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Original Research

The Impact of Advanced Static Magnetic Units on Water Properties and the Performance of Aeroponic and NFT Systems for Lettuce

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Abstract

The current study was conducted during two seasons, 2018 and 2019, to determine the optimal coupling of hydroponic systems with magnetized water levels (MWLs) to improve irrigation water characteristics, water productivity and lettuce production quality. Three hydroponic nutrient film technique (NFT; tower aeroponic and pyramidal aeroponic) systems and three levels of magnetic units (magnetized water level 1; MWL1 = 3800 gauss, level 2; MWL2 = 5250 gauss, level 3; MWL3 = 6300 gauss, and regular water (RW) was represented as a control) were tested. There was an increase in total dissolved solids (TDS) and a decrease in pH of water by increasing the magnetic level over time during the irrigation period. Maximum contents of nitrogen (N; 72.8 ppm), phosphorus (P; 223.3 ppm), and potassium (K; 425.0 ppm) were recorded in nutrient solution under irrigation with MWL3. The increase in magnetic intensity resulted in lower water consumption in all hydroponic systems compared to control. On the other hand, tower and pyramidal systems consumed less water compared to the NFT system. Maximum water consumption (3719.7 and 4175.4 m^3 ha^{-1} for both seasons, respectively) was observed in the NFT system under RW. Maximum water productivity was recorded with the integration of NFT system + MWL3 (83.4 kg m^{-3}) in the first season and tower system + MWL3 (71.2 kg m^{-3}) in the second season. In addition, the highest leaf performance curves and lettuce yield (414 g per head) and its quality (3.50, 0.46, and 7.40 mg L^{-1} for N, P, and K contents) were recorded with the integration of the NFT system + MWL3 compared to other treatments.

Keywords: magnetic unit, hydroponic, NFT, aeroponic, lettuce

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Introduction

The current water shortage in Egypt is 13.5 billion cubic meters per year (BCM year^{-1}). It has been predicted that water scarcity in 2025 will be 26 BCM year^{-1} [1] because less annual demand is more than supply. Low investment and policy will result in not making water available to everyone [2]. Inadequate fresh water leads to competition among field projects to irrigate using groundwater, which is used to an extreme degree in high-evapotranspiration countries. Therefore, technology should be used to help countries develop water productivity, such as hydroponics [3].

There are some limitations and many advantages with hydroponics. The huge initial cost and rapid spread of pathogens in closed water circulation are the most constraints of hydroponics. Specialized managers are also needed [4]. On the other hand, water reuse is one of the most important advantages of hydroponics. In addition, environmental factors around hydroponics can be controlled with diminishing old farming practices such as tillage, cultivation and watering. Among other advantages of hydroponics, producing the same quantity of crops in a smaller area when compared with traditional farming, the time required to grow crops is less, and the roots do not face mechanical obstruction. Nutrient availability, environmental monitoring, reduced maintenance of workers and gardens, and automation of fertilization and irrigation are also advantages of hydroponics. Saving water is the best advantage, along with saving money by recirculating nutrients and water.

In the closed system of hydroponics such as nutrient film technique (NFT), nutrients are recycled to prevent nutrient loss and soil contamination. Pest and disease problems can be controlled while weeds are not found [5]. NFT is part of hydroponics based on the availability of a nutrient solution for plant flow through water. In traditional methods, soil is necessary but in this technique the soil is not used. In NFT, factors of plant culture are controlled with facilities and requirements. This technique is suitable for growing outdoor and indoor plants. Also, the overall productivity of crops is affected by available facilities [6].

As the most advanced hydroponic in the world, aeroponic is a type of hydroponic where the roots of plants are suspended in the air and sprayed with a nutrient solution. Aeroponic plants are generally grown outside the closed room where they receive maximum light [7]. The main problem of hydroponics and aeroponic is that it does not use soil, so any failure of these systems will lead to the rapid death of the plant. Therefore, specialized methods of error detection, control, monitoring and automation of these systems should be used [8]. The nutrient solution flows or falls through the chamber on the roots. It flows to plant roots and then empties into the tank or assembly pipe, where it is used again. Aeroponic systems increase oxygen in the root zone to helps increase plant growth [7].

Solution and magnetic water are produced by liquids passing through the magnetic field at a given specific intensity and flow rate. When this process occurs, water has different changes in physicochemical and electrochemical characteristics [9].

The application of magnetic water (a nutrient solution) results in improvements in seed germination, and stem and root lengths, and reductions in electrical conductivity (EC), total dissolved solids (TDS) and salinity levels in the nutrient solution [10-11]. At present, agronomists consider the technology of magnetic treatment to increase crop yields and water productivity through a magnetic field before irrigation [12]. For lettuce yield, water use efficiency (WUE) is increased by 62 or 121% under the application of 80% of irrigation requirements or magnetic field at 4000 gauss, respectively [13].

Therefore, the main aim of this study was to investigate the potential positive effects of different intensities of magnetic units (e.g., 3800, 5250, and 6300 gauss) in integration with different hydroponic (NFT, Tower aeroponic, and Pyramidal aeroponic) systems to try to reach the maximum possible productivity and quality of water, fresh yield quantity and quality of lettuce.

Materials and Methods

Location of Experiments and Growing Conditions

To examine the potential positive effects of different magnetic levels and regular water to irrigate the hydroponic systems (NFT, tower aeroponic, pyramidal aeroponic), greenhouse experiments and laboratory analyses of water and plant characteristics were conducted in two seasons – 2018 and 2019 – at the Agricultural Engineering Research Institute, Agricultural Research Center, Giza, Egypt. The experiments were conducted under controlled environmental conditions. Climate variables were recorded daily during the seasons: maximum, minimum, average temperature and relative humidity. The maximum and minimum temperatures during growing seasons were 23-25 and 20-22ºC, respectively and 60-65% was relative humidity. Temperature and humidity were controlled by greenhouse equipment (cooling pad, suction van, and monitoring sensor) and climatic data verified by a hygrometer thermo-anemometer (made in Taiwan, model 407412; accuracy ±0.8ºC and ±3% for temperature and relative humidity, respectively). The greenhouse had an iron frame covered with a sheet of polyethylene.

