76cd	9.26bc	32.97a	13.36a
NFT20x25	3.19ef	5.79edef	7.36cde	12.71b	7.26b
Mean	3.21c[3/]	6.00b	7.77b	18.31a	

[1/]in the table of HSPSxVS means with the same letter is not significantly different at 0.05 and 0.01 probability levels (DMRT); [2/]in the column of HSPS means with the same letter is not significantly different at 0.05 and 0.01 probability levels (DMRT); [3/]in the row of VS means with the same letter is not significantly different at 0.05 and 0.01 probability levels (DMRT)

The highest water productivity (WP) was found in NFT20x25 followed by DFT10x12 and DFT20x25 (Table 3). Tokyo Bekana cabbage had significantly the highest WP followed by Green Cos, Green Coral, and Red Coral, respectively. The hydroponic system with plant spacing influenced by WP of vegetable species as the performance of Tokyo Bekana cabbage in NFT20x25 had appreciably higher WP than those in the other treatments. Overall, WP for 4 vegetable species in NFT20x25 was higher than those in DFT10x12 and DFT20x25; whereas WP for 4 vegetable species in DFT10x12 was intermediate between NFT20x25 and DFT20x25 (Tables 2 and 3).

Table 3. Water productivity (g/L)

Hydroponic system with plant spacing (HSPS)	**Vegetable species (VS)**				**Mean**
	Red[1/]	**Green**	**Cos**	**Tokyo**	
DFT20x25	0.9e	1.4de	1.6de	2.7d	1.7c[2/]
DFT10x12	1.5de	2.6de	2.6de	6.1bc	3.2b
NFT20x25	3.3d	5.9c	7.4b	10.6a	6.8a
Mean	1.9d[3/]	3.3c	3.9b	6.5a	

[1/]in the table of HSPSxVS means with the same letter is not significantly different at 0.05 and 0.01 probability levels (DMRT); [2/]in the column of HSPS means with the same letter is not significantly different at 0.05 and 0.01 probability levels (DMRT); [3/]in the row of VS means with the same letter is not significantly different at 0.05 and 0.01 probability levels (DMRT).

Relationships of fresh yield with plant parameters

Plant parameters most significantly influence yield were determined through stepwise multiple regression analysis. There were three plant parameters (number of leaves per plant, plant density, and water productivity) that significantly determined fresh yield in DFT10x12; none in DFT20x25, while there were two common plant parameters (number of leaves per plant and plant height) in NFT20x25. The equations were as follows:

$$\text{Fresh yield}_{(DFT10x12)} = -12.0354 + 0.7813(\text{number of leaves per plant}) + 0.1507(\text{plant density}) + 135.9680(\text{water productivity}) \quad (1)$$

$R^2 = 1.00^{**}$

$$\text{Fresh yield (NFT20x25)} = 10.3811 + 0.3272(\text{number of leaves per plant}) + 0.1379(\text{plant height}) \quad (2)$$

$R^2 = 0.99^{**}$

Fresh yield in DFT10x12 was explained by the number of leaves per plant, plant density and water productivity with 100% accuracy (equation 1). In DFT10x12, the positive coefficient values indicated that by increasing number of leaves per plant, plant density and water productivity, fresh yield also increases. The number of leaves per plant and plant height explained the 99% of the fresh yield in NFT20x25 (equation 2). The positive coefficient values indicated that the increase of yield in NFT20x25 was due to the increase of number of leaves per plant and plant height.

Cost and benefit of vegetable production

The highest gross cost of vegetable production was in NFT20x25 followed by DFT10x12 and DFT20x25, respectively; but the highest gross benefit of vegetable production was found in DFT10x12. Likewise, DFT10x12 contributed to having the benefit and cost ratio (B/C ratio) greater than 1 hence the positive net benefits obtained for Green Coral, Green Cos, and Tokyo Bekana cabbage, except Red Coral (Tables 4, 5 and 6). The gross cost of production for the Red Coral, Green Coral, Green Cos, and Tokyo Bekana cabbage were similar; but it was only the Green Cos that had the value of B/C ratio greater than 1. The values of B/C ratio for all vegetable species grown in DFT20x25 and NFT20x25 were lower than 1; hence they had negative net benefits as their gross costs of production were higher than gross benefits, except the Green Cos grown in DFT20x25 (Tables 4, 5 and 6).

