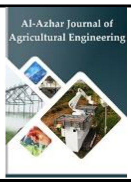
Al-Azhar Journal of Agricultural Engineering 1 (2021) 73-85

Contents lists available at Egyptian knowledge Bank (EKB)

Al-Azhar Journal of Agricultural Engineering

journal homepage: https://azeng.journals.ekb.eg/



Full length article

Applications of magnetized and electrostatic water on irrigation water use efficiency and barley fodder yield under hydroponic system

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ARTICLE INFO

Keywords:
Irrigation water
Magnetization treatment
Electrostatic treatment
Nutrients content
Hydroponic system
Barley irrigation

Water and Irrigation Systems Engineering

ABSTRACT

Modern engineering techniques play an important role in rationalizing the irrigation water use and increasing its production efficiency and thus increasing the productivity of the unit of area. Therefore, the study was conducted by treatment of irrigation water with magnetic and electrostatic fields and follow up the effect of irrigation with them on growing barley seeds (Hordeum vulgare L.) (Giza 123) under the hydroponic system, in terms of the utilization extent of some nutrients, the yield of barley fodder and the water use efficiency. Treated and untreated irrigation water samples were analyzed before planting and after each three days of placing seeds in the planting trays to determine the nutrients content. Some measurements were taken daily to determine the amount of irrigation water discharged from each tray to calculate the amount of water used. Also, some measurements were taken on fresh barley fodder at the end of the experiment to calculate the moisture content, plant length, fresh fodder mass, dry matter mass and irrigation water use efficiency. The results showed that the treated irrigation water with magnetic and electrostatic fields increased the available NPK in growth media, whereas, the mean percentages of decrease in nutrients content in irrigation water were about of 77.35% nitrogen, 29.60% phosphorous and 40.52% potassium for magnetic treatment (MTW), 74.03% nitrogen, 37.44% phosphorous and 29.81% potassium for electrostatic treatment (ETW), and about of 58.51% nitrogen, 16.26% phosphorous and 40.52% potassium for untreated irrigation water (UTW), which lead to an increase in plant absorption of these nutrients by using magnetic and electrostatic treatments, and thus increasing in fresh and dry barley fodder mass compared to the untreated irrigation water. Moreover, the development of seeds were faster, plant growth was statistically significant and finally irrigation water and unit of area productivity increased by using magnetic and electrostatic fields treatments, whereas, the mean values of irrigation water productivity were about of 774.49, 709.74 and 519.99 kg/m^3, while, the mean values of unit of area productivity were about of 34.33, 32.76 and 24.31 kg/m^2, for MTW, ETW and UTW, respectively. Therefore, the results recommend to use magnetic and electrostatic treatments of irrigation water to increase the plant utilization extent of some nutrients dissolved in irrigation water and to increase the productivity of both irrigation water and unit of area.

1. Introduction

Agricultural water use is the main one among all water uses, irrigation water use faces severe competition from non-agricultural users and is challenged by opinion makers and decision makers relative to environmental impacts and the so-called less efficient water use. These conditions create important challenges to farmers, managers, engineers and researchers to develop and adopt practices and techniques that favor the

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Peer review under responsibility of Faculty of Agricultural Engineering, Al-Azhar University, Cairo, Egypt.
Handling Editor - Dr. Mostafa H. Fayed
Received 14 June 2021; Received in revised form 14 July 2021; Accepted 16 July 2021; Available online 21 December 2021

sustainable use of water in agriculture (Pereira, 2005). The total population of Egypt is likely to increase to between 120-150 million by 2050, this high population growth rates will exaggerate the problems associated with water sector allocation. And in terms of water quality, the data available indicate that rapid deterioration is occurring in surface and groundwater quality. Moreover, agriculture consumes the largest amount of the available water in Egypt, with its share exceeding 85% of the total demand for water. In the Egyptian economy, the agricultural sector contributes about 20% to Gross Domestic Product (GDP) and provides about 40% of total employment. In view of the expected increase in demand from other sectors, such as municipal and industrial water supply, the development of Egypt's economy strongly depends on its ability to conserve and manage its water resources (MWRI, 2014). The effect of magnetic field on water in the final result affects the structure of water and hydrated ions as well as the physiochemical properties and behavior of dissolved inorganic salts. Then, because of the limited water resources, better use of available water resources for irrigation is important, the use of poor-quality irrigation water with high salinity is one of the main problems in agriculture. For this reason, the use of techniques such as magnetic water in soil and water reclamation must be studied (Mosin and Ignatov, 2014). Some experiments have shown that the magnetization of water can change water properties. For example, water has flowed through a magnetic field shows weakened hydrogen bonds, reduced polymerization, improved water solubility, and may be increase water productivity and crop yield compared with untreated water, which suggests the potential utility of magnetized water for irrigating crops, including the use of low-quality water such as brackish water (Liu et al., 2019).

Moreover, the application of strong electric fields in water has been studied for several years, because of its importance in electrical transmission processes and its practical applications in biology, chemistry, and electrochemistry (Locke et al., 2006).

The dipole moment is a vector quantity and is responsible for solubility, one of the most important properties of water. High-Voltage Electrostatic Field (HVEF) can increase the viability of seeds and more studies are being conducted to test the effect of HVEF on seeds in electrostatic biology. And some results showed that the HVEF increase seeds activity including earlier germination, higher germination rate, faster growth and stronger resistance of seedlings to stress for both rice seeds germination and chlorophyll content of seedling were increased when rice seeds were treated by HVEF, and the leakage conductivity was decreased (Wang et al., 2009).

The current study aims to design the magnetization and electrostatic water treatment devices to apply magnetic and electrostatic techniques in the irrigation field and study the effect of these techniques on availability of some nutrients to plant absorption, irrigation water use efficiency and barley fodder productivity under the hydroponic system.

2. Materials and methods

The study was made to conduct the effect of magnetic and electrostatic techniques on availability of some nutrients to plant absorption, irrigation water use efficiency and barley fodder productivity under the hydroponic system.

2.1. Materials

2.1.1. Magnetization treatment device

The magnetization treatment device (MTD) used to effect on irrigation water by exposing the water to magnetic field, as previous research has proven that when exposing water to the magnetic field, some of the physical and chemical properties of water were changed, the reason that led to use this technology in agricultural purposes, the magnetic water treatment device used in experiments have a magnetic flux density of 0.5 T (5000 Gauss) and consisted of permanent magnets (Neodymium magnets) arranged in an alternating configuration, two types of magnets were used, the first type dimensions was 50 x 25 x 10 mm with magnetic flux density of 0.220 T, while the second type dimensions was 50 x 25 x 2 mm with magnetic flux density of 0.129 T. Moreover, as the irrigation water contains some chemical salts that contain some nutrients which needed for plants, it was necessary to use water pipe made of material resistant to interaction with those elements. Therefore, the water pipe used in magnetization device was made of stainless-steel No. 316 with external diameter of 17 mm and internal diameter of 14 mm.

Furthermore, the permanent magnets are affected by some factors such as temperature, exposure to shocks and some metallic materials with high magnetic permeability around it which may cause a kind of magnetic field dispersion. Therefore, it was necessary to use some protection layers to cover the magnets.

At first, the magnets were fixed around water pipe by an adhesive layer of transparent plastic, it followed by another layer of synthetic fibers to protect the magnets from shocks, while the third layer consists of cardboard to increase the fixation of previous layer. For the last layer, it was made of white fiberglass, which reflects any radiation that may fall on the magnetic device and may cause the temperature inside to rise and may affect the performance of the magnets efficiently. Consequently, all of these layers may reduce the magnetic field which can be dispersed, as shown in Figure 1.