Plant Material

Lettuce transplants (cv. LimorHyb.) were purchased from the Horticulture Research Institute, Agricultural Research Center, Giza, Egypt. In the three hydroponic

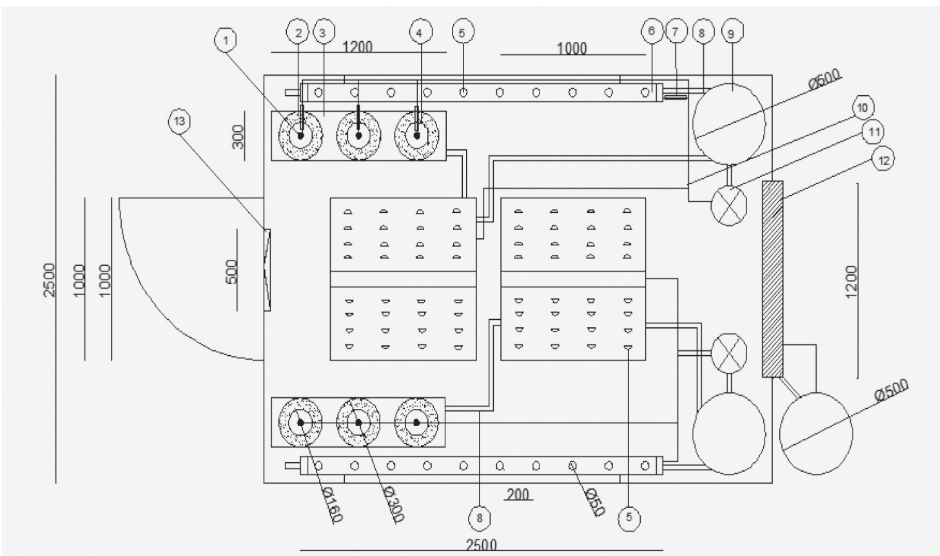
Table 1. Element concentrations in the used nutrient solution.

Element concentration (ppm)										
N	P	K	Ca	Mg	Fe	Mn	Cu	Zn	B	Mo
51	219.29	358.3	135	45	2.7	0.75	0.375	0.113	0.188	0.009

systems, transplants were grown by a 3 cm thickness sponge with high density placed in plastic cups 5 cm in diameter. Transplants were grown for three weeks in deep water culture filled with a thin layer of nutrient solution until rooting was completed. Transplants were ready to be in different soilless systems as a final place on 1 April 2018 and 1 March 2019. Irrigation water was obtained from two 120-liter tanks located in the experimental greenhouse. The nutrient solution was applied to an irrigation water tank where EC was approximately 1.5 dS m^{-1}. The nutrient solution [14] used in the experiments is shown in Table 1.

System Installation and Treatments

There were two main factors in the study; a type of irrigation water (regular water and magnetized water levels) and three different hydroponics (suspended NFT, tower aeroponic, pyramidal aeroponic) systems. Like the growing period, the average temperature, light intensity, irrigation period (15 min h^{-1}), and humidity for all treatments were adjusted. The systems were designed to bear 64 plants m^{-2} as an average capacity in every system. The suspended NFT system consisted of 150 cm height iron stands and 250 cm length, and 110 mm diameter pipes. The pipes were perforated with 5 cm diameter holes. Plants were placed at a distance of 20 cm between them in plastic hydroponic cups (Fig. 1). The pyramidal aeroponic system has a frame made of iron with dimensions of 1.0 m width and 1.0 m length. All frames were attached to an iron bar. High-density plastic sheets with width, length and thickness of 1 m × 1 m × 0.5 m, respectively, were placed on the iron frame (Fig. 1). In holes of these sheets, plants were housed in hydroponic cups. The shape was placed on a 700-micron black polyethylene with a width, length, and height of 1 × 1 × 0.3 m, respectively, to collect the excess nutrient solution, which was directed to the irrigation tank. Irrigation water was pumped with a pump (1hp) for 16 mm polyethylene pipes connected to foggers installed inside the system. Foggers were fixed in the shape, and the properties of the foggers were 0.5 m as the misting diameter, 6 L h^{-1} as the flow rate and operating pressure of 2 bar. The tower aeroponic system consisted of pipes with diameter and height of 1.6 and 1.5 m, respectively. Pipes were installed in 30 cm pots filled with gravel and the pots were placed



Legend:
1. Micro-sprinkler
2. Plots to install pipes
3. Stand to install plots
4. 160 mm PVC pipe
5. 50 mm hole
6. 110 mm PVC pipe
7. Magnetic unit
8. Outflow pipe
9. Irrigation tank
10. Inflow pipe
11. Pump
12. Cooling pad
13. Suction van

Fig. 1. Layout of environmentally controlled greenhouse and experimental treatments.

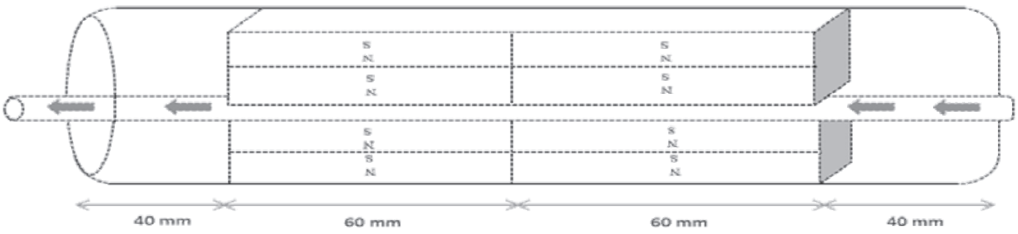


Fig. 2. Layout of magnetic unit.

on a steel stand 40 cm high. The plant was at 20 cm alternately placed in plastic hydroponic cups. Irrigation water was pumped by a 1 hp centrifugal pump through a 16 mm polyethylene pipe that was connected to the upper end of the 160 cm pipes. The fogger has the same characteristics as the previous one.

