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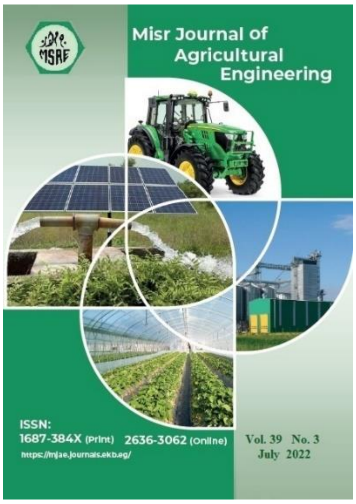
IMPACT OF "A" FRAME ANGLE DESIGN ON HYDROPONIC SYSTEM PRODUCTION

Ahmed F. Khedr[1], Sameh S. Kishk[2] and Abdeltawab M. I. Zedan[3&*]

[1] Assoc. Prof. of Irrigation and Drainage Eng., Ag. Eng. Dept., Fac. of Ag., Suez Canal U. Egypt.
[2] Assoc. Prof. of Ag. Const. Eng. and Environ. control, Ag. Eng. Dept., Fac. of Ag., Suez Canal U. Egypt.
[3] Assoc. Prof. of Irrigation and Drainage Eng., Ag. Eng. Dept., Fac. of Ag., Zagazig U., Egypt.
* E-mail: Mto252000@yahoo.com



Keywords:
Hydroponic; "A" Frame design; Production; Lettuce; Mint.

ABSTRACT

The scarcity of water become global problem, the "A" frame structure system is commercially extended in the hydroponics industry. The objective of this work was to evaluate the impact of different "A" frame angle design for NFT system design, water depth in pipes and pipes position, on growth of two leafy vegetables parameters. The treatments were the angle of "A" frame design (A^o), (45° and 60°), Water depths (4 and 6 cm), and leafy plants (lettuce and mint). The results indicated that, the changing angle from 180° to 60° and 60° to 45° decreased the occupied surface area by 45.0 % and 25.76 %, respectively. The light intensity values were decreased by changing the "A" frame angle from 60° to 45° by 26.4 % for lettuce and 32.0 % for mint. Changing the position of the pipe from center to bottom decreased the light intensity for lettuce by 9.2 % and 11.7 % for 45° and 60° angels, respectively. While increased by 21.2 % for mint with 45° angle only. Root length and stem diameter were increased by changing angle from 45° to 60° and water depth from 4 to 6 cm for both mint and lettuce plants. Optimal yields of lettuce and mint plants grown in "A" frame hydroponic system with 45° angle like those plants grown with 60° angle, indicating from no significant differences in the production of lettuce and mint plants. The "A" frame design with 45° angle can be recommended for production of lettuce and mint.

1. INTRODUCTION

Food is one of the crucial topics in sustainability debates today on a global platform. Hydroponic farming is a type of crop production in which the plants grow without the use of soil. It is mainly done indoors. Hydroponic production has various advantages for the food system, including water efficiency, space efficiency, year-round production, and system productivity. Nowadays, scarcity of fresh water and cultivated land has become a major problem in many countries of the world, due to the increase in the human population. Water is a prerequisite for successful hydroponic operations. Hydroponics is a rapidly developing technique for growing plants in enriched nutrient solutions required without the presence of soil (Nhut *et al*., 2006; Jones, 2016 and Resh, 2022). The term hydroponics derives from the Greek words 'hydro' for water and 'ponos' for labor. It is sometimes referred to as 'soilless culture' and 'hydroculture' (Jones, 2016). Hydroponics is the practice to grow plants in a controlled environment (*i.e.*, temperature, humidity, light intensity) to meet the needs of crops under greenhouses or indoor farming conditions (Takeda, 1997 and Resh, 2022). Hydroponics systems are characterized as open (*i.e.*, the nutrient solution is delivered to the plant roots once without reusing the solution again) or closed (*i.e.*, the nutrient solution is recycled, recovered, and replaced) (Jensen, 1989 and Jones, 2016). There are many systems for growing plants hydroponically such as horizontal, vertical and "A" frame designs, the "A" frame structure system is commercially extended in the hydroponics industry. In hydroponics, there are general growing systems used such as nutrient film technique (NFT), deep flow technique (DFT), dynamic root floating technique (DRFT) and substrate culture (Koohakan et al., 2008).

Hydroponics is the process of growing plants without soil. Instead, plants are grown in a growing medium, and the roots get nutrients from a water-based solution that they are directly immersed in (Griffiths, 2014). Understanding the purpose of soil in a plant's life can give a clear insight into how hydroponics works. Soil is the medium that gives air, support, and balance to a plant, and most importantly, retains water and nutrients and supplies them to the roots (Mason, 2005).

In hydroponics, the support and balance are provided by a growing media, which also helps in maintaining a good water/oxygen ratio and nutrients are delivered by the system adapted. Lettuce is traditionally cultivated in soil but recently, alternative soilless cultivation techniques have been considered. Although the cultivation of the soil is inexpensive, it brings about some risks. Soilless systems are suited to produce with short culture cycles. Plant nutrition can be better controlled in these systems and soil contamination is avoided.

Nutrient Film Technique (NFT) is better for short-statured plants, including Deep Water Culture., but these systems carry far less water per plant and are easier to stack, clean, and customize according to the requirements. (Yuvaraj and Subramanian, 2020). Several studies revealed that hydroponics is contributed to enhancing agriculture productivity by avoiding the environmental limitations at a large-scale (Craver and Williams, 2014). Mainly, ecological factors like temperature, humidity, and light intensity can be maintained or manipulated in a hydroponics system to avoid a decrease in crop productivity due to uncomfortable environmental conditions (Ruiz and Taleisnik, 2013 and Smeets *et al.*, 2008). Hydroponics allows the control of air, and temperature, light, water, plant-available nutrients and it protects the growing plants against adverse climatic conditions (Jones, 2016 and Ruiz and Taleisnik, 2013). Most commercial hydroponics farmers developed hydroponics technology in a controlled environment under greenhouse conditions to achieve the high-quality crop yield through controlling the ambient temperature, humidity and light intensity allowing crop production on a year-round basis commercially (Jones, 2016 and Resh, 2022).

Hydroponics had several advantages over soil-grown plants. First, plant nutrients and water are delivered directly to the plant roots contributing to upward green growth and fruit production without any stress on the growing plants from the lack of nutrients or water. Second, hydroponically plants grow and produce faster than their soil-grown counterparts. Three, numerous plants can be grown in a smaller area. Fourth, hydroponics systems recycle the nutrient solution for reuse in the next watering cycle, conserving water and reducing fertilized waste/run-off. Fifth, nutrients can be more precisely maintained to meet plant requirements by weather conditions and other variables. Finally, it provides the best management practices for pest control (Jensen, 1989; Jones, 2016; Nhut *et al.*, 2006; Resh, 2022 and Takeda, 1997).