Table 4. Gross cost of vegetable production (USD/ha/year)

Hydroponic system with plant spacing (HSPS)	**Vegetable species (VS)**				**Mean**
	Red	**Green**	**Cos**	**Tokyo**	
DFT20x25	194,918.24	189,194.97	197,207.55	190,817.61	193,034.59
DFT10x12	234,148.43	206,933.33	237,615.09	215,652.83	223,587.42
NFT20x25	245,569.81	240,339.62	248,110.69	243,008.81	244,257.23
Mean	224,878.83	212,155.97	227,644.44	216,493.08	

Table 5. Gross benefit of vegetable production (USD/ha/year)

Hydroponic system with plant spacing (HSPS)	**Vegetable species (VS)**				**Mean**
	Red	**Green**	**Cos**	**Tokyo**	
DFT20x25	89,962.26	134,339.62	202,264.15	93,081.76	129,911.95
DFT10x12	104,452.83	234,264.15	279,547.17	331,773.58	237,509.43
NFT20x25	96,301.89	174,792.45	222,188.68	127,899.37	155,295.60
Mean	96,905.66	181,132.07	234,666.67	184,251.57	

Table 6. Benefit and cost ratio (B/C ratio)

Hydroponic system with plant spacing (HSPS)	Vegetable species (VS)				Mean
	Red	**Green**	**Cos**	**Tokyo**	
DFT20x25	0.46	0.71	1.03	0.49	0.67
DFT10x12	0.45	1.13	1.18	1.54	1.08
NFT20x25	0.39	0.73	0.90	0.53	0.64
Mean	0.43	0.86	1.04	0.85	

Discussion

The plant height was positively associated with fresh yield (r = 0.71) through correlation analysis. The tallest plant of Tokyo Bekana cabbage in DFT10x12 obtained the highest fresh yield than in DFT20x25 and NFT20x25. The tallest vegetable species such as Tokyo Bekana cabbage also obtained the highest fresh yield at 18.31 t/ha/single growing season. The shortest vegetable species like Red Coral obtained the lowest fresh yield at 3.21 t/ha/single growing season. The lower number of leaves per plant produced in DFT10x12 represented a source limitation leading to lesser shoot dry weight per plant and total dry weight per plant compared with those in DFT20x25 and NFT20x25. This source capacity of the individual plant, however, is not the major factor limiting fresh yield of vegetables grown at high plant density in DFT10x12 hydroponic system. By increasing plant density, fresh yield in DFT10x12 also increases (r = 0.79). Accordingly, Wiangsamut and Koolpluksee (2020) reported that the highest fresh yield of Pak Choi in DFT10x12 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. Muranyi and Pepo (2013) similarly cited that when the plant density and the length of vegetation time increase, the heights of the individual plants also increase. Likewise, as the number of plants in a planting pattern increases, distance between plants decreases and competition among individuals also increases (Duncan, 1984). This resulted in lower shoot dry weight per plant and total dry weight per plant in DFT10x12. Similarly, the narrowest plant spacing of 50 cm x 50 cm decreased stem dry weight, corm, and total dry weight per plant compared with the other wide plant spacing (Detpiratmongkol *et al*., 2008). Gardner *et al.* (1985) cited that the use of narrow plant spacing reduced the plant's branches resulting in a narrow canopy diameter compared with the use of wide plant spacing. Meanwhile, Detpiratmongkol *et al.* (2008) reported that Chinese water chestnut corm dry weight yield of 50 cm x 50 cm spacing was the highest while the 100 cm x 100 cm spacing was the lowest. Tabngoen *et al.*

(2004) furthermore cited that cassava variety Huay Bong 60 can be planted in all spacing employed and the tendency indicated that the narrowest plant spacing of 80 cm x 80 cm gave the maximum yield compared with those having wider plant spacing. Poothong (1997) confirmed that the yields of Tabasco chili plant in different plant spacing differed significantly as the yield increased with reduced plant spacing at a certain spacing. In addition, Stoffella and Bryan (1988) found similar results as yield of Early Calwander chili plant increased with reduced plant spacing. The narrow plant spacing at 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 a better growth, rapidly planting area coverage, weed depression, resulting in a higher yield per unit of area compared with the wide plant spacing at 100 cm x 100 cm (standardized plant spacing) was also confirmed by Kathong (1994). On the other hand, there was a trend in increasing plant height of soybean at narrow row spacing and plant to plant spacing; it was however statistically similar between treatments (Chauhan and Opena, 2013). Likewise, the plant height of Tabasco chili was not affected by the different plant spacing at any plant growth stages according to Poothong (1997).