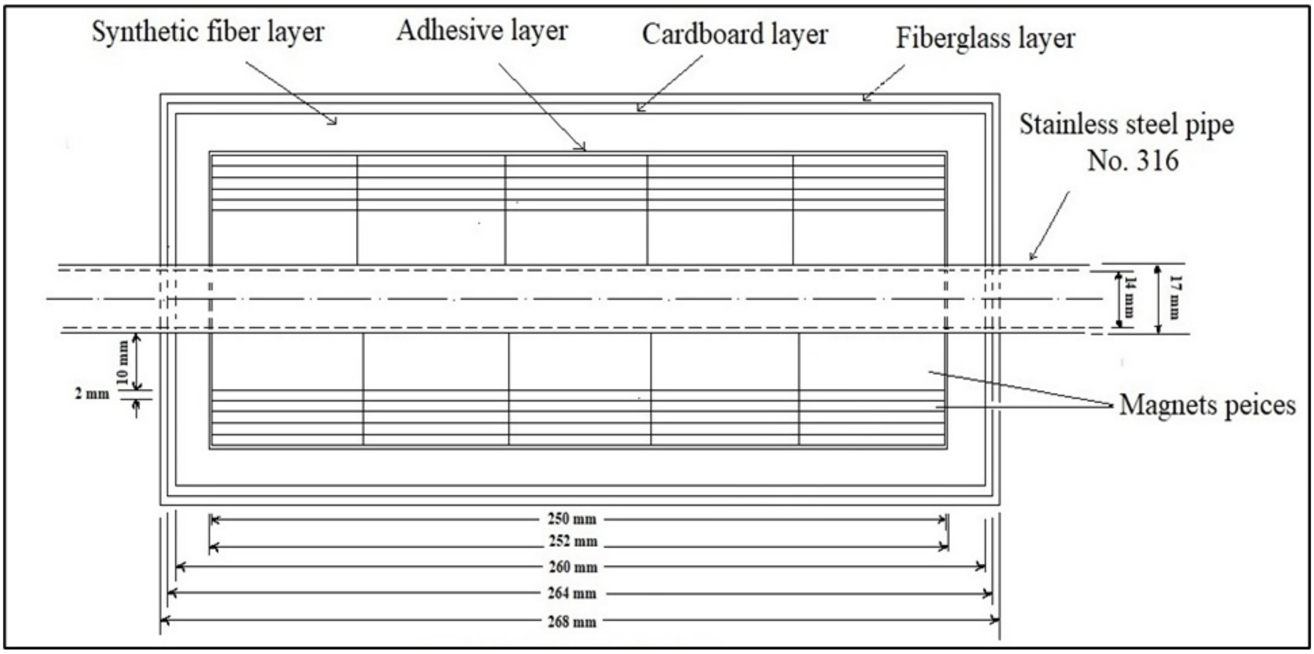

Figure 1. The elevation section of magnetization water treatment device.

2.1.2. Electrostatic treatment device

A principle of the electrostatic water treatment device (ESTD) is used a very high voltage direct current to the anode (+) electrode and the cathode (-) electrode of the pipe structure with very small current about (0.01A or less). Then, when a cylindrical pipe is applied with direct current of anode (+) and cathode (-), an electrostatic field is formed between the anode (+) and the cathode (-). When water exists between the anode (+) electrode and the cathode (-) electrode, an electric field is filled across the water.

2.1.3. Determination of electrostatic field strength (E)

Figure 2 shows cross-section of electrostatic water treatment device, the electrostatic field is generated when current does not flow. Then, according to Bennett, (2002), the following equations used to determine the electrostatic field strength in materials which used in electrostatic water treatment device.

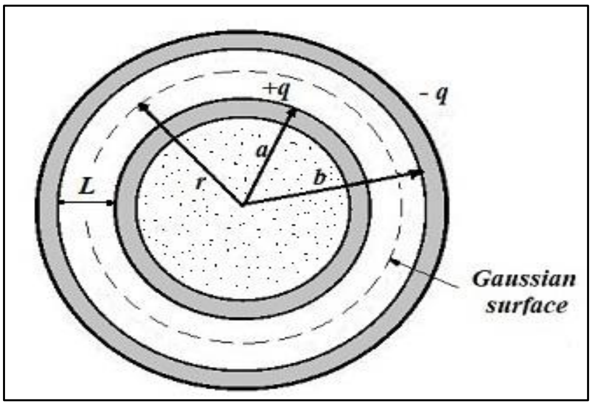

Figure 2. Cross-section in electrostatic water treatment device.

The electrostatic field (E) can be simply described as voltage (V) per unit length (L), it must also follow that the line integral of E between electrodes must be applied voltage V:

$$\int_0^L E_x d_x = V \ldots [1]$$

A capacitor is a device that can store a charge. The magnitude of this charge is described as capacitance and has units of farads. Capacitance (**C**) is defined as the magnitude of the ratio of total free charge ($\mathbf{q_f}$) on either electrode to the voltage difference between electrodes. The equations for capacitance are as follows:

$$C = \frac{q_f}{V} \ldots [2]$$

$$C = \frac{\varepsilon A}{L} \ldots [3]$$

where: C = capacitance "F", ε = capacitor material permittivity, A = the cross-sectional area and L = the gap length of electrodes.

Also, the permittivity is the product of relative permittivity (ε_r) or dielectric constant and the permittivity of free space (ε_0):

$$\varepsilon = \varepsilon_r \varepsilon_0 \ldots [4]$$

where: ε_0 = relative permittivity or dielectric constant of vacuum ($8.854 \mathrm{x} 10^{-12}$ F/m).

2.1.4. Applied electrostatic field equations

The capacitance of a system can be simply increased by placing an object of higher dielectric constant in between the electrodes.

Thereafter, the electrostatic water treatment device is based on the principle of capacitor using the high dielectric constant (**ε** =80 F/m) of water, the capacitance can be expressed as follows:

$$C = \frac{2\,\pi\,\varepsilon_0\,l}{\ln(b/a)} \quad \text{... [5]}$$

or

$$C = \frac{V}{\ln(b/a)} \quad \text{... [6]}$$

Where: a = distance from cylinder center to outer diameter of electrode "mm" and b = distance from cylinder center to inner diameter of pipe "mm".

Then, to determine the electrostatic field distributed through the capacitor "V/m", Gauss's equation was used but instead of Cartesian coordinates the polar coordinates were used. In polar coordinates Gauss's equation as follows:

$$E_r = \frac{C}{r} \quad \text{... [7]}$$

From equations 6 and 7:

$$\therefore E_r = \frac{V}{r\ln(b/a)} \quad \text{... [8]}$$

where: r = the radius of capacitive media "m".

In this study, the radius r of media ranges from a = 0.01 m to b = 0.01475 m, and can be calculated at Gaussian surface as:

$$r = a + \left(\frac{b-a}{2}\right) = 12.375 \text{ mm}$$

Then, the mean value of electric field strength E_r "V/m" within the resistive/capacitive media determined by using equation 8 as follow:

$$\therefore E_r = 4.158\times10^6 \text{ V/m}$$

The electric field in resistors and capacitors media changed when the radius of media between electrodes change with inversely relationship.

Moreover, the relative permittivity and conductivity will help to determine the electric field strength in materials that are described as both resistive and capacitive, a simple diagram of two types of materials in between the electrodes.

