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EFFECT OF MAGNETIZED WATER ON WATER USE EFFICIENCY OF SPINACH UNDER NORTH SINAI CONDITIONS

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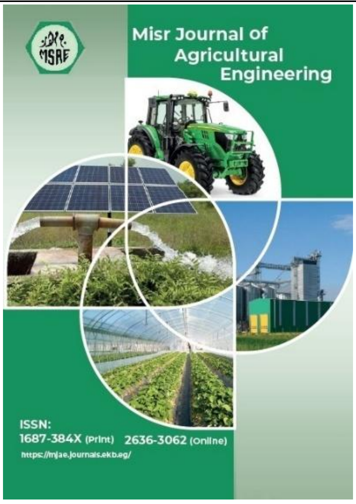

Keywords:
Magnetic water; Salinity irrigation water, Water use efficiency; Irrigation water use efficiency, applied irrigation water stress.

ABSTRACT

An experiment was performed during two successive winter seasons of (2018/2019-2019/2020), at a private farm in Baloza, North Sinai, Egypt, to study the effect of three levels of irrigation water salinity "SL" (1.21, 2.98 and 4.54 dS/m) and four applied irrigation water stresses "IR" (100%, 85%, 70 and 55%) under magnetic (MW) and un-magnetic (UMW) water treatment technique on marketable yield, parameters of crop quality , actual evapotranspiration (ETa), water use efficiency (WUE) and irrigation water use efficiency (IWUE) for spinach leaves by using surface drip irrigation system. The results showed that, the marketable yield and studied quality parameters of spinach leaves gave the highest values when applying treatment SL1 =1.21 dS/m and IR = 100% under MW water for both seasons. While the seasonal ETa of spinach leaves gave the lowest values of 107.91 and 105.10 mm/season for both seasons respectively, when applying treatment, SL1 = 1.21 dS/m and IR = 55% under MW. Finally, the WUE and IWUE of spinach leaves gave the highest values when applying treatment SL1 =1.21 dS/m and IR = 70% under MW. The study concluded that irrigating spinach by using magnetized water may be considered as a promising technique to improve marketable yield productivity and saving a lot of irrigation water added by using surface drip irrigation system.

1. INTRODUCTION

In many regions of the world, salinity of irrigation water is an environmental stress factor that inhibits growth and yield of different crops. In Egypt, salinity is the most serious irrigation water quality problem in agriculture. The impact of salinity on crops production is becoming increasingly important worldwide problem creating a pressing need for improved salt tolerant plants. Crops vary in their resistance to salinity, this induces the necessity to do investigations to list the ability of different plants to tolerate salinity and follow the changes that might take place in their physiological activities under saline irrigation **(Ali et al., 2011)**. Some success has been achieved in controlling the salinity of irrigation water through conservation of water, hydraulic engineering, biological, chemical, and physical methods, also through other comprehensive measures **(Song and Wang, 2015)**.

The magnetic treatment of saline irrigation water had a positive effect in reducing soil salinity after the plants were harvested. Where values of relative change ($Rc^{\pm}$ %) of soil salinity (ECe), sodium adsorption ratio (SAR), Na^+, Cl^- and SO_2 decreased, while ($Rc^{\pm}$ %) of Mg^{++}, Ca^{++} and K^+ in soil extraction after harvesting increased due to magnetic treatment of irrigation water, compared to irrigation with magnetized fresh water. **(Amer et al., 2014)**.

The magnetic water treatment (MWT) removes the excess of the soluble salts; reduces pH values, due to MWT have solving for soil salts, and leaches the salts away from roots zone **(Mohamed and Ebead, 2013)**. The magnetic water treatment is an interesting research field because the treatment is consuming zero energy **(Esmaeilnezhad et al., 2017)** and has high potential as physical water treatment, which is more environmentally-friendly compared to chemical water treatment, which is not desirable **(Simonic and Urbancl, 2017)**. The magnetic treatment of water used in irrigating saline soils could be a promising technique for the soil and agricultural improvements, besides this technique is considered an environmentally friendly one. It is recommended to use the magnetized water for irrigation to save the irrigation water especially under water shortage conditions. Also, it might increase the fertilizers use efficiency. In addition, it significantly improved the vegetative growth and yield parameters beside the macronutrients content of wheat plants **(Abd El-Rahman and Shalaby, 2017)**.

The irrigation with magnetic water treatment can be considered as a one of the most valuable modern technologies that can improve crop production and alleviate salinity of water and soil, as well as can assist in saving irrigation water **(Fanous et al., 2017)**.