The hydroponic component has a lot of designs for making the best use of floor area and serves as a biofilter, and therefore a separate biofilter is not needed as in other recirculating systems. Biological filtration is defined as the bacteriological conversion of the organic nitrogenous compounds into nitrate. The primary purpose of a biological filter is the conversion of ammonia to nitrite and nitrite to nitrate. This conversion is of great importance in the culture of aquatic organisms because ammonia is highly toxic. Nitrite is less toxic than ammonia, while nitrate is considered relatively nontoxic to most aquatic organisms (Wheaton, 1993). Hayden (2006) Reported that the "A" frame structure a 60° angle Permits 1.7 times more growing area than the unit's footprints in the greenhouse and allows the use of vertical space to provide 34 m^2 of crop growing area in 20 m^2 of greenhouse floor space. The main objective of the present study is to investigate the appropriate water height in the PVC-pipe for (NFT) Hydroponic system beside the optimal angle of "A" frame hydroponic system and the maximum water productivity and best using of occupied surface area with better growth for yield of both lettuce and mint plants.

2. MATERIALS AND METHODS

The experiment was conducted at the building roof of the Agricultural Engineering Department, Faculty of Agriculture, Suez Canal University, Ismailia, Egypt. During season 2021 (from 1st February to 4th March) to study the impact of different angles of the "A" frame design (A^o), water depth in pipes (D) and pipes position (PP) for Nutrient Film Technique (NFT) Hydroponic system on two types of leafy plants (lettuce and mint), water productivity and statistical analysis for plant growth parameters.

Description of NFT Hydroponic System:

The components that were included in this system were an angle iron "A" frame supporting the hydroponic system, PVC pipes, end caps, tanks (reservoir), microtube, lateral pipe, submersible pumps, net cups, and joiner as shown in Figure 1, the design was drawn by using Solid-Work Software (Version 2018). The system was a closed system for recycling water and contains one PVC circular tank with a volume of 1 m^3 that was used as water supply (tank of fish water) and fish water obtained from Fish Farming & Technology Institute, Suez Canal University. A semi-circular tank was used as biological filter put horizontally with dimension 0.25 m width and 0.8 m height, water enters in the tank by the pipe that put cross in it, and passes through a plastic panel that put with 45° angle and save time for more of delivered water to circular a plastic tank for supplying water to PVC pipes system. Two submersible pumps model UNEE HP-8000 with high max 3.5 m and Q max 3500 ℓ/h were used in the system. Submersible pumps were used for the circulation of nutrient solutions. The flow of fish water through the growing channel was established between 1.5 to 2.0 ℓ per minute as recommended by Fumiomi (1999) for short-cycle plants. The "A" frame was made from iron and painted with an anti-rust coating which makes the "A" frame flexible to change the angle and take less area for storage.

The PVC pipes were used with 10 cm (4 inches) diameter, 300 cm length and zero slopes stand on the "A" frame design with row spacing of 35 cm. The pipes were made of PVC material has a white color to reflect the fallen rays from the sun and make the pipe cooler which leads to a more suitable wastewater temperature for roots. The pipes were connected by an inlet and outlet to the tank, the effluent was drained by gravity flow back into the tank through a return pipe.

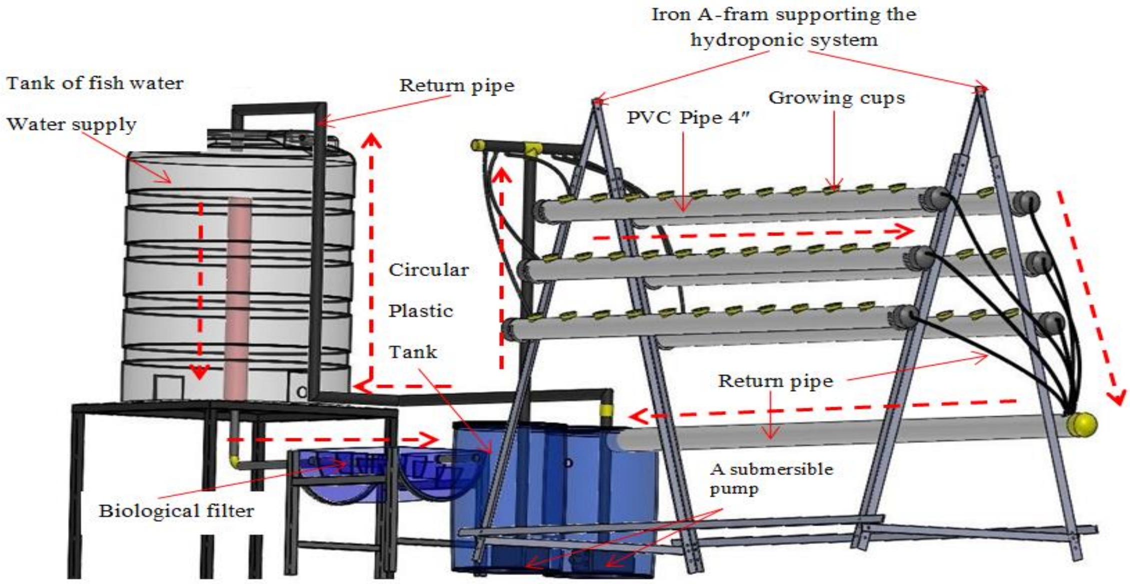


Figure 1: A schematic diagram illustrates the design of the Nutrient Film Technique (NFT) Hydroponic system.

The experimental Treatments:

The hydroponic units in this study consisted of water discharge from the fish farm, the treatments were two "A" frame angles (A^o) 45° and 60°, two water depths in pipes 4.0 and 6.0 cm and two types of leafy vegetables Lettuce and Mint as shown in Figure 2. Intermittent flow (20 minutes "on" and 20 minutes "off") as described by Benoit and Ceustermans (1989).

The "A" frame structure system a 60° angle has a dimension of 220 cm in width, 300 cm length and 180 cm in height. The maximum shading for the system to the lowest pipe for the next one was 120 cm so that the "A" frames interval distance was 120 between widths, and 50 cm between lengths for crop service. By imposing the hectare area (10000 m^2) with a dimension of (100 x 100 m^2) having 812 NFT systems by (29 x 28) for system widths and lengths, respectively. The one system contains 12 growing pipes and the one pipe contains 12 plants with 116928 plants in total surface area for a hectare unit by using an "A" frame structure system at a 60° angle.

In the same trend, an "A" frame design at a 45° angle has a dimension of 165 cm in width, 300 cm length and 200 cm in height. The maximum shading for the system to the lowest pipe for the next one was 130 cm so the "A" frames interval distance was 130 between widths, and 50 cm between lengths for crop service. So that the hectare area has 952 NFT systems (34 x 28) for system widths and lengths, respectively with 137088 plants in total surface area for hectare unit by using an "A" frame structure system at 45° angle.

The water was pumped from the plastic tank to the upper end of the pipes in the NFT hydroponic system, the tank with a 220-liter capacity was used for collecting the drained wastewater by gravity from the end of the pipes, and then the clean water pumped to the fish water tank by a submersible pump.