Figure 3 shows the cylindrical geometry with material (1) (dielectric material) and material (2) (water). At time zero the system acts as a pure capacitor and current will flow freely, thus permittivity will be the controlling factor. With no surface charge density, the field is continuous across the interface so that:

$$\therefore \varepsilon_1 E_1 = \varepsilon_2 E_2 \quad \text{... [9]}$$

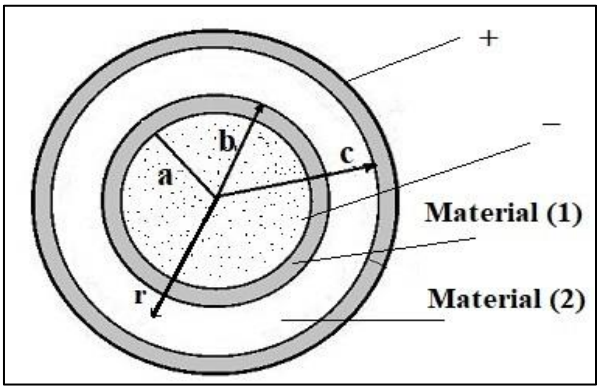

Figure 3. Cylindrical capacitor and two materials used.

The integral of the electric field and set it equal to the voltage drop across the electrodes was used to solve for the electrostatic field equations by using the voltage constraint across materials (1) and (2):

$$\therefore \int_a^b E_r\,dr + \int_b^c E_r dr = V \quad \text{... [10]}$$

From equation 7, find that:

$$\therefore \int_a^b \frac{c_1}{r} dr + \int_b^c \frac{c_2}{r} dr = V \quad \text{... [11]}$$

Then, the integral solution:

$$\therefore c_1 \ln\left(\frac{b}{a}\right) + c_2 \ln\left(\frac{c}{b}\right) = V \quad \text{... [12]}$$

$$E_1 = \frac{c_1}{r}, R_a < r < R_b \quad \text{and} \quad E_2 = \frac{c_2}{r}, R_b < r < R_c \quad \text{... [13]}$$

Using equations 13 and 12, simplifies to:

$$\therefore E_1\, r \ln\left(\frac{b}{a}\right) + E_2 r \ln\left(\frac{c}{b}\right) = V \quad \text{... [14]}$$

At time zero there is no surface charge density and from equation 9 solve for E_1 and E_2 find that:

$$\therefore E_1 = \frac{1}{r} \cdot \frac{\varepsilon_2 V}{\varepsilon_2 \ln\left(\frac{b}{a}\right) + \varepsilon_1 \ln\left(\frac{c}{b}\right)} \quad \text{... [15]}$$

$$\therefore E_2 = \frac{1}{r} \cdot \frac{\varepsilon_1 V}{\varepsilon_2 \ln\left(\frac{b}{a}\right) + \varepsilon_1 \ln\left(\frac{c}{b}\right)} \quad \text{... [16]}$$

The equations 15 and 16 of electric field can be used to determine the electric field in different materials. The electric field is relatively large through the dielectric material and water. Also, it can be seen that the electric field in the water drops off very rapidly further away from the positive electrode.

Moreover, the case for time zero is interesting but it does not best represent the field generated by the electrostatic water treatment device, the permittivity value which was used that of pure water and not permittivity value of water which used in experiments. The permittivity is difficult to determine and therefore, would explain the substitution.

Then, at time infinity, all of the values used will accurately represent the values used in experiments, it is most important to simulate the field that is distributed in the electrostatic water treatment device used, the net positive charge on the inside wall closest to the positive electrode of material (1) and a net negative charge on the inside wall of material (1) closest to material (2). Material (2) has a net negative charge on the surface closest to the negative electrode.

Furthermore, the system is fully charged and the capacitors will no longer pass current. Current will only be flowing through the resistors due to characteristic of the system, thus conductivity will be the controlling factor. The current density must be continuous across the interface and the interface will be such that:

$$\therefore \sigma_1 E_1 = \sigma_2 E_2 \quad \text{... [17]}$$

The electric field equations for a cylindrical geometry at time infinity are very similar to the time zero case. Then, the equations from 10 to 14 used to get an equation in terms of E_1 and E_2, and by using equation 17 the electric field equations at time infinity:

$$\therefore E_1 = \frac{1}{r} \cdot \frac{\sigma_2 V}{\sigma_2 \ln\left(\frac{b}{a}\right) + \sigma_1 \ln\left(\frac{c}{b}\right)} \quad \text{... [18]}$$

$$\therefore E_2 = \frac{1}{r} \cdot \frac{\sigma_1 V}{\sigma_2 \ln\left(\frac{b}{a}\right) + \sigma_1 \ln\left(\frac{c}{b}\right)} \quad \text{... [19]}$$

Then, the equations for the electric field can use to determine the electric field in the different materials. Thereafter, the electrostatic water treatment device as shown in Figure 4 consisted of electrostatic rod (positive charge electrode) which consists of an electrode made of a conducting material (Aluminum) with a radius (a) of 8 mm, the electrode was covered with dielectric insulating material (Material (1) Teflon) with an internal radius of 8 mm, an external radius (b) of 10 mm and electrical conductivity of 1×10^{-23} S/m, the insulator is used to insulate the internal electrode rod but when the insulator is formed with a pinhole, it's may be caused the dielectric breakdown. Thereafter, should be careful of the insulator of internal electrode. The reaction chamber (negative charge electrode) was made of stainless steel (No. 316) and has an internal radius (c) of 14.75 mm and external radius of 16.75 mm. The water (Material 2) which passing through electrostatic treatment device have a distance between electrodes of 4.75 mm, and different electrical conductivity depend on total dissolved solids in it. Moreover, the generator used in the electrostatic water treatment device delivered on the order high voltage of 20 kV with input 12 V and 0.2 mA DC, it was designed by Chinese electronics factory.

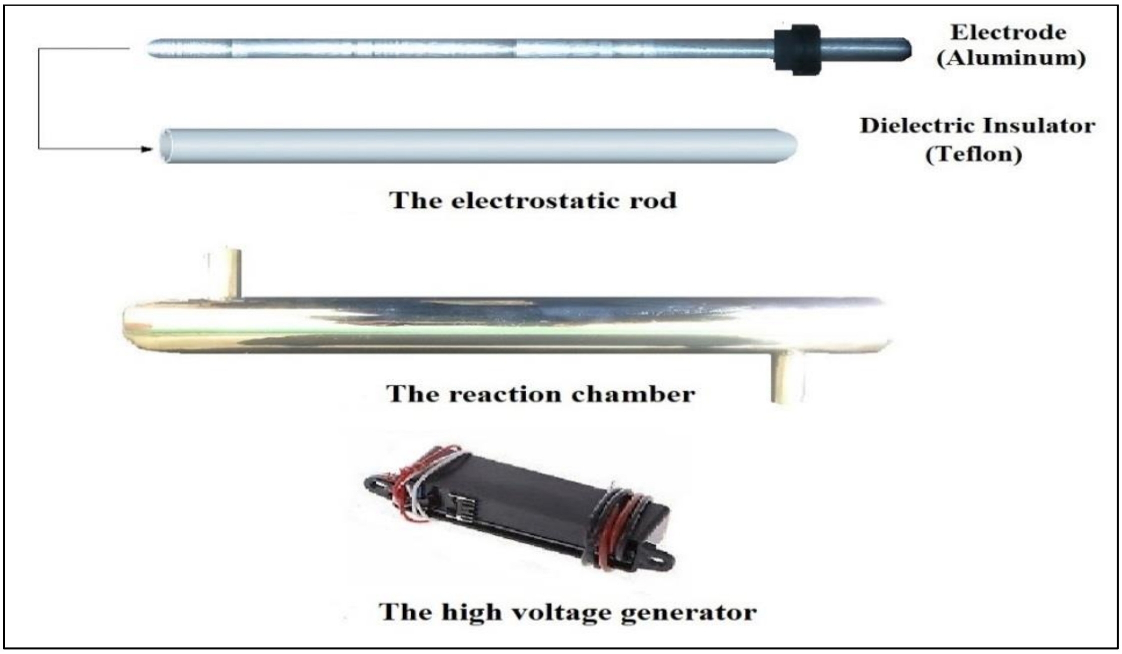

Figure 4. The electrostatic water treatment device.