The physical analysis values of irrigation water decrease as the magnetic field (MF) level increased. Simultaneously, the values of chemical analyses of IR increased with increasing MF levels except for SAR. Meanwhile, the values of (Na^+, K^+, Cl^- and HCO_3^-) were not significant at different MF levels. The quality parameters for lettuce plant and potato tuber increased with increasing MF levels and IR under the surface drip irrigation (SDI) and sub-surface drip irrigation (SSDI) except total sugar (TS) for plant lettuce. The values of ET_a for lettuce and potato crops decreased with increasing MF levels. In comparison, ET_a for both crops increased with increasing IR under SDI and SSDI. The values of water use efficiency (WUE) and irrigation water use efficiency (IWUE) for the lettuce plant under MF= 4000 Gauss, IR=80% and SSDI treatment increased significantly compared to those under control treatment. Also, the values of WUE and IWUE for potato tuber under MF= 4000 Gauss, IR=70% and SSDI treatment increased significantly compared to those under control treatment. Application of MF 4000 Gauss at IR80% under SSDI treatment for a yield of lettuce plant could save about 20% of irrigation water and increased significantly by about 29% compared to that under control treatment. Simultaneously, MF 4000 Gauss at IR70% under SSDI treatment for the yield of potato tuber could save about 30% of irrigation water and increased significantly by about 7% compared to that under control treatment **(Ali et al., 2017)**.

The experiment revealed some beneficial effects of magnetically treated water for germination of maize seeds. Irrigation with magnetically treated water increased the vegetative growth of maize seeds. The use of magnetized saline water for sprouting seeds of maize reduced the mean emergence time as compared to non-magnetized water. Although magnetic water treatment is an environmentally friendly and easy-to-handle technology, more research is needed to understand the mysterious mechanism of the magnetic field in order to transform it into a technology for sustainable agriculture (**Abedinpour and Rohani, 2017)**. Thus, magnetization of irrigation water increases plant metabolism in terms of water absorption and photosynthesis **(Yano et al., 2004)**.

Spinach plants are a medium sensitive to salinity. Threshold soil salinity was 2.0 dS/m and yield lost slope was 7.6% after threshold **(Grieve et al., 2012)**. When spinach plants were irrigated with different six levels of saline irrigation water, the salinity of water did not affect the number of leaves or the diameter of the stems of spinach. Consequently, salinity aided root length. For non-saline and extreme saline environments, the ratio of root mass was found to be higher. Medium salinity conditions influenced the ratio of the root mass negatively. Application of saline water increased soil salinity. Soil salinity to irrigation water salinity ratio was higher under relatively lower saline conditions due to more water consumption. Salinity had a depressing effect on spinach water consumption by causing potential osmotic decreases in soil water solution. This depressing effect should be considered to manage irrigation and salinity precisely. The fresh yield of spinach was affected negatively by salinity **(Ünlükara et al., 2017)**. Also, when spinach plants were irrigated with three amounts of applied irrigation water 100, 85 and 70% of evaporation pan (E_{pan}, the 100% E_{pan} treatment recorded the highest marketable yield (28.06 Mg/ha) and IWUE (9.7 kg/m^3), while 100% E_{pan} treatment in spinach production could be proper for water enough regions due to higher yield and IWUE (**Kuslu et al., 2016)**.

This study aimed to investigate the effect of magnetic water treatment under levels of salinity irrigation water and deficit irrigation water added on spinach crops production, quality growth parameters, actual evapotranspiration, water use efficiency and irrigation water use efficiency.

2. MATERIALS AND METHODS

1. Experiments layout

Field experiments were performed in Baloza area, North Sinai Governorate, Egypt, at 31° 27' 15" N: 32° 34' 07" E. 14 m BSL during two successive winter seasons of 2018/2019 and 2019/2020. In split-split plot design with three replicates, the experimental was divided into 75 m^2 plots; each bounded by 2 m wide barren to avoid horizontal infiltration. The obtained data were subjected to statistical analysis according to **Snedecor and Cochran (1989),** using Co-state software program.

The spinach (*Spinacias Oleracea* L.) was irrigated by three levels of irrigation water salinity were taken from different three wells in the farm SL (SL1= 1.21, SL2= 2.98 and SL3= 4.54 dS/m) and four applied irrigation water stresses (IR100%, IR85%, IR70% and IR55%) under magnetic water treatment (MW) and un-magnetic water treatment (UMW) by using surface drip irrigation system (SDI). Three devices of magnetic water treatment were installed on the main line of drip irrigation system network after the water filter and before fertigation unit (one magnetic unit for each well). These devices were produced by Delta Water Company Alexandria, Egypt. Specifications of delta magnetic water devices as follows:

- Diameter size: 2 inches,
- Magnetic field intensity: 7000 Gauss,
- Flow frequency: 25 m^3/h,

- Pressure (up to): 15 bar,
- Temperature (up to):100°C,
- Weight: 11 kg,
- Material: Stainless steel, and
- Effective for treating medium salinity water up to 8000 ppm.

