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Yield of lettuce (*Lactuca sativa*) plants grown with modified NFT systems in pandemic times

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Abstract

Due to the pandemic caused by COVID-19 worldwide, it is necessary to rethink how to produce vegetables in the free spaces of homes, as many people have lost their jobs and need to generate income for their families. One way to grow plants at home is through hydroponics or soilless culture. For this purpose, a trial was conducted to evaluate the growth and yield of a green leaf type lettuce variety with a modified Nutrient Film Technique (NFT). Three modified NFT systems were evaluated: (1) an 8-channel horizontal system, (2) a 10-channel pyramidal system, and (3) a 13-channel pyramidal system. Significant differences were found in leaf number, root length, plant dry and fresh weight, and yield in $kg \cdot m^{-2}$ and kg per NFT system. The highest plant fresh weight and yield were achieved in plants grown with the 10-channel pyramidal NFT system. Leaf chlorophyll concentration (SPAD units) and photosynthetic photon flux density were evaluated, but no significant differences were found. Yields (fresh weight, $kg \cdot m^{-2}$, kg per NFT system) and utility achieved with the 10-channel modified NFT system were higher.

Keywords: *Lactuca sativa* L., COVID-19, employment generation, PPDF, SPAD, nutrient solutions.

Introduction

Due to the COVID-19 pandemic, millions of jobs have been lost worldwide, and it will probably take several years before people recover their jobs and return to normalcy. In the meantime, millions of households are struggling to find food to survive. One proposal to overcome this crisis is the production of vegetables in homes using low- or mid-tech hydroponic systems, which represents a technique for producing plants in soilless conditions. The soil is replaced with inert substrates, and the plants are irrigated with nutrient solutions containing essential minerals dissolved in water in optimal concentrations. Soilless production makes it possible to obtain vegetables of excellent quality in less time than those obtained with conventional production in soil, ensuring more efficient utilization of water and fertilizers and avoiding environmental pollution. With this technique, it is possible to produce in homes, allowing families to obtain safe food and generate income from selling the vegetables, permitting them to meet the basic needs they stopped meeting when the head of the household lost their job due to the pandemic.

One management option that has been practiced in lettuce is the reuse of the nutrient solution by using an NFT (Nutrient Film Technique) system, in which the plant roots always remain in contact with the nutrient solution without using any substrate. The principle of the system consists of continuously recirculating the solution through a series of white rectangular PVC channels called grow channels (Carrasco and Izquierdo, 1996; Carrasco, 2004; Rodríguez, 2012). Each channel has openings where the plants are

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placed, supported by small plastic pots. The channels are supported on tables or trestles and have a slight slope that facilitates the solution circulation, which is collected and stored in a tank (Rodríguez-Delfín, Chang, Hoyos, and Falcón, 2002). Simplified hydroponic systems are especially suitable for rooftop installation (Rodríguez, Gruda, Eigenbrod, Orsini, and Gianquinto, 2017). To take advantage of the scarce spaces that may remain free in houses, the NFT system, generally horizontal, can be adjusted with pyramid structures and grow more plants in the same area occupied by a horizontal NFT system (Rodríguez et al., 2017).

This research aimed to evaluate three types of the modified NFT system for growing lettuce and determine the most appropriate one to obtain higher yields and crop quality, along with higher profits from sales.

Materials and methods

The experiment was conducted at the Centro de Investigación de Hidroponía y Nutrición Mineral (CIHNM) of the Universidad Nacional Agraria La Molina (UNALM), Lima, Peru (12° 05' 06" South, 76° 51' 00" West; 243 m altitude) during the summer and autumn of 2019. Climatic conditions during the trial: global radiation 16.2 (±0.670) $MJ \cdot m^{-2} \cdot d^{-1}$; average maximum and minimum temperatures 27.8 (±0.26) °C and 19.2 (±0.26) °C, respectively; average day and night temperatures 23.9 (±0.26) °C and 20.1 ±0.26) °C, respectively; average relative humidity 77.9 (±0.76) % and total precipitation 1.3 mm.