2.2. *Methods*

2.2.1. *Experimental procedure*

The experiment was designed as completely randomized design (CRD) with split-split plot, and was divided into three experiments using different concentrations of nutrients in irrigation water C_1, C_2 and C_3 as main plots, and each of these experiments was divided into three experiments that included irrigation water treatments, which are untreated or control treatment (UTW), magnetic (MTW) and electrostatic (ETW) treatments as subplots with three replicates to study the effect of irrigation water treatments more accurately.

The experiments were carried out at a room equipped for barley fodder production with a hydroponic system in Tanta, Egypt, whereas the mean room temperature ranged between of 16 - 22ºC. While, the water and plants measurements were carried out at the laboratory of Soils and Water Science, Faculty of Agriculture, Tanta University, Tanta, Egypt. Some measurements were carried out at laboratory of Physics and Mathematical Engineering, Faculty of Engineering, Tanta University, Tanta, Egypt.

Regarding to Irrigation water preparation and nutrients content used, three forms of irrigation water used to irrigate plants under hydroponic system, they were prepared according to Hoagland and Arnon, (1950) method to get full Hoagland strength, half Hoagland strength and quarter Hoagland strength, it can be expressed as C_1, C_2 and C_3 respectively, Table 1 shows irrigation water properties and various concentrations of macronutrients NPK used in experiments. The plant depends on its need of nutrients in different proportions. Then, accordingly it appears if there are a difference between magnetic and electrostatic irrigation water treatments and the control treatment.

Table 1
Irrigation water properties and macronutrients content.

Concentrations (C)	Properties			Macronutrients "ppm"		
	EC "dS/m"	pH	TDS "ppm"	N	P	K
C_1	2.59	6.90	1657.60	130.50	21.77	428.31
C_2	1.66	7.10	1062.40	93.20	14.11	287.68
C_3	1.11	7.30	710.40	81.50	10.36	116.91

Furthermore, the experiment that prepared to study the effect of magnetic and electrostatic devices on irrigation water by using hydroponic system which consisted of three units wooden stand that were coated with waterproofing material, each stand divided into three shelves which contain nine planting trays, the hydroponic unit dimensions as shown in Figure 5.

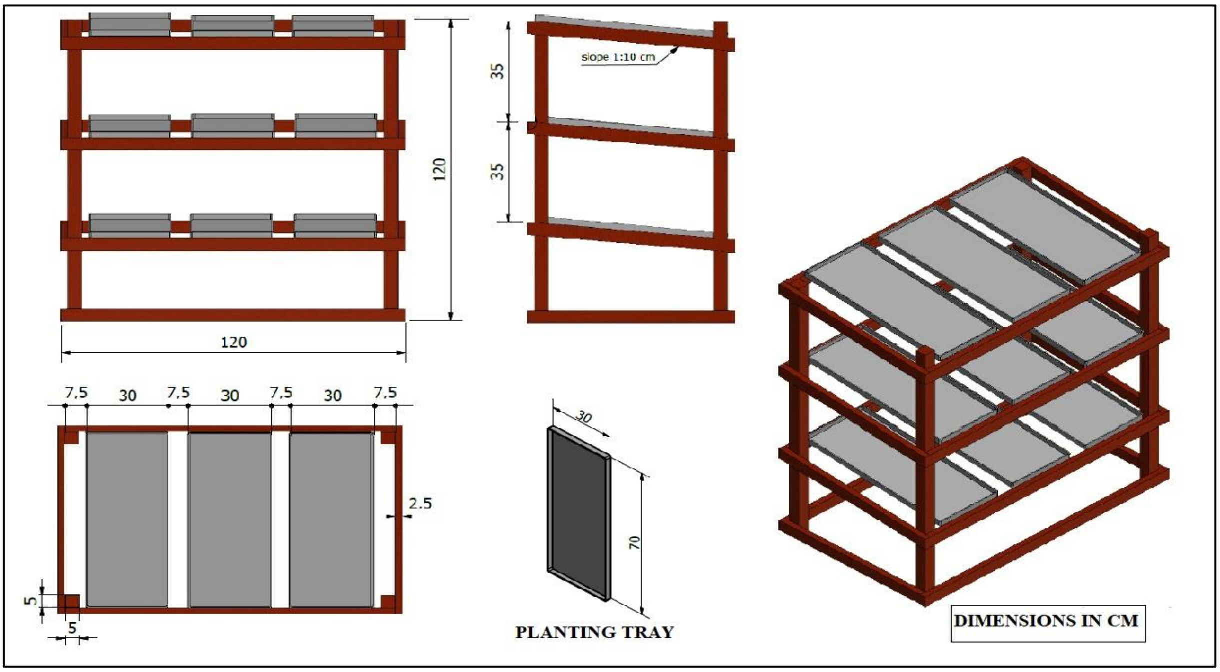

Figure 5. The hydroponic unit dimensions used in experiments.

Moreover, the irrigation water unit consisted of: the storage tank with volume of 10 liter ($0.01m^3$) to store the irrigation water and nutrient solution, the submersible pump was immersed in the water tank to the bottom to transfer water from the storage tank to the irrigation system, it was connected to irrigation system by using polyethylene pipe (P. E.) of 8mm internal diameter and length of 120 cm for main line, but for electrostatic and magnetic experiments, the main line was of appropriate length to allow connection with the magnetic and electrostatic devices. Whereas, the irrigation water was passed through magnetic and electrostatic treatment devices, it was exposure to these forces for a certain time. Thus, it was necessary to calculate the irrigation water flow velocity.

The velocity of water outflow was determined by the continuous equation as the following:

$$Q = A.v \quad \ldots [20]$$

where: Q = the flow rate of water "m^3/s", A = the section area of stainless-steel pipe "m^2" and v = the velocity of flow water "m/s".

Moreover, the valves were used to control amount of water that feeding water into the plant supporting trays. While the irrigation system timing opening/closing was controlled by the digital timer. Subsequently, the water flow velocity through treatment devices used is 0.119m/s with discharge about of 5.985 cm^3/s. The irrigation water level used in the present study was about 600 cm^3 / 12 h (with two times per day) for each tray.

With regard to the total water use, drained water out of irrigation was collected in plastic containers for each planting tray.

The lighting operating hours in the hydroponic system to conserve the fodder crop lighting requirements were 14 h / day with intensity of 2000 lux. The lighting intensity was achieved by six white fluorescent lamps (120 cm length, 38 W power and 2700 lumen) to cover area of 9 m^2 and obtained 2000 lux (1 lux = 1 lumen / m^2). The lamps were fastened on wooden stand in the center of hydroponic system to obtain the best lighting distribution for all trays. The operating time of lighting system is manually controlled.

An aeration unit was used to cooling the air in experiment place, the aeration system was worked at for 3 min after every 2 h, and it was controlled by timer.

The seeds of barley of all experiments were cleaned from debris and other foreign materials. Then, the seeds were sterilized by soaking for 10 min in a solution 0.1% Sodium hypochlorite (5%) (Household bleach) to control the formation of mould.

Then, the seeds were washed well from residues of bleach and soaked in tap water for 12 h before planting. Also, the trays were cleaned and disinfected by the same solution, then washed by tap water to remove any chemical traces.