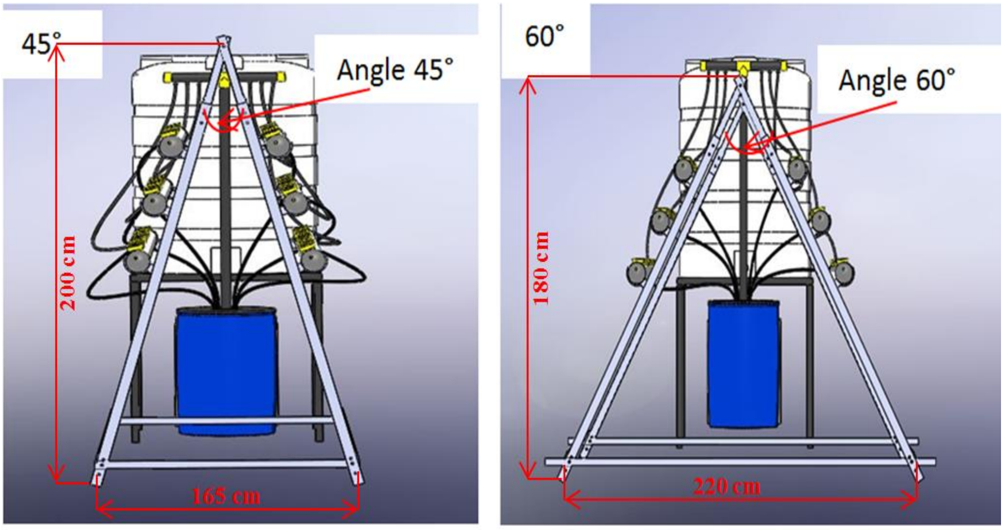


Figure 2:"A"frame NFT hydroponic system with two angles 45° and 60°.

Plant materials:

The seedlings Lettuce (*Lactuca sativa L.*) and Mint (*Menthe L.*) were obtained from private a nursery. Planting pipes and the growing net cups also were cleaned. Lettuce and mint plants were transplanted in net plastic cups (7 cm diameter and 7 cm height) filled with gravel for supported plants and were inserted in the NFT hydroponic system and the planting depths were 4 cm and 6 cm at the two different "A" frame structure systems at 60° and 45° angle (A^o). The net cups were irrigated daily; the planting spacing on the row was 20 cm, according to Khater (2006). The experimental period was from 1st February to 4th March 2021.

Nutrient solution management:

The nutrient solution is the most important chemical in the hydroponic system. Plants require essential elements for their growth and development. Without these nutrients, plants cannot complete their life cycles and their roles in plant growth cannot be replaced by any other elements. All essential nutrients were supplied to hydroponics in the form of nutrient solution, which consists of fertilizers salts dissolved in water. In the present study, the nutrient solution was prepared by the following method which is Cooper (1979) illustrated in Table 1. The solution was prepared by mixing different chemicals like calcium nitrate, potassium nitrate, sulphate of potash, monopotassium phosphate, magnesium sulphate and Fe chelated with water. Electrical conductivity EC at 2 - 2.5 ds/m and pH 6 - 6.5 values of the nutrient solution were adjusted at the optimum range of growth. A complete replacement for the nutrient solution was done. For nutrient solution management daily measurements were made of pH and EC in the nutrient solution tank. For correction of electrical conductivity, the nutrient solution prepared was used. For pH control, Stock solution of phosphoric acid was used. Nutrient solutions were monitored and adjusted daily for pH and electrical conductivity (EC) throughout the experimental time.

Table 1: Nutrient elements concentration in 1000 liters of water (Cooper, 1979).

Nutrient elements source	Elements	Concentration, ppm
$Ca(NO_3)_2$ Calcium nitrate	N	200
$H3PO_4$ Phosphoric acid	P	60
$K2SO_4$ Potassium sulfate	K	300
$Ca(NO_3)_2$ Calcium nitrate	Ca	170
$MgSO_4$ Magnesium sulfate	Mg	50
Fe EDTA (12%) Iron chelate	Fe	5.0
Mn EDTA (12%) Manganese chelate	Mn	1.0
$CuSO_4$ Copper sulfate	Cu	0.1
Zn EDTA (12%) Zinc chelate	Zn	0.1
$H3BO_3$ Boric acid	B	0.4
$(NH_4)_6MO7O_{24}$ Ammonium molybdate	Mo	0.05

Plant Growth Parameters Measurements:

The plant growth parameters, yield measurements and environmental conditions were light intensity (LUX), water temperature, °C (T), growth parameters such as Length of Root, cm (LR), Stem diameter, mm (SD), fresh (Fr) and dry mass of root (R) and shoot (Sh) g/plant at different water depths (D) and pipes position (PP) for lettuce and mint plants and the occupied surface area by plants was measured.

Root diameter was measured by a digital micrometer, light intensity was measured by Lux meter model LX 1010BS, pH was measured by the pH meter model 3510, EC was measured by the EC meter model AD31, the water temperature was measured by a digital thermometer and fresh and dry weight was measured by digital balance device and pH and EC were measured directly in the system to keep constant range for pH 6 - 6.5 and 2 - 2.5 ds/m for EC, the measured was daily during the experimental period. The root and shoot lengths were estimated by setting a scale using the ruler beside the plant according to Nunes Maciel et al. (2013).

At the end of the experiment, plants were harvested. Roots and shoots were separated. Roots and shoots were thoroughly washed with distilled water. Plant material was dried in an oven at 60^{o}C for three days and weighted to measure crop production and the fresh and dry weight of shoot and root was measured at the end of the experimental period. After measuring fresh weight the plants were dried in the electrical oven at 70°C their dry biomasses were determined (Awad et al., 2017) until a constant weight was reached.

Water productivity:

Definition of water productivity as the physical mass of production or the economic value of production measured against gross inflow, net inflow, depleted water, process depleted water, or available water. Water productivity is usually estimated as the amount of agricultural output produced per unit of water consumed. Mathematically water productivity is expressed as: Water Productivity (kg/m^3or \$/m^3) = Output derived from water use (kg or \$) / Water input (m^3).

Water productivity defined as the ratio of the mass of agricultural output to the amount of water used and economic water productivity defined as the value derived per unit of water used (Kijne et al., 2003)

Planting pipes were irrigated every day by intermittent flow (20 minutes "on" and 20 minutes "off") as described by Benoit and Ceustermans (1989) for each NFT hydroponic system to provide enough water that keep the seedlings moist. Daily amounts of water used in irrigation were recorded to compute the total amounts used in irrigation throughout the experimental period. Drained water was recycled in the plastic tanks which were placed under each planting system. The total water used by plants (liters/pipe) was computed as the following:
Water consumption (m^3/m^2) = Total irrigation water in the tank at the beginning of the experiment - Total irrigation water in the tank at the end of the experiment.

Statistical analysis:

Data were statistically analyzed using SPSS program version 23. The averages of different study factors and standard errors (SE) were calculated. The two-way ANOVA test was performed for comparison between the different level of study factors (i.e., angle (A^o), water depth, and their interaction) and followed by a post hoc test using the Duncan multiple range (DMR) test for comparisons between means of study factors, where the means followed by the same letter are not significantly different from each other at the 5-percent probability level (p-value at 0.05).