Green leaf-type lettuce (*Lactuca sativa* L.) Ariana variety from the Feltrin® company, heat tolerant for production even in summer seed was used. The seeds were sown in a 0.40 m × 0.40 m container, lined with an eight µm thick black polyethylene sheet. Medium-textured quarry sand was used as the substrate, previously washed and disinfected with 2 % sodium hypochlorite solution; then, the substrate was rinsed and placed in a container. Seedling emergence was observed six days after sowing, remaining in the seedbed for eight more days. Fifteen days after sowing, the seedlings were transplanted to a floating root system to adapt to the hydroponic system that consisted of a 0.40 m × 0.40 m × 0.10 m container; this stage was called first transplanting or post seedling. The transplanted seedlings were placed on a 2.5 cm thick expanded polystyrene sheet, and to hold them on the sheet, a 1.25 cm thick sponge (expanded polystyrene) was used so that the roots remained in direct contact with the nutrient solution prepared with La Molina hydroponic formulation (Rodríguez-Delfín et al., 2002), with the following nutrient concentrations (mg/L or ppm): N 190; P 35; K 210; Ca 150; Mg 40; S 98; Fe 1.0; Mn 0.8; B 0.6; Zn 0.20; Cu 0.15 and Mo 0.10. The pH values ranged from 6.0 to 6.5, and electrical conductivity ranged from 2.0 to 2.2 $dS \cdot m^{-1}$.

At the root floating stage, the nutrient solution was oxygenated using a clean hand mixer to stimulate root growth and prevent root rot from lack of oxygen. After 15 days, that is, 30 days after sowing, the plants were transplanted into the grow channels of three modified NFT systems: a) 8-channel horizontal system, b) 10-channel pyramidal system, and c) 13-channel pyramidal system (Figure 1), the systems were designed and implemented by the CIHNM of the UNALM. The spacing between channels in the three pyramidal systems was 0.20 m and 0.18 m from plant to plant, implying an area of 3.0 m × 1.5 m for each system. The number of lettuce plants grown per modified NFT system was 120, 150, and 190, respectively. The modified NFT systems were installed in an environment shaded using 50% black shade netting, set 4.5 m from the soil surface, which contributed to reducing the temperature of the microenvironment by 2.0 to 3.0 ºC.

To assess the modified NFT systems on plant growth, the following were evaluated: fresh weight, dry weight, number of leaves, root length, yield$\cdot m^{-2}$, and yield per system. Photosynthetic photon flux density (PPFD) and SPAD index (leaf chlorophyll concentration) data were also obtained; these data were collected on March 22, 25, and 29, 2019.

To obtain the SPAD values, it was used a Minolta® meter (SPAD-502 Plus), which measures the chlorophyll content of the leaves; apart from being fast and non-destructive, it performs an evaluation based on the spectral transmittance properties of the leaves (Ribeiro, Katz, de Pádua, and Martínez, 2015). In addition, a PPFD meter (Spectrum® 3415F) was used to measure light, an Oakton Eco Testr waterproof conductivity meter, an Oakton pH 2 Testr waterproof pH meter, and a Memmert 1060 oven to obtain the dry weight of the samples.

A completely randomized experimental design with eight replications was used for each system. The plants at the edges were excluded from the data collection. Data were processed by variance analysis and measure comparison tests using Tukey's statistic, with a significance level of 0.05, and utilizing Minitab versio 18.

Results and discussion

Agronomic analysis

Significant differences ($P \leq 0.05$) were found between the three NTF systems for all variables evaluated (Table 1). The highest values of plant fresh weight (FW) and yield per square meter (YLD) and per system (NFTYLD) were achieved in plants grown using the 10-channel pyramidal NFT system, obtaining 112.63 g of FW per plant and yields of 4.75 ($kg \cdot m^{-2}$) and 21.38 (kg per system) in YLD and NFTYLD, respectively. In addition, the same variables

Figure 1. From left to right, 8-, 10-, and 13-channel modified NFT modules.

Table 1. Effect of three modified NFT systems on growth and yield of lettuce plants.