Magnetic Device (MU)

The magnetic unit consisted of a 3-inch pipe with a length of 20 cm and permanent magnets. These static magnets were made from an alloy of neodymium, iron, and boron (NdFeB). The structure of tetragonal crystalline was to protect the magnets, giving it high resistance to be demagnetized. Magnets were used to build a magnetic unit that retained its magnetic properties for a long time and was remembered magnetically without an external magnetic field (Fig. 2). The intensity of magnetic levels was measured by a gauss meter (Electronica flux meter DC 34, England), and the measurements were checked by a gauss/tesla meter (F.W. BELL 5080, U.S.A).

Four pairs of permanent magnets were arranged in every unit, divided into three levels. The dimensions of 60 × 20 × 6 mm, 60 × 18 × 5 mm, and 60 × 17 × 5 mm were for the first (piece A), second (piece B) and third (piece C) levels, respectively. The magnetic units were constructed according to equation [15], where the highest magnetic level at the operating point was achieved by pairing the magnets according to the increasing magnet length.

$$A_m = \frac{B_g A_g}{B_m} \tag{1}$$

…where B_m is the magnetic flux density at an operating point, A_m is the cross-section of the magnet, A_g is the cross section of void, and B_g is the magnetic flux density in the void. The different arrangements of magnets to achieve the applied flux densities used in experiments are represented in Table 2. Water flow velocity through the magnetic unit at 3.15×10^{-3} m sec^{-1} was calculated by equation (2) [16].

$$Q = A \times V \tag{2}$$

…where Q is the water flow rate (m^3 sec^{-1}), A is the cross-section area (m^2), and V is the velocity of water (m sec^{-1}). Different magnetic arrangements to achieve the applied flux densities used in experiments are represented in Table 2. The magnets provide their magnetic power without an external magnetic field of up to 230 cm measured by pH meter, where the pH meter was used as a measure of memory in the magnetic field [17].

Table 2. Different flux densities for magnetic units.

Magnetic water level	Magnets paired	Flux intensity (Gauss)
MWL1	B + C // B + C	3800
MWL2	A + B // A + B	5250
MWL3	A + A // A + A	6300

Assessment Criteria

The water flow rate was measured by special units that were specially designed to calculate the flow of water through pipes. The measuring unit consisted of an Arduino microcontroller, breadboard, pull-up resistor, flow rate sensor, wires, battery and memory card (Fig. 3). The properties of the nutrient solution under control (regular water) and different magnetic levels were measured. These measured characteristics were the concentrations of N, P, and K (ppm), total dissolved solids TDS (ppm) and pH through each season at different growing stages. At harvest stage (54 days after transplanting), 3 plants were randomly selected from each treatment to measure plant parameters such as fresh head weight, number of leaves per plant, and the leaf contents (mg g^{-1}) of chlorophylls, N, P, and K. Plant weight was taken by a digital balance (Chyo Balance

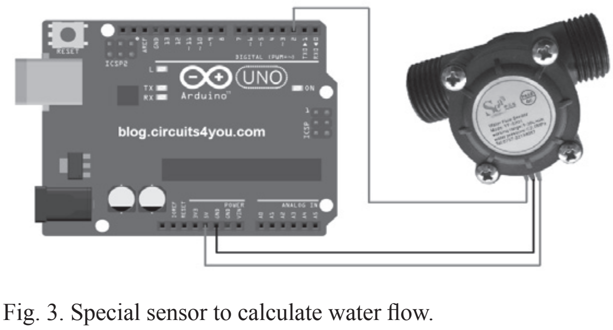


Fig. 3. Special sensor to calculate water flow.

Corp, Japan, Accuracy 0.01 g). Chlorophyll content was assessed by a chlorophyll meter (SPAD-502, Japan) [18]. The contents of N, P, and K were determined in leaf samples after being dried in an electric oven (locally manufactured, 10 liter capacity, temp. range 0-250ºC) at 70ºC for 48 h. The dried leaves were then digested in H_2SO_4 and $HClO_4$ [19]. The electrical conductivity (EC) of irrigation water was measured by an EC meter (Ecosence EC300, 0.2% accuracy, Germany). The pH of irrigation water was assessed by a pH meter (Ecosense pH 100, Accuracy 0.1%, Germany). The crop water used for every system was calculated by using Equation (3) [20]:

$$CWU = \frac{Q_1 - Q_2}{A} \times 10.00 \quad (3)$$

…where CWU is the crop water use (m^3 ha^{-1}), Q_1 is the inflow volume to every system (m^3 m^{-2}), Q_2 is the drainage outflow volume from the greenhouse (m^3 m^{-2}), and A is the area of the system (m^2). Water productivity (WP) was computed using equation (4) [21].

$$\text{Water productivity (kg m}^{-3}\text{)} = \frac{\text{yield (kg } ha^{-1}\text{)}}{Crop\ water\ use\ (m^3 ha^{-1})} \quad (4)$$

Statistical Analysis

Statistical analysis of the obtained data was conducted using ANOVA in SAS [22]. Separation of the means using LSD ($P \leq 0.05$) was performed in the same program, where it was convenient for randomized complete block design in factorial arrangement (two factors; hydroponic systems, irrigation water treatments and their replicates as blocks). The mean square of the values resulted from the interaction between the hydroponic systems, and irrigation water treatments were used as an error term. The least significant difference (LSD) of Duncan's test was applied to define the statistically significant differences between average groups in the ANOVA.