3. RESULTS AND DISCUSSION

The influence of "A" frame hydroponic design for NFT hydroponic system on two different leafy crops (lettuce and mint) plants growth. The work was divided into two categories; firstly, the research assesses the optimal angle of "A" frame design (A^o) which affects the light intensity and the occupied surface area. Secondly, study the effect of the angle of "A" frame design and water effluent depths in the pipes on plant growth parameters, total fresh yield and water use efficiency (WUE). The results will be showing the impact of each factor clearly and their interaction.

The influence of "A" frame design angles (45° and 60°) on light intensity and water effluent temperature for lettuce and mint plants, under the following parameters.

The impact of "A" frame angle (A^o) on the occupied surface area:

The result revealed that there were variations in the occupied surface area according to the treatments. The occupied surface area by plants was decreased by using "A" frame angle and influenced by changing its angle. Figure 3 shows the comparison between "A" frame angles (60° and 45°) for occupied surface area (m^2). The occupied surface area was decreased by decreasing the angle from 180° (datum level) to 60° and 45° "A" frame angle as (12 to 6.6 m^2 by 45.0 %) and (12 to 4.90 m^2 by 59.17 %), respectively. As the same trend the occupied surface area decreased by decreasing the "A" frame angle (A^o) from (60° to 45°) as (6.6 to 4.90 m^2 by 25.76 %), these results agree with Ahmed (2019).

The impact of "A" frame angle (A^o) on Light intensity:

The light intensity (*LUX*) was influenced by "A" frame angle, plant type and pipes position for all pipes except the top. The *LUX* was relatively increased by increasing the "A" frame angle for both lettuce and mint plants as shown in Table (2) and Figure (4). The average intensity values increased by increasing the "A" frame angle from (45° to 60°) for the maximum growth of lettuce plant as (1200 to 1630 *LUX*) on center and from (1090 to 1440 *LUX*) on the bottom pipe position, respectively due to highest exposure of sunlight that falls on the big width. As the same, the intensity values increased from (1320 to 1940 *LUX*) for the mint plant in the center and from (1600 to 1730 *LUX*) on the bottom pipe position, respectively according to Ahmed (2019). The intensity values decreased at the maximum growth from top to bottom position pipes with an angle of 60° for both lettuce and mint plants. On the other hand, the intensity increased in the bottom than the center pipe in the mint plant with an angle of 45° may be, due to the bigger shoot height for a mint plant in the bottom pipe in addition to the shadow from the top causing more shadow to the center one.

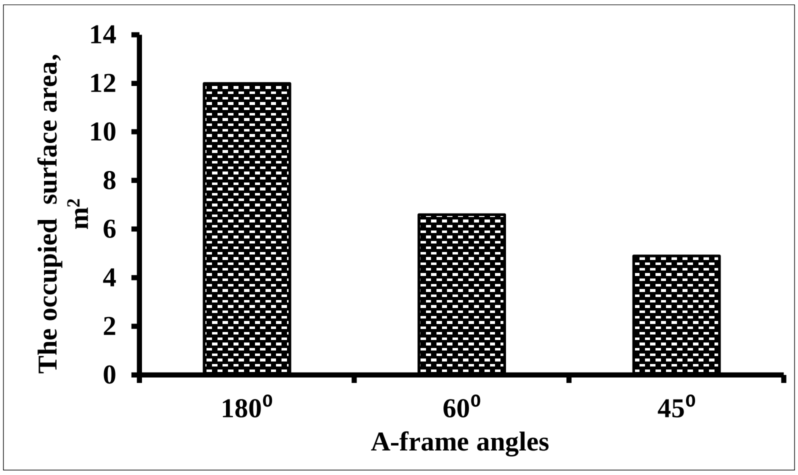


Figure 3: The assessment between "A" frame angle **(A^o),** (60° and 45°) for occupied surface area (m^2).

The light intensity values were decreased by changing the "A" frame angle from 60° to 45° by 26.4 % for lettuce and 32.0 % for mint. But, changing pipe position from center to bottom decreased the light intensity for lettuce by 9.2 % and 11.7 % for 45° and 60° angels, respectively. While increased by 21.2 % for mint with 45° angle only. The light intensity that fall on lettuce was lower than mint in "A" frame angled (45° and 60°). This is due to the increase in the shooting width of the lettuce to the mint plant.

Table 2: The impact of "A" frame angle (A^o) on light intensity (*LUX*) and water temperature (*T*) at different water depths (*D*) and pipes position (*PP*) for lettuce and mint plants.

Angle, A°	45°											
Depth,(cm)	4						6					
Plant	Lettuce			Mint			Lettuce			Mint		
Pipes position	Top	Center	Bottom	Top	Center	Bottom	Top	Center	Bottom	Top	Center	Bottom
LUX	1730	1200	1090	1800	1320	1600	1930	1630	1440	2125	1940	1730
Water temperature (°C)	22	20.5	21.3	22	20.5	21.3	23.2	22.9	22	23.2	22.9	22
Angle, A°	60°											
Depth,(cm)	4						6					
Plant	Lettuce			Mint			Lettuce			Mint		
Pipes position	Top	Center	Bottom	Top	Center	Bottom	Top	Center	Bottom	Top	Center	Bottom
LUX	1730	1200	1090	1800	1320	1600	1930	1630	1440	2125	1940	1730
Water temperature (°C)	22.6	22.3	22.5	22.6	22.3	22.5	23.4	22.6	22	23.4	22.6	22

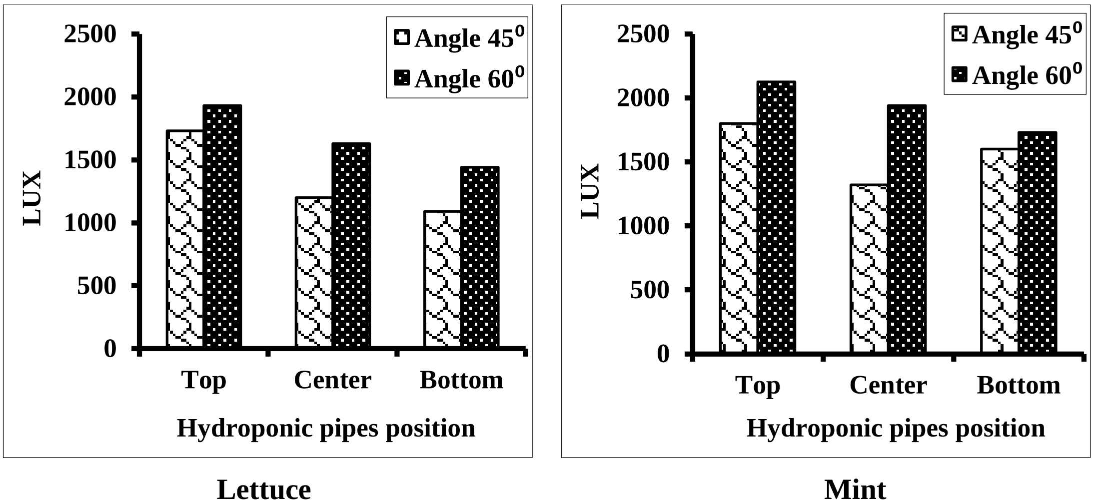


Figure 4: The impact of different "A" frame angles and pipes positions on light intensity (LUX) for lettuce and mint plants.