NFT channels	RL (cm)	No. of leaves	DW (g)	FW (g)	YLD ($kg \cdot m^{-2}$)	NFTYLD (kg·SYS)
8	18.12 a[Z]	10.4 a	7.60 a	94.25 ab	2.51 b	11.32 b
10	14.50 b	9.0 b	5.07 b	112.63 a	4.75 a	21.38 a
13	17.75 a	10.5 a	5.54 b	79.87 b	2.66 b	11.97 b

[Z]Averages with the same letter, within columns, are equal according to Tukey's test ($P \leq 0.05$); NFT: nutrient film technique; RL: root length; DW: plant dry weight; FW: plant fresh weight; YLD: yield per square meter; NFTYLD: yield per NFT system.

were similar in plants grown using the eight-channel horizontal NFT system and the 13-channel pyramidal NFT system. Finally, the highest dry weight (DW, 7.6 g) value was obtained from plants grown using the eight-channel system, while the highest number of leaves was recorded from the eight- and 13-channel systems. These results could be since the shape of the trestle in the modified NFT systems determines the structure of the system in which the plants grow. Also, the pyramidal NFT systems with 10 and 13 channels make the best use of vertical space, allowing more plants per unit area than the eight-channel system (Figure 1). Depending on the angle of the structure or trestle, the plants can get shading from each other, decreasing light absorption in the lower levels of the trestle. It can affect the resulting plant size, thus explaining what happened between the 10- and 13-channel systems; that is, the density of 190 plants could negatively affect light uptake and yield.

In an NFT system for the production of 120 lettuce plants, Fraile-Robayo, Álvarez-Herrera, Reyes, Álvarez-Herrera, and Fraile-Robayo, (2017) found a total dry matter accumulation of 13.2 and 16.5 g in two lettuce growing cycles 43 and 36 days after transplanting, respectively, while the trial cycle was 30 days after transplanting. The difference in dry weights obtained may also be explained by climatic conditions. In that work, the trial was conducted in conditions of average temperatures of 17.5 °C, at 2,690 m altitude, while in La Molina (at 240 m altitude), the trial was conducted in summer, with maximum and minimum temperatures of 27.8 and 19.2 °C, respectively. In the warm season, lettuce yields are lower than those obtained in autumn-winter because it is a cool-season crop, where optimum temperatures range from 17 to 28 ºC daytime and 3 to 12 ºC overnight (Morgan, 1999). The lettuce crop develops loose and puffy heads when supra-optimal temperatures are available (Jenni and Yan, 2009).

Table 2. SPAD units and photosynthetic photon flux density (PPFD) values in the microenvironment where lettuce plants were grown in three modified NFT systems.

NFT channels	SPAD			PPFD ($\mu mol \cdot m^{-2} \cdot s^{-1}$)		
	Evaluation date in 2019			Evaluation date in 2019		
	March 22nd	March 25th	March 29th	March 22nd	March 25th	March 29th
8	17.20 a[Z]	20.60 a	18.52 a	316.0 a	410.0 a	313.3 a
10	17.12 a	20.23 a	15.96 a	403.3 a	380.0 a	289.3 a
13	16.05 a	26.36 a	22.66 a	470.0 a	430.0 a	450.0 a

[Z]Averages with the same letter, within columns, are equal according to Tukey's test ($P \leq 0.05$); NFT: nutrient film technique; SPAD: leaf chlorophyll concentration index; PPFD: photosynthetic photon flux density.

Under fall-winter conditions, fresh weights from 91 to 145 g have been reported for the same seven heat-tolerant lettuce varieties. The yields were higher in the second trial due to lower fall temperatures (Rodríguez, Chang, and Hoyos, 2001). In an autumn trial (maximum temperature 22.9 °C and minimum 14.9 °C), Coronel, Chang and Rodríguez (2009) reported dry weights of 9.0 and 11.5 g and fresh weights of 147 and 248 g in lettuce grown hydroponically in a floating root system in Manuela (butterhead type) and Asterix (oak leaf type) varieties, respectively. Valverde, Chang and Rodríguez (2009) reported dry weights of 8.6 and 9.5 g and fresh weights of 123.6 and 276.0 g in five lettuce varieties grown in summer in environments with and without 50 % black netting, respectively; being the Fanfare variety green leaf type, a one that produced the highest dry and fresh weight (9.9 and 224.5 g, respectively).