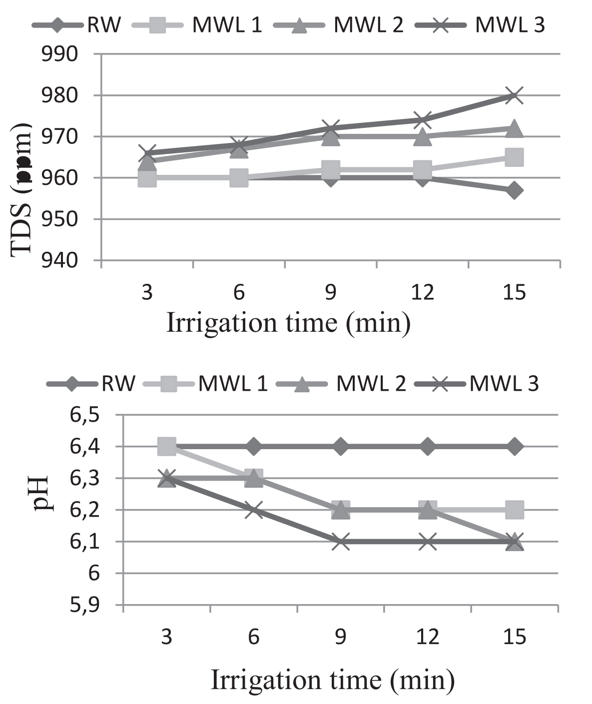


Fig. 4. Effects of different magnetic levels on pH and TDS through the nutrient solution circulation period.

Results and Discussion

Nutrient Solution Characteristics

The pH and TDS values were changed during the irrigation period (15 min) by changing the magnetic flux density and circulation time, and the changes were irregular. Magnetic water levels (MWLs) had an effect on TDS of the nutrient solution circulation and pH, where the pH was stabilized in the solution of regular water (RW; control) at 6.4. However, pH was

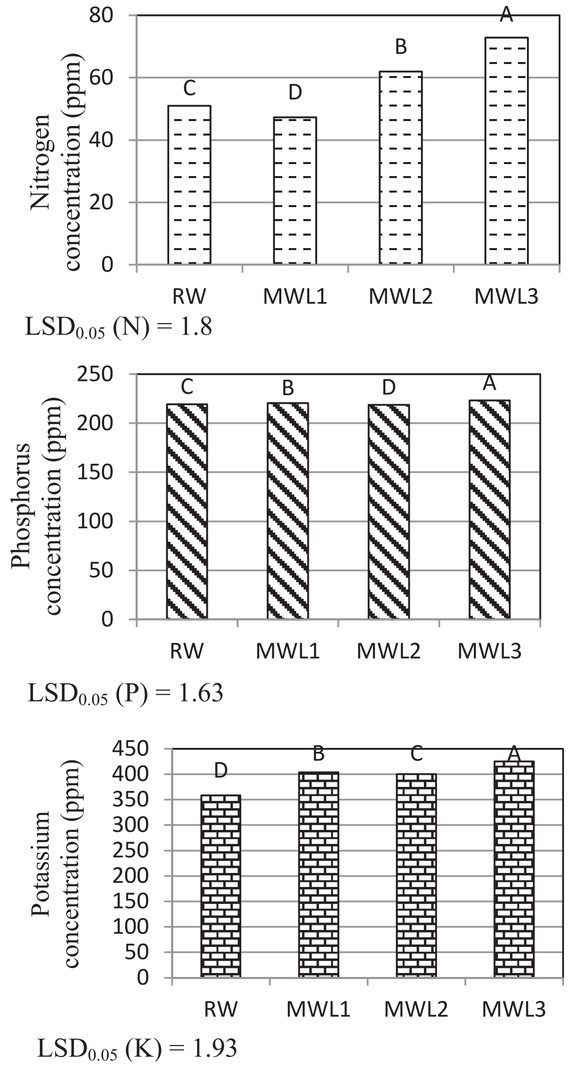


Fig. 5. Effects of different magnetic levels on N, P and K concentrations of nutrient solution.

decreased with increasing magnetic flux density in MWL1, MWL2, and MWL3. MWL had effects on TDS that increased with increasing magnetic flux density. The highest TDS was obtained with MWL3, while the lowest was recorded with RW (Fig. 4). Nutrient (N, P, and K) concentrations were significantly ($P \leq 0.05$) affected by magnetic flux intensity. They were increased with increasing magnetic flux density. The highest N, P, and K concentrations were observed with MWL3, while the lowest concentrations were recorded with RW (Fig. 5).

Previous outcomes of pH, TDS, and nutrient (N, P, and K) concentrations agreed with those in [11], where a decrease in pH and an increase in TDS and P concentration were observed by the magnetization of water. In addition, it has been reported that the characteristics of irrigation water used after magnetization were changed, where EC was increased and pH decreased [23].

Water Consumption

Irrigation water added to lettuce plant was calculated in various hydroponic systems under RW and magnetized water levels (MWLs) after transplantation per 6 days over the two seasons of 2018 and 2019