In DFT10x12, the high plant density of Tokyo Bekana cabbage resulted in high number of plants and number of leaves per unit area. The more numbers of leaves per unit area, the more leaf areas to intercept light for photosynthesis, consequently assimilates increased by the sources (vegetables' leaves). These assimilates were then translocated to the sinks (whole plants' parts) resulted in the faster growth and development including high biomass accumulation as indicated by the values of shoot dry weight per plant and total dry weight per plant. In addition, the more number of plants per unit area compensated for the loss of production on an individual plant basis—the shoot dry weight per unit area and total dry weight per unit area in DFT10x12 increased. Therefore, the yield was significantly higher—Tokyo Bekana cabbage in DFT10x12 obtained the highest fresh yield (32.97 t/ha/single growing season) followed by Green Cos (9.26), Green Coral (7.76) and Red Coral (3.46), respectively. However, this is not in accordance with Somboonya (2005) and Sompituk (2005) who reported that the growth of Pakchoy (*Brassica campestris* var. *chinensis*) is the best in NFT25x25 due to its widest and highest number of leaves, tallest, highest total weight, and highest edible plant parts.

Water productivity (WP) was positively associated to the fresh yield ($r = 0.45$). This means that by increasing WP, fresh yield also increases. It is greatly impacted by plant water management. Tokyo Bekana cabbage had significantly the highest WP among other vegetable species tested as the plants used only 1 liter of water to produce 6.5 g of the total plant dry weight. Meanwhile, the total plant dry weight production for the other species was as follows: 1 liter of water was used to produce 1.9 g for Red Coral (the lowest WP); 3.9 g for Green Cos, and 3.3 g for Green Coral. WP in NFT20x25 was 6.8 g/L, significantly higher than that in DFT10x12 (3.2 g/L) by 113%. This means that there is less water used to produce fresh yield in NFT20x25, but its fresh yield decresed by 46% compared with that in DFT10x12. Whereas WP in NFT20x25 (6.8 g/L) was also appreciably higher than that in DFT20x25 (1.7 g/L) by 300% and its fresh yield was also increased by 24%. Thus, DFT10x12 hydroponic system is better than NFT20x25 and DFT20x25. Tokyo Bekana cabbage in NFT20x25 had significantly the highest WP at 10.6 g/L. This WP increased by up to 42% with less water used (water saved by up to 75%) but fresh yield signicantly reduced by 61% compared with those in DFT10x12. Likewise, Green Cos, Green Coral, and Red Coral in NFT20x25 had significantly higher WP than those in DFT10x12. By increasing WP in NFT20x25 through less water use, fresh yields decreased by 21%, 25% and 8%, respectively. While Green Cos, Green Coral, and Red Coral in NFT20x25 was overall better than those in DFT20x25; the increasing WP in NFT20x25 with less water used brought about increase in fresh yields by 10%, 30% and 7%, respectively, compared with those in DFT20x25. Thus, WP for the four vegetable species in DFT10x12 was appreciably better than those in NFT20x25 and DFT20x25. The results correspond with those of Borell *et al.* (1997) and Lu *et al.* (2000) who reported that during the 1990s, International Rice Research Institute (IRRI) and national researchers tested several water-saving technologies such as saturated soil culture, saturated soil and soil drying, and alternate wetting and drying (AWD) in rice farmers' fields. These methods have reportedly increase water productivity by reducing water input by up to 35% compared with continuous flooding (CF) though grain yield decreased.

Grown in DFT10x12, there were 800 plants per table, one plant per hill for Red Coral, Green Coral, and Green Cos while Tokyo Bekana cabbage had 1,600 plants per table, two plants per hill. The costs of production were USD 8.46, USD 3.33, USD 3.21, and USD 0.82/kg, respectively. The selling price for Red Coral, Green Coral, and Green Cos in DFT10x12 was high at USD 3.77/kg while it was low for Tokyo Bekana cabbage at USD 1.26/kg. The most feasible investment was for Tokyo Bekana cabbage production in DFT10x12 as measured by the value of B/C ratio (1.54), followed by Green Cos (1.18) and Green Coral (1.13); but a loss for Red Coral (0.45).

Grown in NFT20x25, there were 192 plants per table, one plant per hill for Red Coral, Green Coral, Green Cos while Tokyo Bekana cabbage had 384 plants per table, two plants per hill. The fresh yields per hectare per single growing season for Red Coral, Green Coral, Green Cos, and Tokyo Bekana cabbage were 3.19 tons, 5.79 tons, 7.36 tons, and 12.71 tons, respectively. The costs of production were USD 9.62, USD 5.19, USD 4.21, and USD 2.39/kg, respectively. The selling price for Red Coral, Green Coral, and Green Cos in NFT20x25 was high (USD 3.77/kg) while it was low (USD 1.26/kg) for Tokyo Bekana cabbage. With these results, plant species grown in NFT20x25 were not feasible for investment as indicated by the values of B/C ratio all less than 1. According to Wiangsamut *et al*. **(**2013**)**, Wiangsamut and Koolpluksee (2018), Wiangsamut *et al.* (2015), Tongaram (2004), and Bangchaud (2001), most of investors would select a project that could gain the net profits in the shortest period based on the value of B/C ratio. The value of B/C ratio that is more than 1 could mean that the project is more feasible for investment while the B/C ratio that is equal to 1 could mean that the project is still feasible; whereas the value of B/C ratio that is less than 1 could mean that it is not feasible at all due to a possible loss.