After soaking, the seeds were spread in the polyethylene trays of 70×30×4 cm, the seeding rate used in this experiment was about one kg (weighted before soaking) for each tray in actual planting area about 0.162 m^2 (60×27 cm). The seeds were left without light for 24-36 h to stimulate root growth, such as the seeds were buried in soil.

2.2.2. Measurements

The measurements were taken for all samples of irrigation water in water tank before irrigation process and after each three days of planting for treated and untreated irrigation water. Some analyses were performed on irrigation water to determine the macronutrients NPK content. Some measurements were taken daily to determine amount of drained water from each tray to calculate amount of water used, as the following:

$$TWU = TWA - TDW \quad \ldots [21]$$

where: TWU = total water used "m^3/tray", TWA = total water added for irrigation "m^3/tray" and TDW = total drained water from trays "m^3/tray".

Also, some measurements (plant growth, root length, fresh fodder mass and dry matter mass) were carried on fresh barley fodder at the end of experiment to calculate the moisture content, irrigation water use efficiency and unit area productivity, as the following:

$$MC\,\% = 100\,(FM - DM) / FM \quad \ldots [22]$$

where: MC = moisture content "%", FM = fresh mass "kg" and DM = dry mass "kg".

$$WUE \text{ or } IWP = TFP / TWU \quad \ldots [23]$$

where: WUE = water use efficiency and it can also be expressed as IWP = irrigation water productivity in "kg/m^3" and TFP = total fresh fodder produced "kg/tray".

$$UAP = TFP / APA \quad \ldots [24]$$

where: UAP = unit area productivity in "kg/m^2" and APA = actual planting area "m^2/tray".

3. Results and discussions

The data collected on the changes of macronutrients content which dissolved in irrigation water during irrigation period after each three days of planting to study the effect of magnetic and electrostatic treatments on extent of the nutrients utilization by the plant, irrigation water productivity and barely fodder yield at different nutrients concentrations C_1, C_2 and C_3.

3.1. The effect of magnetization and electrostatic treatments on macronutrients content

The results showed decrease in NPK content in irrigation water after each three days of planting. For nitrogen (N) content, the values decreased in irrigation water by using magnetic (MTW) and electrostatic (ETW) treatments of irrigation water, where values decreased from 130.50, 93.20 and 81.50 ppm to the lowest mean values of 33.70, 25.10 and 12.40 ppm for MTW and 41.32, 25.80 and 15.13 ppm for ETW, while for UTW the lowest mean values were of 58.62, 44.45 and 25.97 ppm, as exponential equations all previous results for C_1, C_2 and C_3, respectively, as shown in Figure 6.

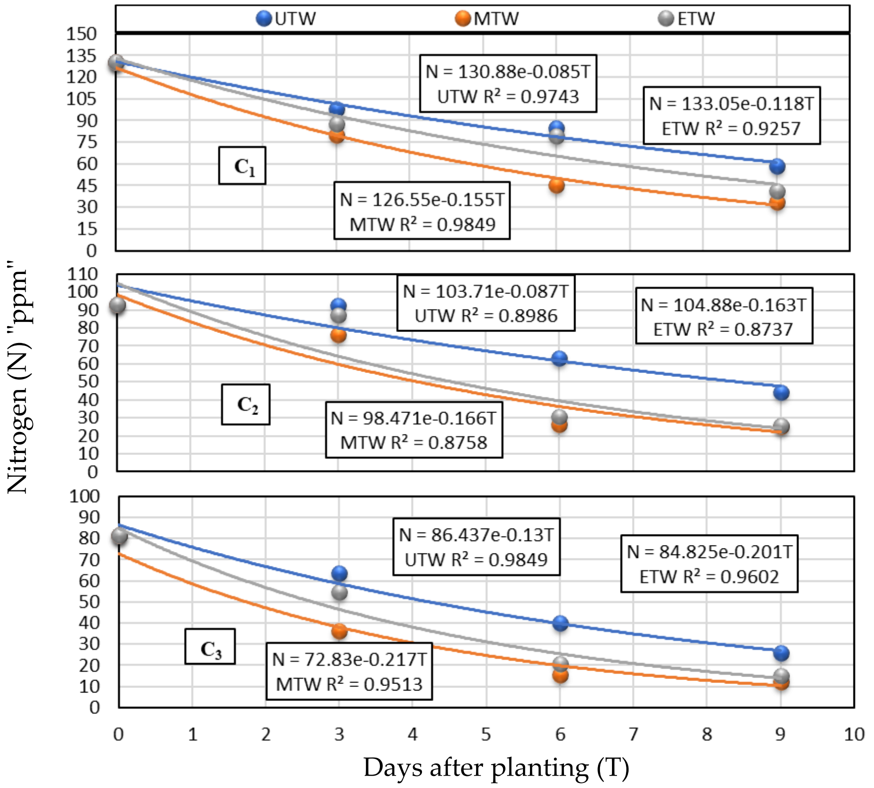

Figure 6. Effect of magnetization and electrostatic treatments on Nitrogen "ppm" in irrigation water at different concentrations after certain days of planting.

Regarding to the phosphorous (P) content, the values also decreased in irrigation water by using MTW and ETW from 21.77, 14.11 and 10.36 ppm to the lowest mean values of 14.80, 10.40 and 7.20 ppm for MTW and 13.90, 8.20 and 6.81 ppm for ETW, while for UTW the lowest mean values were of 16.20, 13.10 and 8.70 ppm, as exponential equations all previous results for C_1, C_2 and C_3, respectively, as shown in Figure 7.

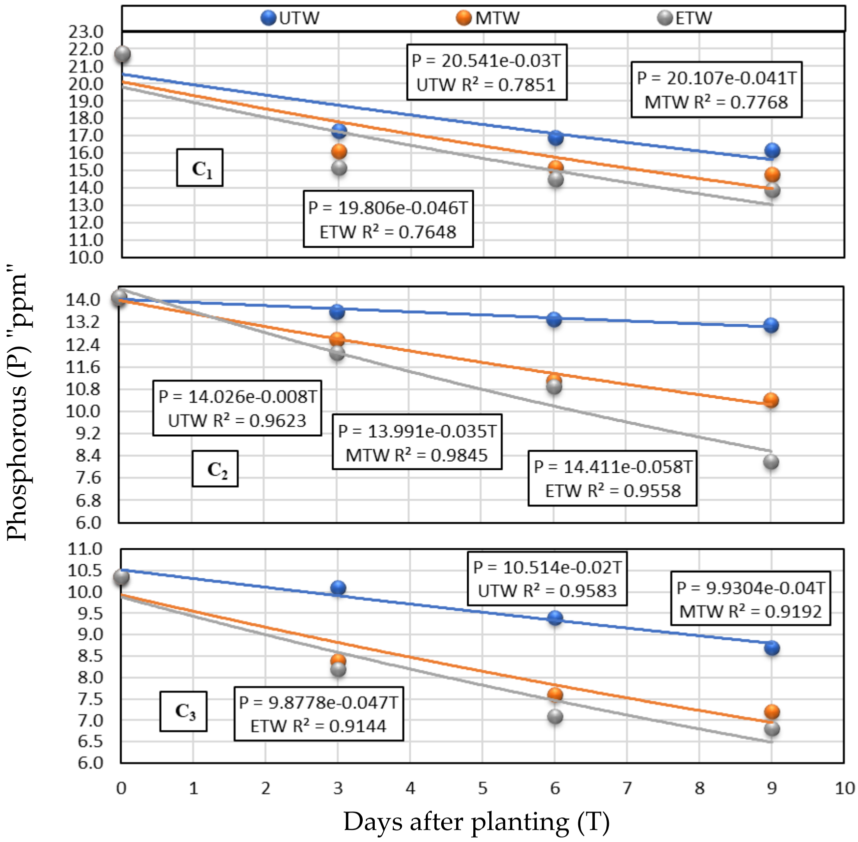

Figure 7. Effect of magnetization and electrostatic treatments on Phosphorous content "ppm" in irrigation water at different concentrations after certain days of planting.