<u>Growth parameters and fresh yield:</u>

The growth parameters and total fresh yield were influenced by "A" frame angle, water depth and pipes positions for both lettuce and mint plants.

The impact of "A" frame angle (A^o) on root length and stem diameter:

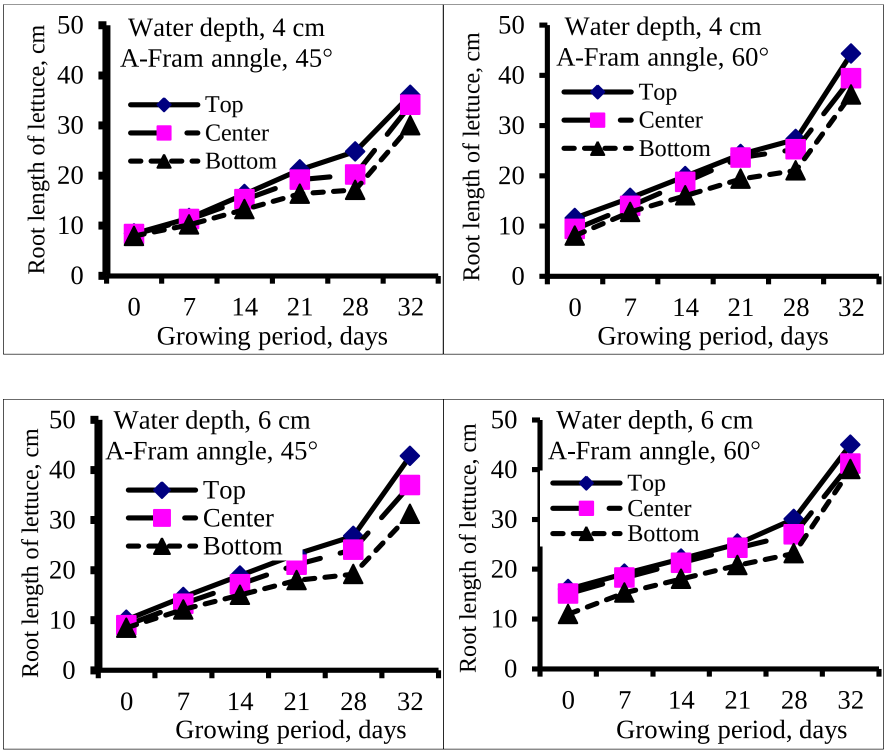
The results indicate that the root length and stem diameter were relatively increased by increasing the "A" frame angle and water depth for both lettuce and mint plant at each pipe position.

Where the root length values increased at the maximum growth from (45° to 60°) at "A" frame angle in 4 cm water depth on the center pipe from 34.1 to 39.4 cm and from 30.0 to 36.2 cm on bottom pipe, and in 6 cm depth from 37.0 to 41.2 cm on center and from 31.2 to 40.1 cm on bottom pipe position for lettuce plant, respectively. While, the root length values increased at the maximum growth from 45° to 60° at "A" frame angle in 4 cm water depth from 26.8 to 31.7 cm on center and from 28.9 to 31.0 cm on bottom pipe, and in 6 cm depth as 28.5 to 32.5 cm on center and from 30.5 to 31.4 cm on bottom pipe position for the mint plant, respectively as shown in Figures (5 and 6) and Table 3. These results agree with those obtained by Fahim (1989), Khater and Ali (2105).

The root length and stem diameter values from center to bottom pipe position with 45° and 60° "A" frame angle in 4 and 6 cm water depth decreased for the maximum growth of the lettuce plant. Also, the "A" frame angle 60° in 4 and 6 cm water depth values decreased from center to bottom pipe position for the mint plant. While root length and stem diameter values from center to bottom pipe with 45° "A" frame angle in 4 and 6 cm water depth increased for the growth of the mint plant as shown in Table 3.

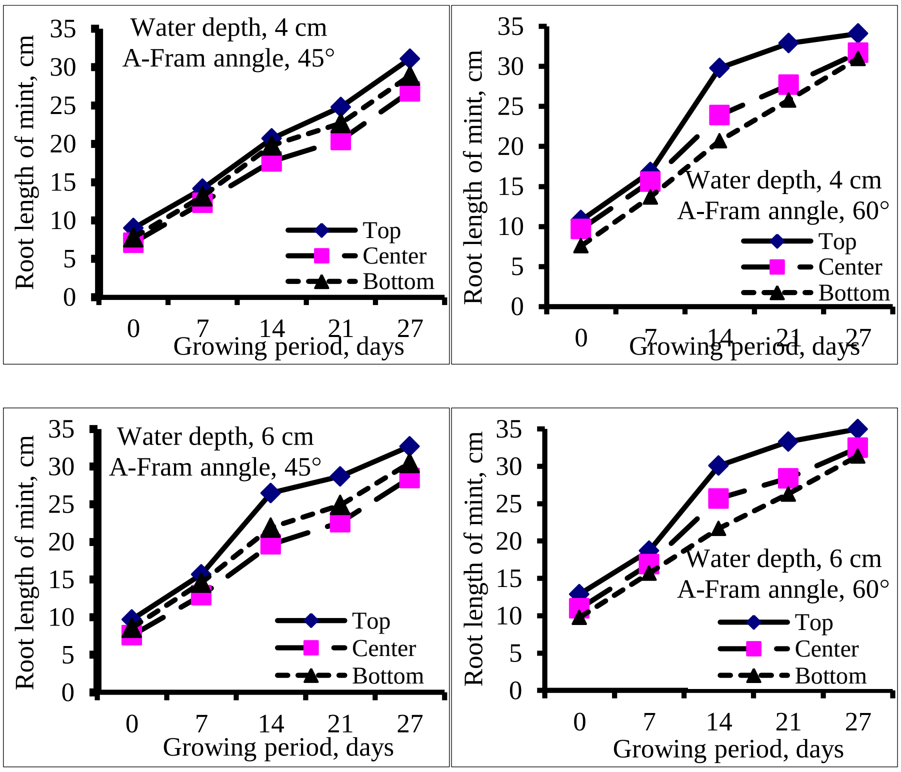
The influence of different “A” frame angles and water depth on fresh and dry weight:

The results showed that the fresh and dry weight of root and shoot were relatively increased by increasing the "A" frame angle from 45° to 60° and water depth from 4 to 6 cm for both lettuce and mint plant by each pipe position at the same root length and stem diameter but different values as shown in Figures 7 and 8. In contrast, fresh and dry mass of shoot and root increased for mint in the bottom than center pipe position with 45° angle. This is due to the increase in the shooting width of the lettuce to the mint plant and the increase in the light intensity.



"A" Frame of angle, 45° "A" Frame of angle, 60°

Figure 5: The impact of different "A" frame angles, water depth and pipe positions on lettuce root length for the growing period.