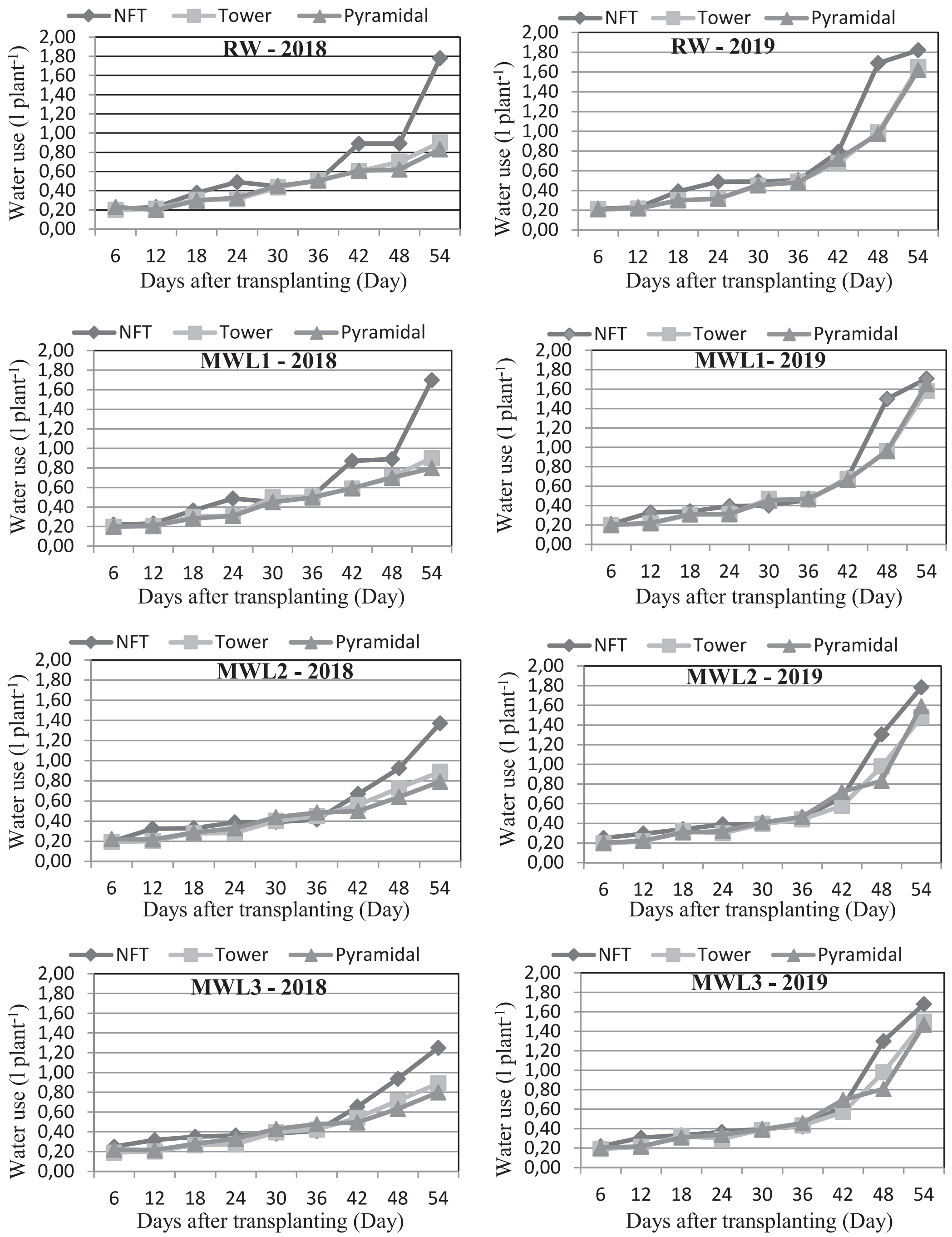


Fig. 6. Water consumption for different hydroponic systems under regular and magnetized water levels.

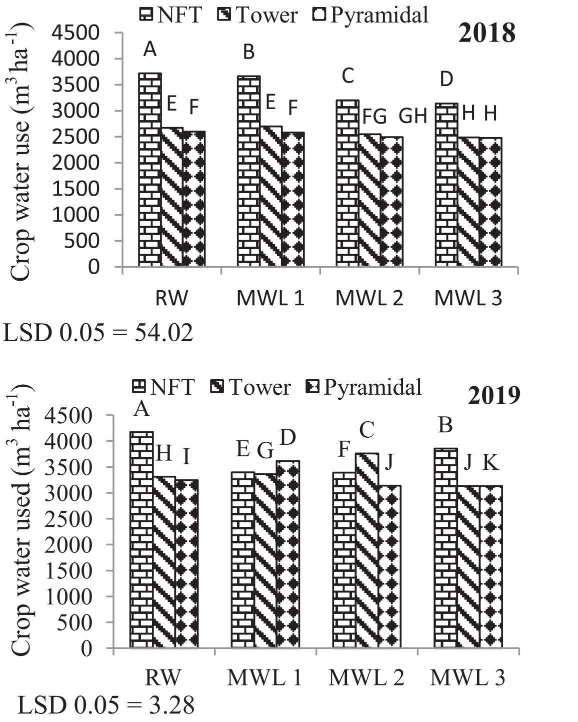


Fig. 7. Total crop water consumption for different hydroponic systems with regular and magnetic water.

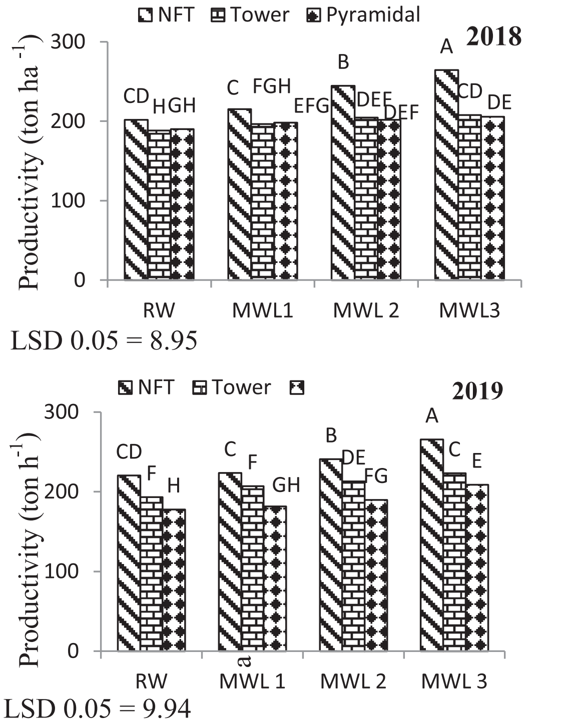


Fig. 8. Productivity of different hydroponic systems under normal and magnetic water.