Furthermore, the data in Figure 8 shows that the potassium (K) content decreased in irrigation water by using MTW and ETW from 428.31, 287.68 and 116.91 ppm to the lowest mean values of 288.50, 144.60 and 71.10 ppm for MTW and 257.30, 137.50 and 47.30 ppm for ETW, while for UTW the lowest mean values were of 358.10, 176.10 and 76.70 ppm, as exponential equations all previous results for C_1, C_2 and C_3, respectively.

The decreasing in macronutrients content NPK in irrigation water may be attributed to the effect of magnetic fields on the increasing of fertilizer compounds analysis and facilitate of solubility, and thus increase their absorption by the plant, which lead to a decrease in concentration in the irrigation water compared to the control treatment. This in agree with those of Maheshwari and Grewal (2009).

Moreover, due to the application of the electrostatic field, water molecules can be polarized, redirected and tend to align with the electrostatic field direction. The distribution of dipole moments along the electrostatic field results in the most stable condition and the Boltzmann distribution function will reach a maximum value, resulting in an increase in water solubility of nutrients, which may make it available for absorption from the plant. This in agreement with those of Sun et al., (2008).

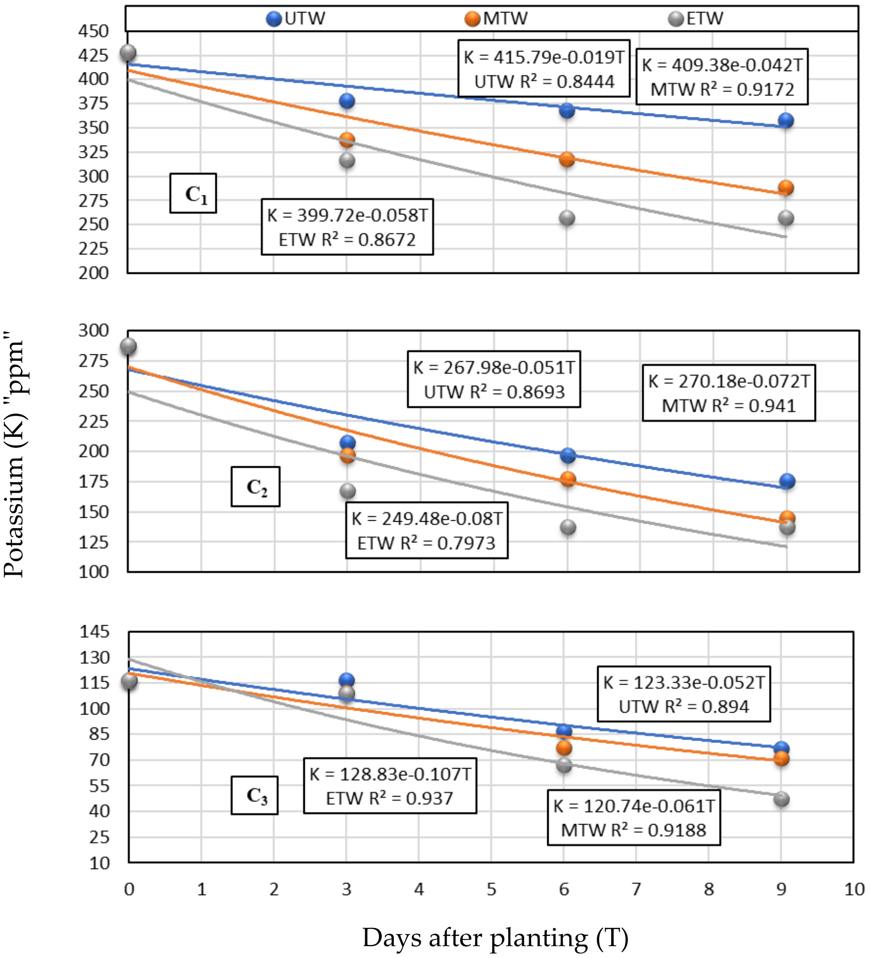

Figure 8. Effect of magnetization and electrostatic treatments on Potassium content "ppm" in irrigation water at different concentrations after certain days of planting**.**

3.2. The effect of magnetic and electrostatic treatments on barley fodder yield

The results in Figure 9 shows that the using of magnetic and electrostatic treatments of irrigation water leads to increase of plant length "mm", moisture content "%" and fresh barley fodder yield "kg/tray" for different nutrients concentrations in irrigation water under hydroponic system. For MTW, the highest means of plant length were about of 215.2, 220.4 and 230.8 mm, the means of moisture content in barley fodder were about of 88.50, 87.59 and 88.50 %, and the mean values of fresh mass for each tray were about of 5.98, 5.29 and 5.41 kg/tray, all previous results for C_1, C_2 and C_3, respectively. Moreover, for ETW, the highest means of plant length were about of 204.3, 211.4 and 219.5 mm, the means of moisture content in barley fodder were about of 87.75, 87.23 and 88.35 %, and the mean values of fresh mass for each tray were about of 5.39, 5.12 and 5.41 kg/tray, all previous results for C_1, C_2 and C_3, respectively.

While the results of UTW showed that the highest means of plant length were about of 144.2, 162.8 and

169.2 mm, the means of moisture content in barley fodder were about of 87.08, 86.47 and 85.85 %, and the mean values of fresh mass for each tray were about of 4.11, 3.98 and 3.72 kg/tray, all previous results for C_1, C_2 and C_3, respectively.