The significant difference in growth and yield in lettuce plants in the different modified NFT systems in this experiment did not influence chlorophyll content since no significant differences were found in SPAD units (Table 2). SPAD readings correlate with chlorophyll and the Rubisco enzyme content, net photosynthetic rate, and photosystem II quantum yield, so the SPAD meter has the potential to estimate leaf photosynthetic capacity (Kumagai, Araki, and Kubota, 2009). Chlorophyll content increases in proportion to the nitrogen content in the leaf. A high SPAD value indicates a healthy plant (Son, Jeon, and Oh, 2016). SPAD units in the same plant reach relatively higher and lower values in adult and young leaves, respectively (Maleki, Massah, and Dehghan, 2012). Fraile-Robayo et al. (2017) found low chlorophyll content (SPAD units) in butterhead lettuce type, variety Black Simpson, producing pale green leaves, similar to the variety Ariana used in the trial. Plants with adequate nitrogen, magnesium, iron, and manganese nutrition have higher chlorophyll content (SPAD values) and correlates with a higher photosynthetic rate (Son et al., 2016). The SPAD values obtained in lettuce plants can change depending on the variety, environmental light conditions where the crop grows, and nitrogen, magnesium, iron, and manganese concentration. The nutrient solution used by Fraile-Robayo et al. (2017) had nitrogen, magnesium, iron, and manganese concentration of 224.0, 82.0, 4.0, and 2.0 $mg \cdot L^{-1}$, respectively, while the nutrient solution used in the trial had concentrations of 190.0, 40.0, 1.0 and 0.8 $mg \cdot L^{-1}$, respectively. The higher nitrogen, magnesium, iron, and manganese concentrations in the nutrient solution used by Fraile-Robayo et al. (2017) would explain the relatively high SPAD value (27) achieved in lettuce plants at 39 days after transplanting, while the SPAD values in the present trial ranged from 18.5 to 22.6 at 30 days after transplanting (Table 2). Escalona, Santana, Acevedo, Rodríguez, and Merú (2009) found SPAD values of 20.5 and 29.1 in external leaves and 13.6 to 21.6 in internal leaves of Great Lakes 659 lettuce variety grown with different nitrogen sources, finding the highest SPAD values and nitrate content when the nitrogen source was calcium nitrate. Other mineral elements such as strontium, although not an essential nutrient, can increase SPAD values in lettuce leaves grown in nutrient solution obtaining the highest SPAD values (16 to 20) in plants grown with concentrations of 2.5 and 10.0 mM (Yan et al., 2019).

No significant differences were found in the incident PPFD values in the area where lettuce plants grew and developed (Table 2), ranging from 289.3 to 470.0 $\mu mol \cdot m^{-2} \cdot s^{-1}$. In the external environment, over the 65 % shade screen, the PPFD ranged from 900 to 1,000 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Photosynthetic photon flux density (PPFD) is a way to measure light efficiency or intensity. Environments with values ranging from 200 to 400 $\mu mol \cdot m^{-2} \cdot s^{-1}$ are ideal for seedling growth, and values ranging from 400 to 600 $\mu mol \cdot m^{-2} \cdot s^{-1}$ are optimal for early to late-stage vegetative cycles. Both, Albrigh, and Langhans (1998) evaluated six combinations of PPFD ($mol \cdot m^{-2} \cdot d^{-1}$) and CO_2 concentration ($\mu mol \cdot mol^{-1}$) in lettuce grown 35 days after transplanting. Plant growth in treatments was similar, generating average yields of 190 g fresh weight, with a dry matter percentage of 3.7 %. Both, Albright, Langhans, Reiser, and Vinzant (1997) evaluated different levels of PPFD (from 8 to 22 $mol \cdot m^{-2} \cdot s^{-1}$) in Bibb-type lettuce variety Ostinata, observing differences in marketable lettuce head yield (150 g fresh weight) 24 days after transplanting when plants were grown with a PPFD of 17 $mol \cdot m^{-2} \cdot d^{-1}$. Kang, Krishnakumar, Atulba, Jeong, and Hwang (2013) applied four levels of PPFD (200, 230, 260, and 290 $\mu mol \cdot m^{-2} \cdot s^{-1}$) using LED lights on lettuce plants with a combination of three different 18-h photoperiods (one 18/6 cycle, two 9/3 cycles, and three 6/2 cycles). The combination of PPFD of 290 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and long 18-h photoperiod (one 18/6 cycle) resulted in higher fresh weight, root length, and leaf dry weight. Environments with PPFD of 290 $\mu mol \cdot m^{-2} \cdot s^{-1}$ with a shorter photoperiod of three 6/2 cycles produce good plant growth and lettuce development.