Leaf area (LA) cm^2, calcium content (Ca) mg/100 g FW (Fresh Weight), vitamin C content (VC) mg/100 g FW and β carotene content (βC) mg/100 g FW were determined for spinach plant. These parameters were measured at The Central Laboratory of Analytical Chemistry, Faculty of Agriculture, Al-Azhar University, Nasr City, Cairo, Egypt. Actual evapotranspiration ET_a (mm), water use efficiency WUE (kg/m^3) and irrigation water use efficiency IWUE (kg/m^3) were calculated at different SL at IR under MW and UMW for spinach plots.

2. Soil properties

Soil samples were collected for some physical and chemical soil properties. The methodological procedures were according to **Page et al. (1982)** and **Klute (1986)**. The soil physicochemical properties presented in **Tables (1) and (2)**.

3. Quality of irrigation water

Chemical analyses of the irrigation water were measured according to **Ayers and Westcot (1985)**, **Table (3).**

4. Reference evapotranspiration (ET_o)

The reference evapotranspiration ET_o) shown in **Table (4)** was calculated based on Penman-Monteith method **(Savva and Frenken, 2002)**.

5. Crop evapotranspiration (ET_c)

The crop evapotranspiration ET_c shown in **Table (5)** was calculated by using the equation [1] **(Savva and Frenken, 2002)**.

$$\mathbf{ET_c = K_{c\,FAO} \times ET_o} \quad ...[\mathbf{1}]$$

where: ET_c is the crop evapotranspiration in mm/day, $K_{c\,FAO}$ is the crop coefficient (**Allen et al., 1998)** and ET_o is the reference crop evapotranspiration in mm/day.

6. Leaching requirement

The leaching requirement LR shown in **Table (6)** was calculated by using the equation [2] **(Savva and Frenken, 2002)**.

$$\mathbf{LR = EC_w/[5(EC_e) - EC_w] \times 100} \quad ...[\mathbf{2}]$$

where: LR is the leaching requirement in %, EC_w is the electrical conductivity of the irrigation water, dS/m and EC_e is average electrical conductivity of the soil solution extract, dS/m.

Table (1): Some physical characteristics of experimental soil.

Soil depth (cm)	Particle size distribution %			Textural class	OM[1] (g/kg)	ρ_b[2] (Mg/m^3)	HC[3] (m/day)	FC[4] (%)	PWP[5] (%)	AW[6] (%)
	Sand	Silt	Clay							
0-15	87.91	7.13	4.96	Sandy	2.5	1.54	11.12	10.68	3.75	6.93
15-30	88.16	6.95	4.89	Sandy	2.1	1.57	10.85	10.42	3.53	6.89
30-45	88.44	6.81	4.75	Sandy	1.7	1.59	10.67	10.34	3.48	6.86

[1]Organic matter content, [2]Bulk density, [3]Hydraulic conductivity, [4]Field capacity, [5]Permanent wilting point and [6]Available water,

Table (2): Some chemical characteristics of experimental soil.

Soil depth (cm)	EC[1] (dS/m)	pH[2] (1:2.5)	$CaCO_3$ %	CEC[3] (cmolc/kg)	Soluble ions (mmolc/L) in the soil paste extract							
					Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	HCO_3^-	CO_3^{--}	SO_4^{--}
0-15	4.62	8.15	5.39	7.51	19.34	2.79	13.42	10.65	19.49	2.95	0.00	23.76
15-30	4.65	8.09	4.37	7.46	19.42	2.91	13.48	10.69	19.65	3.03	0.00	23.82
30-45	4.71	7.97	3.31	7.39	19.67	3.04	13.56	10.83	19.72	3.17	0.00	24.21

[1]Soil paste extract, [2]1:2.5 w/v soil water suspension and [3]Cation exchange capacity.

Table (3): Some chemical analysis for irrigation water

Sample	pH	EC (dS/m)	SAR*	Soluble cations (mmolc/L)				Soluble anions (mmolc/L)			
				Na^+	K^+	Ca^{++}	Mg^{++}	CL^-	HCO_3^-	$CO_3^=$	$SO_4^=$
SL1	7.15	1.21	3.19	5.46	0.78	3.24	2.62	3.34	3.79	0.00	4.97
SL2	7.42	2.98	4.15	11.78	1.92	8.26	7.84	9.29	9.67	0.00	10.84
SL3	7.69	4.54	5.58	18.84	3.76	12.39	10.41	14.06	15.13	0.00	16.21

* Sodium adsorption ratio.