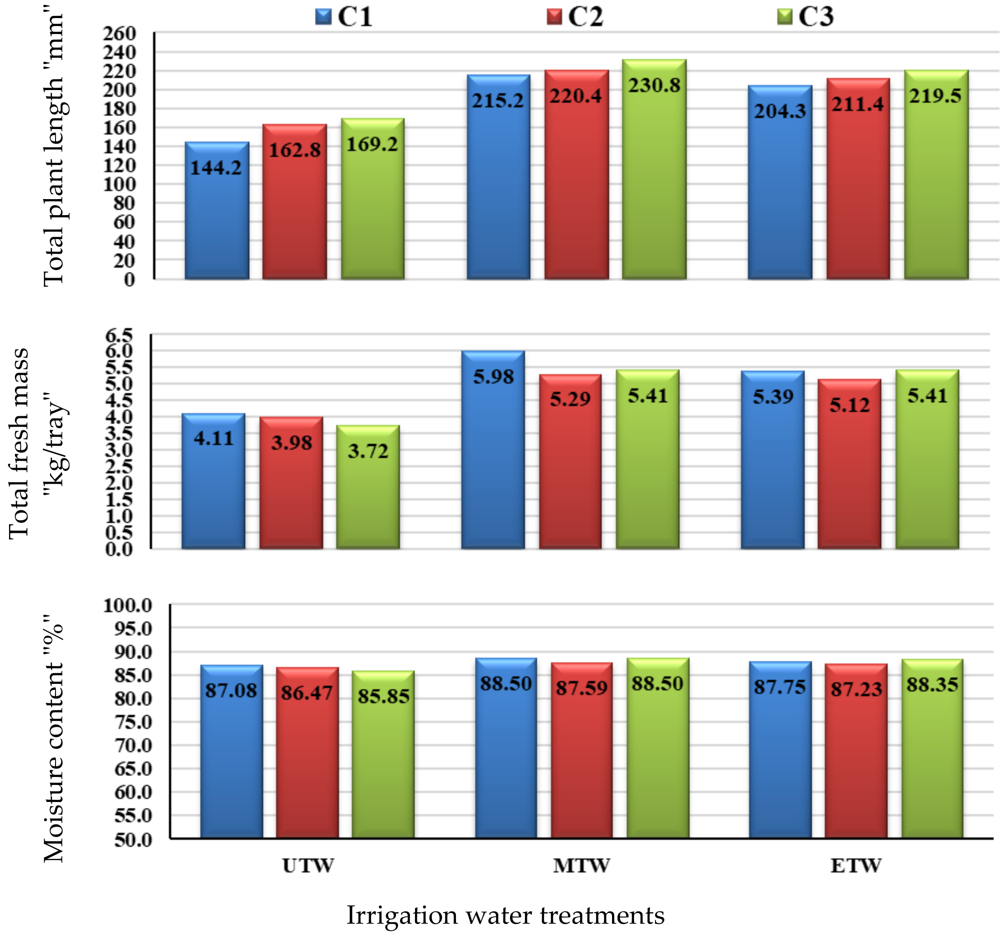

Figure 9. Effect of magnetization and electrostatic treatments on plant length, moisture content (MC %) and fresh yield of barley fodder "kg/tray" at different irrigation water nutrients concentrations.

With regard to the effect of magnetic and electrostatic fields on barley fodder productivity, it was expressed through calculating irrigation water productivity IWP "kg/m^3" and unit of area productivity UAP "kg/m^2". For MTW, the results showed that the IWP of fresh yield increased with a values about of 830.00, 747.50 and 745.97 kg/m^3, and the UAP of fresh yield increased by using MTW with values about of 36.94, 32.67 and 33.39 kg/m^2, all previous results for C_1, C_2 and C_3, respectively. Also, for ETW, the IWP of fresh yield increased with a values about of 728.45, 672.33 and 728.46 kg/m^3, and the UAP of fresh yield increased by using ETW with values about of 33.29, 31.61 and 33.40 kg/m^2, all previous results for C_1, C_2 and C_3, respectively. While, the results of UTW showed that the IWP of fresh yield values were about of 552.18, 520.11 and 487.69 kg/m^3, and the mean values of UAP of fresh yield were about of 25.37, 24.58 and 22.97 kg/m^2, all previous results for C_1, C_2 and C_3, respectively, as shown in Figure 10.

Furthermore, by using MTW and ETW the IWP and UAP of dry matter were increased. As shown in Figure 11, for MTW, the results showed that the IWP of dry matter increased with values about of 95.43, 92.76 and 85.71 kg/m^3, and the UAP of dry matter increased by using MTW with values about of 4.25, 4.06 and 3.84 kg/m^2, all previous results for C_1, C_2 and C_3, respectively. Also, for ETW, the IWP of dry matter increased with values about of 89.25, 85.85 and 84.86 kg/m^3, and the UAP of dry matter increased by using ETW with values about of 4.08, 4.04 and 3.89 kg/m^2, all previous results for C_1, C_2 and C_3, respectively. While the results of UTW showed that the IWP of dry matter values were about of 71.25, 70.31 and 68.94 kg/m^3, and the mean values of UAP of dry matter were about of 3.27, 3.32 and 3.25 kg/m^2, all previous results for C_1, C_2 and C_3, respectively.

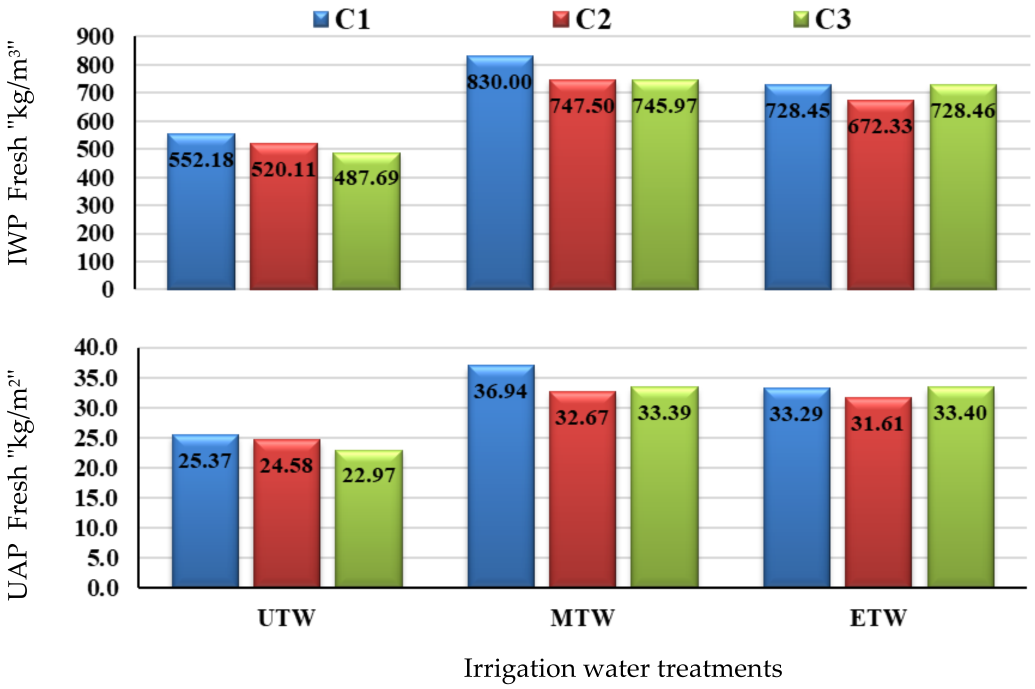

Figure 10. Effect of magnetization and electrostatic treatments on productivity of both irrigation water (IWP) and unit of area (UAP) of barley fodder fresh yield.

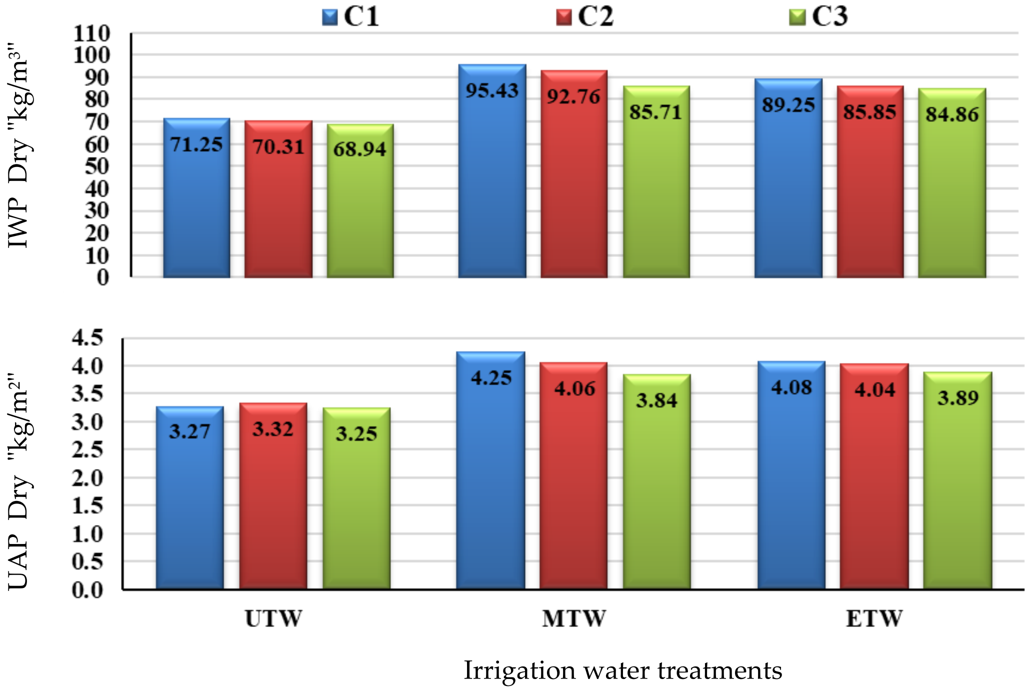

Figure 11. Effect of magnetization and electrostatic treatments on productivity of both irrigation water (IWP) and unit area (UAP) of barley fodder dry yield.