(Fig. 6). The results indicate that higher water consumption by plants was observed in the NFT system under RW and different MWLs compared with both tower and pyramidal systems. There were significant ($P \leq 0.05$) differences among the total water applied under different hydroponic systems at the end of both seasons. Maximum water consumption (e.g., 3720 and 4176 m^3 ha^{-1} for both seasons, respectively) was observed in the NFT system under RW (Fig. 7).

Low water consumption in the magnetization state can be explained on the basis of a surface tension mechanism that plays an important role in the uptake of water by plant roots. Surface tensions of water lead to a strong gradient in hydrostatic pressure that favors the apoplastic component of water uptake, wherein the transport process in the plant composite, the cohesion and tension mechanism of the ascent of sap plays an important role [24]. On the other hand, the surface tension of water is influenced by magnetic intensity [25], where the magnetic field leads to a minimum surface tension coefficient, the surface tension decreased the most [26].

Yield and Water Productivity

There was a significant ($P \leq 0.05$) difference between yields obtained with different hydroponic systems under different irrigated water treatments. Maximum yield (e.g., 264 and 266 ton ha^{-1} for both seasons, respectively) was recorded with the NFT system under irrigation with MWL3 (Fig. 8). On the other hand, minimum yield (40%) was obtained using the tower system under RW in the first season, while in the second season, the pyramidal system under RW scored the lowest yield

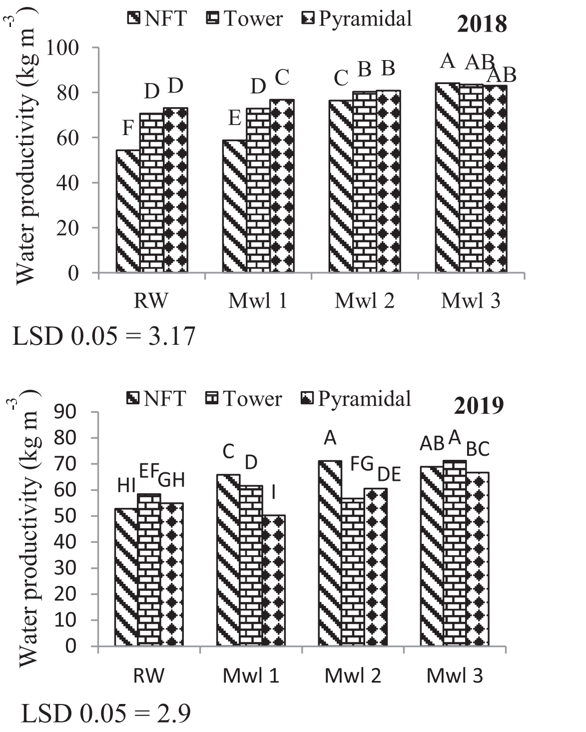


Fig. 9. Water productivity of hydroponic systems under normal and magnetic water levels.

(49%). These results are consistent with those in [27], in which radish yield productivity is increased by 76% when seeds are exposed to magnetic fields of 40, 80, and 110 mT for 2.5, 5, and 10 min, respectively.

In the first season, although maximum water productivity (83.4 kg m^{-3}) was recorded with the NFT system under irrigation with MWL3, there were no significant differences among the different systems (NFT, tower and pyramidal) under irrigation using MWL3 (Fig. 9). In the second season, maximum water productivity (71.2 kg m^{-3}) was recorded with the tower system under irrigation with MWL3. In addition, there were no significant differences among the tower and NFT systems under irrigation with MWL3 and the NFT system under irrigation with MWL2. Maximum water productivity exceeded its minimum water productivity by 55% and 42% in both seasons, respectively (Fig. 9).

It has been proven that water productivity increases by 4-12% by using a magnetic field [11]. In the same context, water use efficiency (WUE) can be improved by aeroponics to some extent by optimizing fertilizer and water interactions that manage the nutrient solution [28]. On the other hand, there was a quality parameter that was observed with the naked eye by monitoring the water in the irrigation tanks of all treatments, which add water to the hydroponic systems. Use of a magnetic field in hydroponic systems is of great importance, where it prevents the growth of mosquito larvae, which grow significantly in regular water tanks, preventing harm to public health. This result is consistent with that in [29], where the magnetic field affects a number of mosquito larvae that have reached the adult stage and that will reach the environment and cause weak offspring and spread diseases. As a result, the increase in magnetic intensity significantly increased larval mortality.

Leaf Performance Curves

The number of leaves was recorded every six days as a different growth phase with different hydroponic systems under irrigation with RW and three magnetized waters. The NFT system under irrigation with MWL3 had the best effect on leaf performance curves in both seasons, followed by the tower system under irrigation