In summary, the high plant density in DFT10x12 reduced the number of leaves per plant, shoot dry weight per plant, and total dry weight per plant compared with those in DFT20x25 and NFT20x25. Taller plants and higher plant density in DFT10x12 compensated its low number of leaves per plant, low shoot dry weight per plant, and low total dry weight per plant therefore its fresh yield was significantly higher than those in DFT20x25 and NFT20x25 by 56% and 46%, respectively. The plant density in DFT10x12 was significantly higher by 76% than those in DFT20x25 and NFT20x25. Tokyo Bekana cabbage gave the highest yield, followed by Green Cos, Green Coral, and Red Coral, respectively. Moreover, Tokyo Bekana cabbage in DFT10x12 had the highest plant density and fresh yield. Red Coral in DFT20x25 had the lowest. Overall, DFT10x12 yielded consistently higher than those in NFT20x25 and DFT20x25. Only Tokyo Bekana cabbage, Green Cos, and Green Coral in DFT10x12 were feasible for production. The only feasible for production in DFT20x25 was Green Cos. For this reason, it is suggested that DFT10x12 is the most commercially feasible for investment of vegetable production such as Green Coral, Green Cos, and Tokyo Bekana cabbage as measured by the values of B/C ratio that are greater than 1. On the other hand, the investment in NFT20x25 was a loss as measured by the values of B/C ratio that are less than 1. Therefore, only Tokyo Bekana cabbage, Green Cos, and Green Coral grown in DFT10x12 were overall better than those grown in DFT20x25 and NFT20x25 in terms of growth, fresh yield, water-wise use and high economic values.

Acknowledgements

The author would like to offer particular thanks to Assoc. Prof. Manoch Koolpluksee for his suggestion and advice regarding this research work. The author would also like to thank

Rajamangala University of Technology Tawan-Ok Chanthaburi Campus for allowing the use of experiment station.

References

Agricultural Knowledge Article (AKA) (2003). Thai fruit and vegetable being both food and medicine in the lettuce episode. Faculty of Natural Resources, Prince of Songkla University, Hatyai Campus. (Online) . Retrieved from http://www.natres.psu.ac.th [July 12, 2019].

Bangchaud, T. (2001). An economic analysis of hydroponics vegetable farm. (Master Thesis). Kasetsart University, Thailand.

Borell, A., Garside, A. and Fukai, S. (1997). Improving efficiency of water use for irrigated rice in a semi-arid tropical environment. Field Crops Research, 52:231-248.

Chauhan, B. S. and Opena, J. L. (2013). Effect of plant spacing on growth and grain yield of soybean. American Journal of Plant Sciences 4:2011-2014. Retrieved from http://file.scirp.org/Html/37680.html [July 25, 2019].

Detpiratmongkol, S., Yoosukyingsataporn, S. and Ubolkerd, T. (2008). Effect of corm size and plant spacing on growth of Chinese water chestnut. Full paper, Proceedings of the 46th Kasetsart University Annual Conference, Kasetsart, Thailand, pp.295-302.

Duncan, W. G. (1984). A theory to explain the relationship between corn population and grain yield. Crop Science, Madison, 24:1141-1145.

Food and Agriculture Organization of the United Nations (FAO) (2014). Small-scale aquaponic food production - integrated fish and plant farming. (Online). Retrieved from http://www.fao.org/3/a-i4021e.pdf [July 19, 2020].

Gardner, F. P., Pearce, R. B. and Mitchell, R. L. (1985). Physiology of crop plants. IOWA State University Press. The United States of America, pp.327.

Kathong, S. (1994). Cassava cultivation. Department of Agriculture, Bangkok, Thailand. Cassava Academic Document, pp.71-83.

Khamwongsa, A. (2010). Ways of hydroponic vegetable production and investment for making money. Naka Intermedia Company Limited, Bangkok, Thailand.

Lu, J., Ookawa, T. and Hirasawa, T. (2000). The effects of irrigation regimes on the water use, dry matter production and physiological responses of paddy rice. Plant and Soil, 223:207-216.