The increasing in yield and water productivity may be attributed to that the development of seeds were faster and plant growth was statistically significant by using magnetic and electrostatic treatments, which leads to the increasing of plant absorption for water and nutrients as result of the decreasing of surface tension, viscosity and density of water compared untreated samples. These results in agreement with those of Morar et al. (1999).

Moreover, Yang and Shen (2011) stated that the absorbing water ability of seeds were promoted, germination initiation time of seeds were shortened and increased plant height at room temperature and under light.

4. Conclusions

The results in the present study could be summarized in the following conclusion:

1. The magnetic and electrostatic treatments of irrigation water tend to increase available NPK which lead to an increase in plant absorption of these nutrients, compared to the untreated irrigation water.
2. The development of seed was faster, plant growth was statistically significant and increased both productivity of irrigation water and unit of area by using magnetic and electrostatic treatments.

In conclusion, it is important to note the importance of improving the engineering and physicochemical techniques, the technologies aimed at increasing the efficiency of irrigation water use, economy and resource saving in technologies for Fertigation and irrigation water treatments while minimizing chemical risk.

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تطبيقات الماء الممغنط والإلكترو ستاتيكي على كفاءة استخدام مياه الري وإنتاجية علف الشعير تحت نظام الزراعة المائية

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الملخص العربي

إن التقنيات الهندسية الحديثة تقوم بدور هام في ترشيد استخدام مياه الري وزيادة الكفاءة الإنتاجية لها وبالتالي زيادة إنتاجية وحدة المساحة، ولذلك أجريت الدراسة بتطبيق التقنيات المغناطيسية والإلكتروستاتيكية على مياه الري، وتحديد تأثيرهما على مياه الري المستخدمة لري الشعير (جيزة ١٢٣) تحت نظام الزراعة المائية، من حيث مدي الاستفادة من بعض العناصر الغذائية وإنتاجية علف الشعير وكفاءة استخدام مياه الري.

قسمت التجربة باستخدام التصميم العشوائي الكامل CRD بترتيب القطع المنشقة إلى ثلاث تجارب باستخدام تركيزات مختلفة من العناصر الغذائية في مياه الري كوحدات أساسية، وكل تجربة من هذه التجارب قسمت إلى ثلاثة تجارب تشمل معاملات مياه الري بدون معاملة (كنترول)، معاملة مغناطيسياً ومعاملة الكتروستاتيكياً كوحدات ثانوية في ثلاث مكررات.

تكررت التجربة ثلاث مرات مع محاولة الحفاظ على الظروف المحيطة بقدر الإمكان وقد تم تحضير العناصر الغذائية الكبرى NPK باستخدام محلول هوجلاند، والتي يمكن التعبير عنها بمياه الري C_1 : نيتروجين ١٣٠,٥٠، فوسفور ٢١,٧٧، وبوتاسيوم ٤٢٨,٣١ جزء في المليون، ومياه الري C_2: نيتروجين ٩٣,٢٠، فوسفور ١٤,١١، وبوتاسيوم ٢٨٧,٦٨ جزء في المليون، ومياه الري C_3: نيتروجين ٨١,٥٠، فوسفور ١٠,٣٦، وبوتاسيوم ١١٦,٩١ جزء في المليون، حيث تم عمل تحليل لمياه الري بعد كل ثلاثة أيام من وضع البذور في صواني الزراعة لتحديد محتوى المياه من العناصر الغذائية، كما أخذت بعض القياسات يومياً لتحديد كمية مياه الري المنصرفة من كل صينية وحساب كمية المياه المستخدمة، بينما أخذت القياسات على علف الشعير الأخضر في نهاية التجربة لحساب المحتوى الرطوبي، وزن العلف الأخضر، وزن المادة الجافة وكفاءة استخدام مياه الري (الكفاءة الإنتاجية لمياه الري).

أظهرت النتائج أن المعاملات المغناطيسية والإلكتروستاتيكية لمياه الري تؤدي إلى انخفاض محتوى مياه الري من العناصر الغذائية الكبرى مع مرور الوقت وكان معدل الانخفاض متوافق مع شكل المعادلة الأسية ($y= be^{-ax}$) حيث y = تمثل تركيز العناصر الغذائية في مياه الري، x = عمر النبات (الأيام بعد الزراعة)، b = الجزء المقطوع من محور y و a = ميل منحنى الدالة، وهذا يعتبر دليل على زيادة امتصاص النبات لهذه العناصر الغذائية مقارنة بمياه الري غير المعاملة، حيث كان متوسط مجموع نسب الانخفاض للعناصر الغذائية في الثلاث تركيزات (C_1، C_2 و C_3) باستخدام المعاملة المغناطيسية لمياه الري حوالي ٧٧,٣٥٪ للنيتروجين، ٢٩,٦٠٪ للفوسفور و ٤٠,٥٢٪ للبوتاسيوم، وباستخدام المعاملة الإلكتروستاتيكية لمياه الري كانت نسبة الانخفاض المتوسطة حوالي ٧٤,٠٣٪ للنيتروجين، ٣٧,٤٤٪ للفوسفور و ٥٠,٥٦٪ للبوتاسيوم، بينما كانت هذه النسبة في مياه الري غير المعاملة حوالي ٥٨,٥١٪ للنيتروجين، ١٦,٢٦٪ للفوسفور و ٢٩,٨١٪ للبوتاسيوم.

وبالتالي كان تطور البذور أسرع، وكذلك نمو النباتات ذو دلالة إحصائية وزيادة إنتاجية مياه الري باستخدام المعاملات المغناطيسية والإلكتروستاتيكية لمياه الري، حيث بلغ متوسط إنتاجية مياه الري من العلف الأخضر في الثلاث تركيزات للعناصر الغذائية باستخدام المعاملة المغناطيسية لمياه الري ٧٧٤,٤٩ كجم / م^{٣}، وباستخدام المعاملة الإلكتروستاتيكية لمياه الري كان متوسط الإنتاجية ٧٠٩,٧٤ كجم / م^{٣}، بينما ٥١٩,٩٩ كجم / م^{٣} للمياه غير المعاملة. بالإضافة إلى ذلك، بلغ متوسط إنتاجية وحدة المساحة من العلف الأخضر في الثلاث تركيزات للعناصر الغذائية باستخدام المعاملة المغناطيسية لمياه الري ٣٤,٣٣ كجم / م^{٢}، وباستخدام المعاملة الإلكتروستاتيكية لمياه الري كان متوسط إنتاجية وحدة المساحة ٣٢,٧٦كجم / م^{٢}، بينما ٢٤,٣١ كجم / م^{٢} للمياه غير المعاملة.

ولذلك، توصي النتائج باستخدام المعاملات المغناطيسية وتليها الإلكتروستاتيكية لمياه الري لزيادة استفادة النباتات من العناصر الغذائية الذائبة في مياه الري، وزيادة إنتاجية كلا من مياه الري ووحدة المساحة، وأنه من المهم ملاحظة أهمية تحسين مثل هذه التقنيات الهندسية.