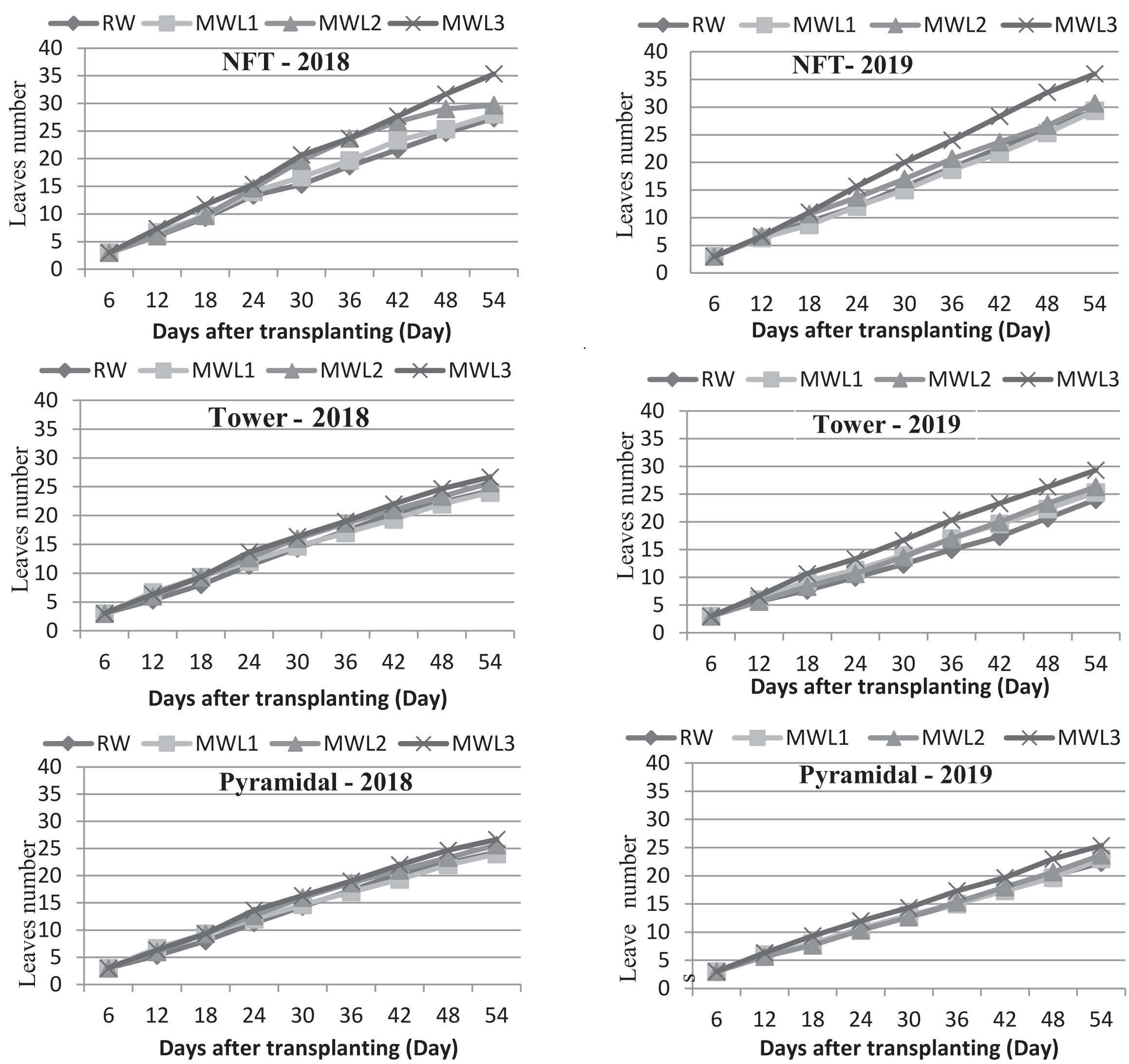


Fig. 10. Effect of hydroponic and magnetic levels through different stages on leaf numbers.

Table 3. Influence of hydroponic systems and irrigation water treatments on fresh weight, chlorophyll content, dry matter, and nutrient contents (N, P and K) of lettuce.

Irrigation water treatment (I)	2018				2019			
	Hydroponic (S)							
	NFT	Tower Aeroponic	Pyramidal Aeroponic	Mean	NFT	Tower Aeroponic	Pyramidal Aeroponic	Mean
Fresh weight of lettuce head								
RW	315 def	295 h	297 gh	302 d	344 cd	302 f	278 h	308 d
MWL1	336 c	307 fgh	310 efg	318 c	349 c	324 e	284 gh	319 c
MWL2	382 b	320 def	315 def	339 b	376 b	333 ed	297 fg	335 b
MWL3	413 a	325 cd	322 de	353 a	415 a	349 c	327 e	364 a
Mean	362 a	312 b	311 b		371 a	327 b	296 c	
LSD 0.05	S = 7	I = 8	S × I = 14		S = 8	I = 9	S × I = 16	
Chlorophyll content								
RW	25.2 ef	24.1 f	24.0 f	24.5 c	27.4 bc	24.4 f	25.5 def	26.1 c
MWL1	28.3 bc	25.7 def	25.5 ef	26.5 b	28.7 bc	25.4 ef	26.1 cde	27.0 c
MWL2	28.8 bc	27.2 cde	26.0 def	27.4 b	29.5 b	27.5 c	27.4 cd	28.1 b
MWL3	32.3 a	29.5 b	27.8 bcd	29.9 a	31.7 a	30.3 ab	27.1 cde	28.7 a
Mean	28.7 a	26.6 b	25.9 b		29.6 a	26.9 b	26.7 b	
LSD 0.05	S = 1.11	I = 1.28	S × I = 2.22		S = 0.97	I = 1.12	S × I = 1.90	
Nitrogen (N)								
RW	3.79 a	2.62 ab	2.17 b	2.86 a	3.19 a	3.31 a	3.48 a	3.18 a
MWL1	3.33 ab	2.97 ab	2.92 ab	3.08 a	3.84 a	2.73 a	2.98 a	3.32 a
MWL2	3.48 ab	3.07 ab	2.72 ab	3.09 a	3.35 a	4.08 a	3.20 a	3.54 a
MWL3	3.50ab	2.92 ab	2.82 ab	3.09 a	3.68 a	3.93 a	3.13 a	3.58 a
Mean	3.53 a	2.89 ab	2.65 b		3.52 a	3.50 a	3.19 a	
LSD 0.05	S = 0.69	I = 0.30	S × I = 1.39		S = 0.77	I = 0.89	S × I = 1.54	
Phosphorus (P)								
RW	0.28 cde	0.27 de	0.24 de	0.26 b	0.23 ef	0.31 bcd	0.15 g	0.23 b
MWL1	0.37 abc	0.25 de	0.24 de	0.29ab	0.35 ab	0.22 efg	0.26 cde	0.28 a
MWL2	0.33 bcd	0.25 de	0.42 ab	0.33 a	0.17 fg	0.33bc	0.24 def	0.25ab
MWL3	0.46 a	0.20 e	0.27 de	0.31ab	0.26 cde	0.41 a	0.18 fg	0.28 a
Mean	0.36 a	0.24 c	0.29 b		0.25 b	0.32 a	0.21 c	
LSD 0.05	S = 0.05	I = 0.06	S × I = 0.10		S = 0.04	I = 0.04	S × I = 0.07	
Potassium (K)								
RW	6.50abc	4.80 d	4.60 d	5.30 a	5.38 ab	5.75 ab	4.90 b	5.34 b
MWL1	7.60 a	4.60 d	4.90 cd	5.70 a	5.19 ab	6.13 ab	5.85 ab	5.72 ab
MWL2	6.90ab	6.20abcd	4.60 d	5.90 a	6.60 a	5.38 ab	5.80ab	5.94 ab
MWL3	7.40ab	5.80bcd	4.90 cd	6.03 a	6.51 a	5.66 ab	6.50 a	6.23 a
Mean	7.10 a	5.35 b	4.75 b		5.92 a	5.73 a	5.78 a	
LSD 0.05	S = 0.81	I = 0.93	S × I = 1.61		S = 0.73	I = 0.85	S × I = 1.46	