Maneepong, S., Songkesonchat, M. and Boonsong, O. (2011). The comparison on nutrient solution for soilless vegetable culture in tropical zone. Walailak university. Center for library resources and educational media. Nakhon Si Thammarat, Thailand.

Muranyi, E. and Pepo, P. (2013). The effects of plant density and row spacing on the height of maize hybrids of different vegetation time and genotype. World Academy of Science, Engineering and Technology International Journal of Biological, Veterinary, Agricultural and Food Engineering, 7:681-684.

Natural Resources Conservation Service (NRCS) (n.d.). *Lactuca serriola* L. United States Department of Agriculture. Retrieved from http://en.wikipedia.org/wiki/Lettuce [28 July 2019].

Nuntagij, I. (2000). Soilless culture system. Division of Soil Science, Faculty of Agricultural Technology, King Mongkut's Institute of Technology Ladkrabang, Thailand.

Poothong, S. (1997). Effect of shading and spacing on seed yield and quality of *Capsicum frutescens* cv. Tabasco. (Master Thesis). Kasetsart University, Thailand.

Somboonya, T. (2005). The suitable nutrient solution, spacing and media on the growth of pakchoy (*Brassica campestris* var. chinensis) in NFT system. (Special problem). Valaya Alongkorn Rajabhat University, Pathum Thani Province, Thailand.

Sompituk, T. (2005). The suitable nutrient solution, spacing and media on the growth of pakchoy (*Brassica campestris* var. chinensis) in NFT system. (Special problem). Valaya Alongkorn Rajabhat University, Pathum Thani Province, Thailand.

Statista Research Department (SRD) (2016). Sales of vegetables in the U.S. by category (in USD per store/week). (Online). Retrieved from https://www.statista.com/statistics/275326/vegetable-department-sales-in-the-us-by-category/ [July 19, 2020].

Stoffella, P. J. and Bryan, H. H. (1988). Plant population influences growth and yields of bell pepper. Journal of the American Society for Horticultural Science, 113:835-839.

Tabngoen, S., Vichukit, V., Changlek, P., Serivichayaswadi, P., Samutthong, N., Somwang, T. and Lim-aroon, S. (2004). Optimum spacing of cassava varieties: Huay Bon 60, Kasetsert 50 and Rayong 5 planted on Mab soil series. Proceedings of the 42nd Kasetsart University Annual Conference, Kasetsart, Thailand, 3-6 February 2004. pp.318-324.

Thongket, T. (2001). Soilless lettuce culture in NFT system. Department of Horticulture, Faculty of Agriculture, Kasetsart University, Thailand.

Tongaram, D. (2004). Marketing: analysis of decision making for soilless culture. Handout for training entitled "Hydroponics: soilless culture technique" at the conference room 4, building 1, Thailand Institute of Scientific and Technological Research [July 21-23, 2004].

Tongaram, D. (2000). Concept in soilless vegetable production for commerce in Thailand. (photocopy).

United States Department of Agriculture Economic Research Service (USDA) (2019). Fruit and vegetable prices. Retr ieved from https://www.ers.usda.gov/data-products/fruit-and-vegetable-prices.aspx [July 20, 2020].

Wiangsamut, B. (2016). Manual for hydroponic culture. Department of Crop Production and Landscape Technology, Faculty of Agro-Industrial Technology, Rajamangala University of Technology Tawan-Ok Chanthaburi Campus, Chanthaburi, Thailand.

Wiangsamut, B. and Koolpluksee, M. (2018). Effect of various ethephon concentrations on flowering, yield, costs and returns of productions of four pineapple varieties. International Journal of Agricultural Technology, 14:2215-2228.

Wiangsamut, B., Lafarge, T. A., Mendoza, T. C. and Pasuquin, E. M. (2013). Agronomic traits and yield components associated with broadcasted and transplanted high-yielding rice genotypes. eSci Journal of Crop Production, 2:19-30.

Wiangsamut, B., Umnat, P. and Koolpluksee, M. (2015). Growth, yield components, agronomic traits, kernel yield, cost and benefit of the NK48 corn genotype grown in tillage and no-

tillage soils with different rice residue management practices. Journal of Agricultural Technology, 11:2127-2147.
Wiangsamut, B. and Koolpluksee, M. (2020). Yield and growth of Pak Choi and Green Oak vegetables grown in substrate plots and hydroponic systems with different plant spacing. International Journal of Agricultural Technology, 16:1063-1076.

(Received: 14 August 2020, accepted: 4 April 2021)