Financial analysis

The difference in cost between the three modified systems evaluated is mainly explained by the number of materials used for each module, of which the 13-channel pyramidal system requires the highest number of 3" × 3 m PVC pipes and 3" PVC covers, followed by the 10- and 8-channel modules, respectively (Table 3). Although the three systems use three trestles, the cost of the 13-channel module trestles is higher because it requires more materials (corrugated iron) for its assembly and consequently higher labor costs. So each trestle is priced at 720.00 MX pesos, i.e., 16. 6 % and 33.3 % more than the 10- and 8-channel module trestles, costing 600.00 MX pesos and 480.00 MX pesos, respectively, without considering additional accessories such as a ¾" connector light cell, ¾" SE curve and 16 mm × m PE hose, among others, contributing to the higher budget. In this context, the number of materials determines that the cost per NFT module of 3.0 m × 1.5 m is 3,532.20 MX pesos, 4,144.20 MX pesos, and 4,869.00 MX pesos for the 8-, 10- and 13-channel systems, respectively. It implies 14.8 % and 27.4 % lower investment in the 8- and 10-channel systems versus the 13-channel system.

Table 3. Materials and cost of three 3.0 m × 1.5 m modified NFT (Nutrient Film Technique) modules.

Materials	NFT System			Unit Price (Mx Pesos)
	8	10	13	
3" × 3 m PVC pipe	8	10	13	69.0
3" PVC cap	16	20	26	6.0
2" × 3 m PVC pipe	1	1	2	45.0
2" PVC cap	2	2	2	3.0
2" PVC Elbow	0	1	2	9.0
2" PVC tee	1	0	1	12.0
2" PVC Y-joint	0	2	3	14.4
1" PVC union with thread	1	1	1	10.8
¾" light cell connector	8	10	13	6.0
¾" SE bend	8	10	13	3.0
3 mm × m microtube	2	3	5	9.0
1 to ¾" reducing bushing	3	3	3	12.0
16 mm elbow	2	2	2	6.0
16 mm tee	2	2	2	4.8
16 mm stopcock	2	2	3	12.0
PE hose 16 mm × m	8	10	14	3.6
100 liter tank	1	1	1	240.0
0.5 HP electric water pump	1	1	1	600.0
8 Horizontal trestle	3	0	0	480.0
10 Pyramidal trestle	0	3	0	600.0
13 Pyramidal trestle	0	0	3	720.0
Gallon of white enamel	1	1	1	210.0
Gallon of hinner	1	1	1	120.0
Cost in MX pesos	3,532.20	4,114.20	4,869.00	
Cost in USD	176.61	205.71	243.45	

Parity: 1 USD = 20.00 Mx pesos; NFT (Nutrient Film Technique)