Means followed by the same letter are not significantly different from one another based on Duncan's protected LSD test at $P \leq 0.05$

with MWL3 in the second season. The tower system under irrigation with different waters in the first season and the pyramidal system under irrigation with different waters in both seasons did not have a significant impact on leaf numbers at all stages, where leaf performance curves are often closed to each other. The lowest leaf growth rate was recorded with the pyramidal system under irrigation with all water types in the first season (Fig. 10). These results are consistent with those in [30], in which leaf numbers of *Glycine max* were enhanced significantly by using magnetic field treatments and laser.

Plant Growth and Quality Parameters

In both seasons, maximum fresh head weights (413 and 415 g, respectively) were recorded using the NFT system with MWL3, while the tower and the pyramidal aeroponic systems both with RW recorded minimum fresh head weights in the first and second seasons, respectively. These results mean that the weight of lettuce increased with increasing water and nutrient solution applied to plants with different systems, where NFT is the highest water supply system. In addition, with the highest magnetization level (6300 gauss) of water, the weight of lettuce was greatly affected, where the plant had more benefits from water and nutrients. The same results were obtained to some extent by [31].

In the first season, maximum chlorophyll content was recorded with the integration of the NFT system and irrigation with MWL3, while the integration of the pyramidal system and irrigation with RW recorded the lowest content. There was no significant difference between the pyramidal system with RW and the tower system with RW. On the other hand, in the second season, maximum chlorophyll content was observed with the integration of the NFT system and MWL3, which was not significantly different with the integration of the tower system and MWL3. The highest content of chlorophyll was recorded with different systems in integration with MWL3. Therefore, the magnetized water had the greatest effect on the chlorophyll content in lettuce leaves. This finding is consistent with that in [32-33], in which chlorophyll content is increased with magnetized water in some vegetables.

Maximum leaf N content was recorded with the integrated treatment of NFT system + RW. There were no significant differences between the NFT system + RW and other integrations, except with the pyramidal system + RW in the first season. In the second season, the interaction between the tower system and MWL2 recorded maximum N content. There were no significant differences among all interactions (Table 3). Highest leaf P content was recorded with the integrated NFT system + MWL3 treatment. There were no significant differences between the NFT system + MWL3 and the pyramidal system + MWL2 in the first season. In the second season, maximum P content was recorded with the interaction of the tower system + MWL3, which recorded no significant differences with the NFT system + MWL1 (Table 3). The integrative treatment of the NFT system + MWL1 was most effective on leaf K content. This integrative treatment recorded no significant differences with the NFT system + MWL3 and the NFT system + MWL2 in the first season. In the second season, highest K content was recorded with the NFT system + MWL2. There were no significant differences among the three integrative treatments: NFT system + MWL2, NFT system + MWL3, and pyramidal system + MWL3 (Table 3).

According to the leaf contents of N, P, and K obtained with lettuce, it can be observed that the type of system (e.g., NFT, tower and pyramidal), as well as the different quantities of water applied in these systems, did not affect plant physiology. Lettuce plant can be irrigated with less amount of irrigation water to obtain higher mineral contents and save water, but with lower water productivity [34]. In this study, chlorophyll and nutrient contents were affected by magnetic treatments, which agreed with [35], in which chlorophyll and mineral contents increased by magnetic treatment in bitter gourd. In addition, these enhancements in chlorophyll and mineral contents by magnetic treatment and laser light are supported by their positive effects obtained on enzyme activities, and N and chlorophyll contents in soybean [36]. Partially, these results are not agreed upon due to chlorophyll content obtained in [37], in which magnetic field treatment did not significantly affect chlorophyll content of pea leaf by exposing pea seeds to full-wave rectified sinusoidal magnetic fields.

Conclusions

The present study evaluated the scenarios of three hydroponic systems under irrigation with three levels of magnetized water. These scenarios can be effective tools for increasing water productivity, especially the integration of the NFT system + MWL3. The increase of magnetized water level, especially MWL3, led to a significant increase in nutrient (N, P, and K) concentrations and TDS, although pH was decreased in the nutrient solution. The integration of the NFT system + MWL3 had the best effect on fresh lettuce yield and number of leaves during different growth stages. Maximum chlorophyll content as a notable growth biomarker was recorded with the integration of th NFT system + MWL3 in both seasons. Overall, these systems that can increase water productivity while maintaining quality should be implemented extensively on any scale to support environmental agriculture.

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Conflict of Interest

The authors declare no conflict of interest.

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