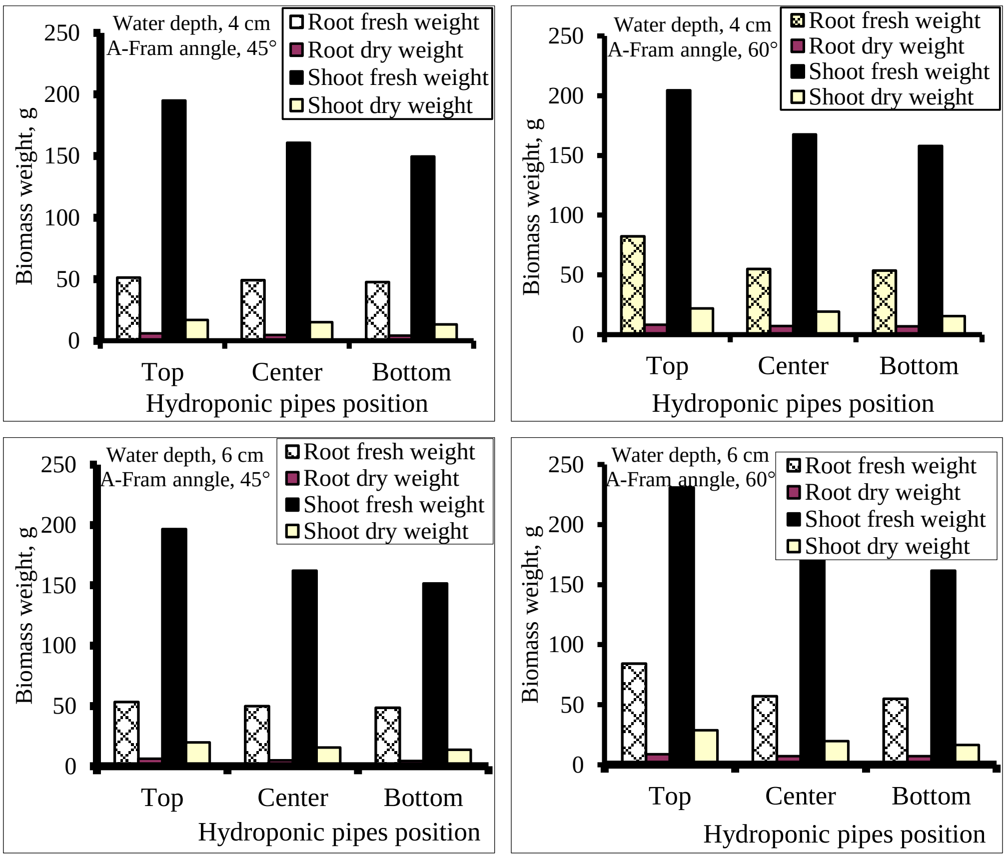


"A" Frame of angle, 45° "A" Frame of angle, 60°

Figure 6: The impact of different "A" frame angles, water depth and pipe positions on mint root length for the growing period.

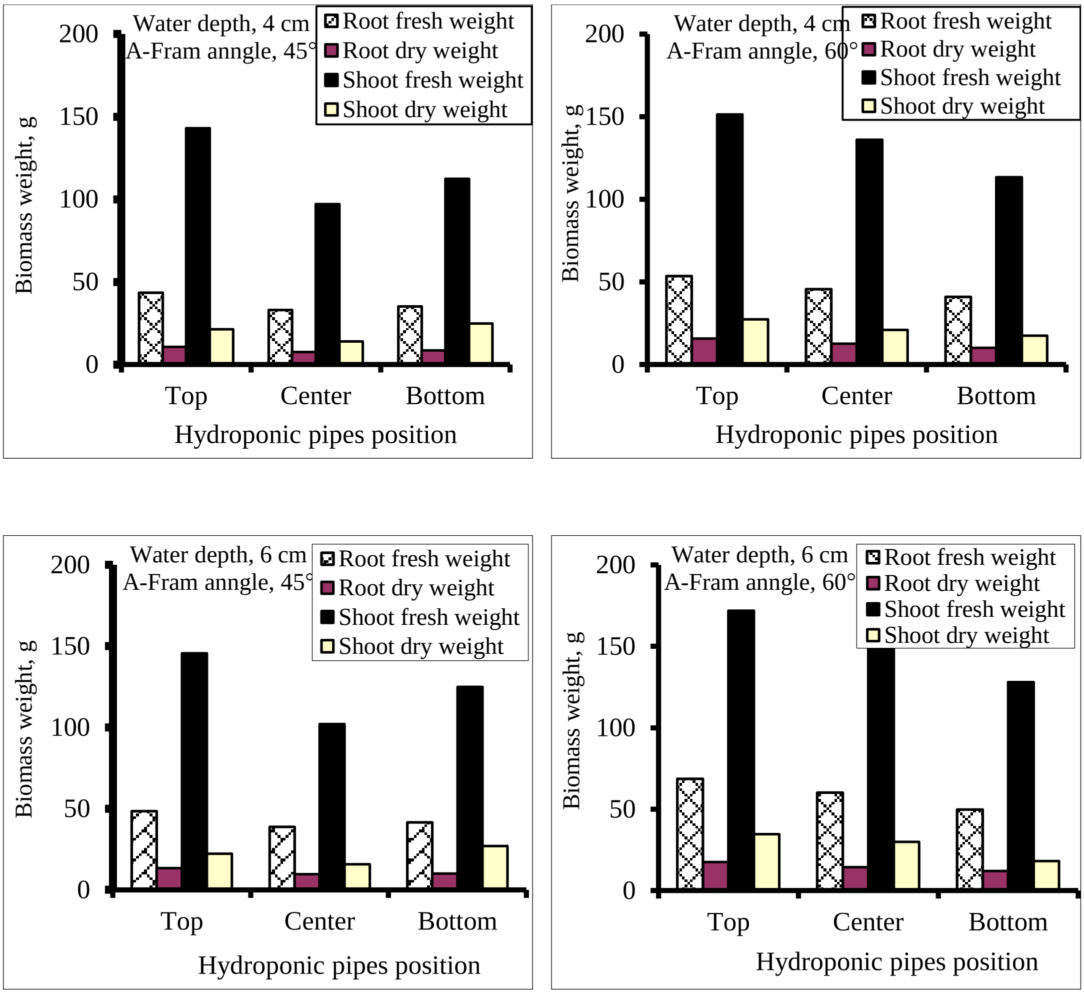
Table 3: Effect of different "A" frame angles on stem diameter at water depth (D) and pipe position (PP) for lettuce and mint plants through the growth season.

Date	D. (cm)	Angle	Stem diameter of plant, mm						
			Lettuce Pipe position			Date	Mint Pipe position		
			Top	Center	Bottom		Top	Center	Bottom
20/2/2021	4 cm	45°	13.76	9.79	8.36	20/2/2021	3.57	2.53	3.03
		60°	15.94	13.65	11.70		4.06	3.65	2.92
	6 cm	45°	15.28	12.86	10.86		3.70	2.70	3.10
		60°	17.43	14.60	12.09		4.15	3.80	3.20
4/3/2021	4 cm	45°	15.75	13.47	12.20	27/2/2021	3.90	2.80	3.70
		60°	18.07	16.19	15.06		4.39	3.80	3.10
	6 cm	45°	16.60	14.72	12.72		4.10	2.90	3.90
		60°	19.44	16.61	15.36		4.45	4.02	3.25



"A" Frame of angle, 45° "A" Frame of angle, 60°

Figure 7: The influence of different "A" frame angles and water depth on lettuce biomass weight for hydroponic pipes positions.