Tables 4, 5, and 6 show the quantity and cost of inputs and production costs of lettuce plants grown in three 3.0 m × 1.5 m modified NFT modules, respectively. In Table 5, a six-month amortization is considered for variable cost inputs and, according to the economic analysis, the lettuce production cost in 8-, 10-, and 13-channel modified NFT systems resulted in 6.17, 5.51, and 4. 90 MX pesos, respectively (Table 6). Although it is worth mentioning that the production cost does not consider labor, since the production proposal involves 3.0 m × 1.5 m small modules that can be installed somewhere in the house, generating income for the family as a way of remuneration for the care and work of growing lettuce. The hydroponic lettuce price in supermarkets varies from 15.00 MX pesos (in the packaging of polypropylene bags) to 36.00 MX pesos if the packaging of the piece is in a plastic container or clamshell. If each lettuce is sold at 12.00 MX pesos, even in bulk, without polypropylene bags, a profit of 83.5 %, 117.4 %, and 243.9 % will be achieved for lettuce grown in the 8-, 10-, and 13-channel systems, respectively. However, considering that the minimum weight requested by the market is 200 to 250 g per lettuce or package, the 10-channel modified NFT system would be the most profitable since it allowed obtaining plants with higher fresh weight (112.63 g) and higher yields of 4.75 $kg \cdot m^{-2}$ and 21.38 kg per NFT system (Table 1). According to Conchouso and Rodriguez-Delfin (2015), a hydroponic lettuce's selling price in Mexico in 2011 was 7.00 MX pesos (0.50 USD, SEGOB, (2011). Pertierra and Gonzabay (2020), using the floating root system, reported a selling price of 0.50 USD per lettuce from the grower to the supermarket, while the supermarket sells the unit for 1.00 USD to the consumer. Currently, the selling price in Mexican supermarkets can range from 10.00 MX pesos to 15.00 MX pesos (0.50 USD to 0.75 USD, SEGOB, (2021). In an area of 100 m^2, 2,500 lettuces can be grown monthly with a horizontal NFT system so that the weekly income would be 4,038.00 MX pesos and an outflow of fixed and variable costs of 1,219.70 MX pesos. So there is a positive difference of 2,819.70 MX pesos per week (201.4 USD) (Conchouso and Rodríguez-Delfín, 2015), which makes hydroponic production with NFT system profitable.

Table 4. Lettuce production inputs in three 3.0 m × 1.5 m modified NFT modules.

Production inputs	Cost (MX pesos)	Multi-channel NFT systems		
		Horizontal 8	Pyramidal 10	Pyramidal 13
Salt set for 1,000 liters	240.00	1	1	1
Lettuce seed (1,000-seed envelope)	210.00	130	160	200
Small pot for holding seedlings	1.80	120	150	190
40 x 40 cm Floating root container for 70 seedlings	90.00	2	3	4
40 x 40 Seedling container	60.00	1	1	1
Substrate quarry sand x sack	60.00	1	1	1
0.5 m3 x Water	30.00	1	1	1
6 x Yellow traps	18.00	1	1	1
6 x Blue traps	18.00	1	1	1
350 ml x Entomological rubber	120.00	1	1	1

Parity: 1 USD = 20.00 Mx pesos; NFT (Nutrient Film Technique)

Table 5. Six-month amortization of input investment for lettuce production grown in three 3.0 m × 1.5 m modified NFT modules.

Production inputs	Multi-channel NFT systems		
	Horizontal	Pyramidal	
	8	10	13
Salt set for 1,000 liters	240.00	240.00	240.00
Lettuce seed (1,000-seed envelope)	27.30	33.60	42.00
Small pot for holding seedlings	36.00	45.00	57.00
40 x 40 cm Floating root container for 70 seedlings	30.00	45.00	60.0
40 x 40 Seedling container	10.00	10.00	10.00
Quarry sand substrate x sack	10.00	10.00	10.00
0.5 m3 x Water	30.00	30.00	30.00
6 x Yellow traps	3.00	3.00	3.00
6 x Blue traps	3.00	3.00	3.00
350 ml x Entomological rubber	20.00	20.00	20.00
Cost in MX pesos	409.30	439.60	475.00
Cost in USD	20.47	21.98	23.75

Parity: 1 USD = 20.00 Mx pesos; NFT (Nutrient Film Technique)

Table 6. Production cost (MX pesos) of lettuce grown in three 3.0 m x 1.5 m modified NFT modules.

Production inputs	Horizontal 8	Pyramidal 10	Pyramidal 13
NFT system materials (1 year)	294.36	342.84	405.78
Production inputs (6 months)	409.30	439.60	475.00
Total production cost	703.66	782.44	880.78
Total lettuce production	120	150	190
Loss 5 %.	6	8	10
Lettuce production minus loss	114	142	180
Unit cost in Mx pesos	6.17	5.51	4.90
Unit cost in USD	0.31	0.28	0.24

Parity: 1 USD = 20.00 Mx pesos; NFT (Nutrient Film Technique)

Conclusions

Of the systems evaluated, the 10-channel pyramidal module is the most appropriate for growing lettuce in a hydroponic system because it generated the highest yield and product weight for the market along with the highest utility, representing an alternative to producing in houses with reduced space.

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