"A" Frame of angle, 45° "A" Frame of angle, 60°

Figure 8: The influence of different "A" frame angles and water depth on mint biomass weight for hydroponic pipes positions.

The growth parameter and yield values from center to bottom pipe position with 45° and 60° "A" frame angle in 4 and 6 cm water depth decreased for lettuce plant. Also, the "A" frame angle 60° in 4 and 6 cm water depth values decreased from center to bottom pipe position for the mint plant. But, growth parameter and yield values from center to bottom pipe with 45° "A" frame angle in 4 and 6 cm water depth increased for the growth of the mint plant. There were no significant differences in fresh and dry weight of lettuce and mint plants grown in different water depths in "A" frame angle hydroponics systems with 45° and 60°. These results agreed with those obtained by Khater (2006) and Genuncio et al., (2012).

The influence of different "A" frame angles and water depth on total fresh yield:

Table 4 showed the fresh mass of shoots production (fresh yield) of lettuce and mint plants grown in the NFT hydroponic system at different "A" frame angles (45° and 60°) and water depths (4 and 6 cm) at the end of the growing period (32 days). The results indicate that the higher fresh yield of shoots was 23.10, 23.32 ton/ha and 16.11, 17.03 ton/ha with 45° "A" frame angle in 4 and 6 cm water depth for the growth of lettuce and mint plant, respectively. This may be due to a system with an "A" frame angle of 45° having a small and occupied surface area so the hectare area having 952 NFT systems higher than when using the system with an "A" frame angle of 60° having 812 NFT systems. These results agreed with those obtained by Genuncio et al., (2012) and Joseph et al., (2015).

The effect of different "A" frames angles and water depth on water productivity:

Hydroponic produced lettuce and mint were found to enhance the water productivity (WP). Producing lettuce and mint under hydroponic conditions is a highly efficient process in terms of water-saving when compared to field production of different plants like lettuce. In this study, the results in Table 4 showed that the highest values of (WP) were obtained at 8.25, and 8.32 kg/m^3 with 45° "A" frame angle in 4 and 6 cm water depth for the growth of lettuce plant, respectively, the highest value for the mint plant was 7.04 kg/m^3 obtained with 60° "A" frame angle in 6 cm water depth. Generally, most hydroponic systems will utilize water more efficiently than conventional farming; however, the 45° "A" frame hydroponic system delivers the water more efficiently, with a larger percentage of the water going to plants evapotranspiration, agreement with (Sanchez 2007).

Table 4: The effect of different "A" frame angles and water depth on total fresh yield and water productivity.

A°	*D, cm*	Plant	Total water consumption, m^3/m^2	Total fresh yield, (ton/ha)	Total fresh yield, (kg/m^2)	Water productivity kg fresh yield/m^3
45°	4	Lettuce	0.28	23.10	2.31	8.25
	6			23.32	2.33	8.32
60°	4			20.76	2.07	7.39
	6			21.94	2.19	7.82
45°	4	Mint	0.25	16.11	1.61	6.44
	6			17.03	1.70	6.81
60°	4			15.61	1.56	6.24
	6			17.64	1.76	7.04

In the analysis of variance presented in Tables 5 and 6, the results indicated a significant differences ($P<0.05$) observed in growth parameters such as root length, stem diameter and root mass values with different "A" frame angle A^o (45^o and 60^o), while no significant differences were observed with water depth and interaction between angle and water depth showed significant differences for root length of lettuce and mint plants. The results also indicated no significant differences ($P<0.05$) observed on fresh yield (the production) of lettuce and mint plants. The results concluded that the interaction between angle and water depth is not effects on yield. So, the "A" frame design with a 45° angle can be recommended for the production of lettuce and mint by Nutrient Film Technique (NFT) Hydroponic system because the "A" frame design at a 45° angle has a small dimension and has a small and occupied surface area and more plants in total surface area for hectare unit to produce the highest total fresh yield for lettuce and mint plants.

Table 5: Means of growth parameters and lettuce biomass weight as affected by the interaction between different "A" frame angle A° (45° and 60°) and water depth (4 and 6 cm), (Mean±SE).

Study factors	Growth parameters		Root mass (g/plant)		Shoot mass (g/plant)		fresh yield±SE (g/pipe)
	LR±SE (cm)	SD±SE (mm)	Fr. ±SE	Dry±SE	Fr. ±SE	Dry±SE	
A° effect							
Angle 45°	35.200 b ± 1.88	14.250 b ± 0.71	49.867 a ± 0.84	5.217 b ± 0.35	169.317 a ± 8.63	15.767 a ± 0.97	8127.200 a ± 414.3
Angle 60°	41.033 a ± 1.33	16.800 a ± 0.68	64.350 a ± 5.92	7.583 a ± 0.31	182.183 a ± 11.9	20.200 a ± 1.93	8744.800 a ± 571.23
Depth effect							
4 cm	36.683 a ± 1.98	15.150 a ± 0.85	56.367 a ± 5.24	6.267 a ± 0.62	172.600 a ± 9.02	17.000 a ± 1.26	8284.800 a ± 432.85
6 cm	39.550 a ± 2.00	15.900 a ± 0.92	57.850 a ± 5.39	6.533 a ± 0.62	178.900 a ± 12.14	18.967 a ± 2.16	8587.200 a ± 582.74
Interaction effect							
45°*4	33.400 b ± 1.8	13.833 a ± 1.05	49.300 a ± 1.07	5.067 b ± 0.54	168.500 a ± 13.69	15.200 a ± 1.07	8088.000 a ± 656.99
45°*6	37.000 ab ± 3.35	14.667 a ± 1.13	50.433 a ± 1.43	5.367 b ± 0.54	170.133 a ± 13.58	16.333 a ± 1.81	8166.400 a ± 651.96
60°*4	39.967 ab ± 2.36	16.467 a ± 0.88	63.433 a ± 9.29	7.467 a ± 0.42	176.700 a ± 14.23	18.800 a ± 1.88	8481.600 a ± 682.96
60°*6	42.100 a ± 1.48	17.133 a ± 1.19	65.267 a ± 9.38	7.700 a ± 0.55	187.667 a ± 21.81	21.600 a ± 3.64	9008.000 a ± 1046.8

Means followed by the same letter are not significantly different according to Duncan's multiple range test (P at 0.05 level).

Table 6: Means of growth parameters and mint biomass weight as affected by the interaction between different "A" frame angle A° (45° and 60°) and water depth (4 and 6 cm), (Mean±SE).

Study factors	Growth parameters		Root mass (g/plant)		Shoot mass (g/plant)		fresh yield±SE (g/pipe)
	LR±SE (cm)	SD±SE (mm)	Fr. ±SE	Dry±SE	Fr. ±SE	Dry±SE	
A effect							
Angle 45°	29.750 b ± 0.86	3.550 b ± 0.23	40.083 b ± 2.29	10.000 b ± 0.83	120.883 a ± 8.4	20.850 a ± 2.07	5802.400 a ± 402.98
Angle 60°	32.617 a ± 0.65	3.835 a ± 0.23	53.117 a ± 4.13	13.700 a ± 1.08	142.200 a ± 8.46	24.750 a ± 2.83	6825.600 a ± 406.03
Depth effect							
4 cm	30.600 a ± 1.02	3.615 a ± 0.23	41.917 b ± 3.03	10.850 a ± 1.18	125.533 a ± 8.58	20.983 a ± 1.99	6025.600 a ± 411.66
6 cm	31.767 a ± 0.9	3.770 a ± 0.24	51.283 a ± 4.62	12.850 a ± 1.19	137.550 a ± 9.97	24.617 a ± 2.93	6602.400 a ± 478.76
Interaction effect							
45°*4	28.933 b ± 1.24	3.467 a ± 0.34	37.200 b ± 3.16	8.933 b ± 0.88	117.533 a ± 13.49	20.033 a ± 3.24	5641.600 a ± 647.38
45°*6	30.567 ab ± 1.21	3.633 a ± 0.37	42.967 b ± 2.83	11.067 ab ± 1.23	124.233 a ± 12.62	21.667 a ± 3.22	5963.200 a ± 605.8
60°*4	32.267 ab ± 0.94	3.763 a ± 0.37	46.633 b ± 3.68	12.767 ab ± 1.59	133.533 a ± 11.04	21.933 a ± 2.9	6409.600 a ± 529.86
60°*6	32.967 a ± 1.07	3.907 a ± 0.35	59.600 a ± 5.44	14.633 a ± 1.57	150.867 a ± 12.68	27.567 a ± 4.88	7241.600 a ± 608.68

Means followed by the same letter are not significantly different according to Duncan's multiple range test (P at 0.05 level).

4. CONCLUSIONS

In this present research work, several conclusions can be obtained and drawn as follows: -

- The occupied surface area that is used in plant cultivation is influenced by changing the angle of the "A" frame design. The occupied surface area decreased by 45 % by changing the angle from 180° (horizontal position, datum surface) to 60° and by 25.76 % from 60° to 45°.
- The light intensity that fall on lettuce was lower than mint in "A" frame angled (45° and 60°). This is due to the increase in the shooting width of the lettuce to the mint plant.
- The light intensity values were decreased by changing the "A" frame angle from 60° to 45° by 26.4 % for lettuce and 32.0 % for mint.
- Root length and stem diameter were increased by changing the angle from 45° to 60° and water depth from 4 to 6 cm for both mint and lettuce plants.
- The "A" frame design with 45° angle can be recommended for the production of lettuce and mint by Nutrient Film Technique (NFT) Hydroponic system because the "A" frame design at 45° angle has small dimension and has a small and occupied surface area and more plants in total surface area for hectare unit to produce the highest total fresh yield for lettuce and mint plants.

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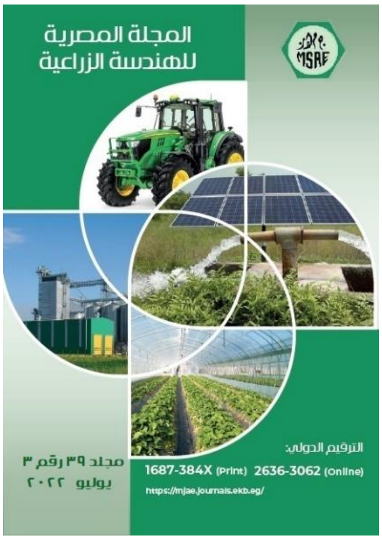
تأثير زاوية تصميم الشكل الهرمي بنظام الزراعة المائية على الإنتاجية

احمد فتحي محمد خضر [١] ، سامح سعيد كشك [٢] و عبد التواب متولى ابراهيم زيدان[٣]

[١] أستاذ مساعد هندسة الري والصرف - قسم الهندسة الزراعية - كلية الزراعة - جامعة قناة السويس - مصر
[٢] أستاذ مساعد هندسة المنشآت الزراعية والتحكم البيئي - قسم الهندسة الزراعية - كلية الزراعة - جامعة قناة السويس - مصر
[٣] أستاذ مساعد هندسة الري والصرف - قسم الهندسة الزراعية - كلية الزراعة - جامعة الزقازيق - مصر.



الكلمات المفتاحية:
الزراعة المائية؛ تصميم الهيكل A؛ الإنتاجية؛ الخس والنعناع.

الملخص العربي

أصبحت ندرة المياه مشكلة عالمية كبرى بسبب زيادة عدد السكان. تم تصميم نظام هيكل الإطار A تجاريًا في تصميم انظمة الزراعة المائية. كان الهدف من هذا العمل هو تقييم تأثير الزوايا المختلفة لتصميم شكل نظام NFT وعمق المياه في داخل الأنابيب وموضع الأنابيب على اثنين من الخضروات الورقية وعلى معاملات نموهما. كانت المعاملات تصميم شكل الإطار بزاوية (٤٥ درجة و٦٠ درجة) ، وعمق المياه داخل الانابيب (٤ و٦ سم) ، والنباتات الورقية (الخس والنعناع). أشارت النتائج إلى أن تغيير الزاوية من ١٨٠ درجة إلى ٦٠ درجة ومن ٦٠ درجة إلى ٤٥ درجة أدى إلى انخفاض مساحة السطح المشغولة بنسبة ٤٥,٠٪ و٢٥,٧٦٪ على التوالي. تم تقليل قيم شدة الاضاءة عن طريق تغيير زاوية الإطار A من ٦٠ درجة إلى ٤٥ درجة بنسبة ٢٦,٤٪ للخس و٣٢,٠٪ للنعناع. تغيير موضع الأنابيب من المركز إلى الأسفل أدى إلى تقليل شدة الضوء للخس بنسبة ٩,٢٪ و١١,٧٪ للزوايا ٤٥ درجة و٦٠ درجة على التوالي. بينما زادت بنسبة ٢١,٢٪ للنعناع مع الزاوية ٤٥ درجة فقط. تمت زيادة طول الجذر وقطر الساق بتغيير الزاوية من ٤٥ درجة إلى ٦٠ درجة وعمق الماء من ٤ إلى ٦ سم لكل من نباتات النعناع والخس. المحصول الأمثل لنباتات الخس والنعناع المزروعة في نظام الزراعة المائية بإطار A بزاوية ٤٥ درجة مثل تلك النباتات المزروعة مع النظام بزاوية ٦٠ درجة ، مما يشير إلى عدم وجود فروق ذات دلالة إحصائية في إنتاج نباتات الخس والنعناع. ولذلك يمكن التوصية بتصميم النظام الهرمي ("A" frame) بزاوية ٤٥ درجة لإنتاج الخس والنعناع.