Table (4): Calculated reference evapotranspiration (mm/day) through spinach growth period.

Month	Nov	Dec	Jan
ET_o mm/day	3.49	3.05	3.21

Table (5): Calculated crop evapotranspiration (mm/day) through spinach growth period.

Stages	Initial	Develop	Mid	Late	Seasonal
Planting date	**10/11 to 29/11**	**30/11 to 19/12**	**20/12 to 13/1**	**14/1 to 18/1**	**10/11 to 18/1**
Period length (day)	20	20	25	5	70
$K_{c\ FAO}$	0.70	0.85	1.00	0.95	--------
ET_o (mm)	69.8	61	78.49	16.05	225.34
$ET_{c100\%}$ (mm)	48.86	51.85	78.49	15.25	194.45

Table (6): Calculation of leaching requirement (%) under different salinity levels of irrigation water.

SL (dS/m)	ECw (dS/m)	ECe (dS/m)	LR (%)
SL1	1.21	4.66	5
SL2	2.98	4.66	15
SL3	4.54	4.66	24

7. Applied irrigation water

The applied irrigation water amounts (IR) shown in **Table (7)** were calculated by using the equation [3] **(Keller and Karmeli, 1974)**.

$$\mathbf{IR = \frac{ET_c \times K_r}{E_a} - R + LR} \quad ...[3]$$

where: IR is the amounts of applied irrigation water in mm/period, ET_c is the crop evapotranspiration, mm/period, K_r is the correction factor for limited wetting according to the

80% spinach canopy coverage, $K_r = 0.90$. **(Smith, 1992)**, E_a is the irrigation efficiency for drip, 85% **(Savva and Frenken, 2002)**, R is the effective rainfall, 0 mm/season and LR is the leaching requirements, under salinity levels of irrigation water (0.05, 0.15 and 0.24 × ET_c) in mm.

Table (7). Calculated applied irrigation water (IR), mm of winter spinach growth period.

SL* (dS/m)	IR (%)	Applied Irrigation water stress (mm) Growth Stages				
		Initial	Develop.	Mid	Late	Seasonal
SL1	100	54.41	57.74	87.41	16.98	216.54
	85	46.25	49.08	74.30	14.43	184.06
	70	38.09	40.42	61.19	11.89	151.58
	55	29.93	31.76	48.08	9.34	119.10
SL2	100	58.90	62.50	94.62	18.38	234.40
	85	50.07	53.13	80.43	15.62	199.24
	70	41.23	43.75	66.23	12.87	164.08
	55	32.40	34.38	52.04	10.11	128.92
SL3	100	63.56	67.45	102.1	19.83	252.94
	85	54.03	57.33	86.79	16.86	215.00
	70	44.49	47.22	71.47	13.88	177.06
	55	34.96	37.10	56.16	10.91	139.12

*SL1= 1.21 dS/m SL 2= 2.98 dS/m SL 3= 4.54 dS/m

Convert mm to m^3 = water per mm depth × Area (8.20 not 10.00 for drip irrigation)

8. Water use efficiency and irrigation water use efficiency

WUE was calculated by equation (4) **(Howell et al., 2001)**, and IWUE was computed according to **Michael (2009)** by using equation (5).

$$\mathbf{WUE = Y/ET_c} \quad \dots [\mathbf{4}]$$

where: WUE is the water use efficiency in kg/ha, Y is the marketable yield of spinach crop, in kg/ha and ET_c is seasonal crop evapotranspiration in $m^{3/}$ha which calculated by equation [6].

$$\mathbf{IWUE = Y/IR} \quad \dots [\mathbf{5}]$$

where: IWUE is the irrigation water use efficiency in kg/m^3 and IR represents the seasonal applied irrigation water in m^3/ha **(Table 7)**.

$$\mathbf{ET_a = \frac{\theta_2 - \theta_1}{100} \times \rho_b \times D} \quad \dots [\mathbf{6}]$$

where: ET_a is the actual evapotranspiration in mm, θ_2 is the moisture content after irrigation in %, θ_1 is the moisture content before irrigation in %, ρ_b is the specific density of soil and D is the mean depth in mm.

3. RESULTS AND DISCUSSION

1. Effect of MW on physical properties for levels of irrigation water salinity

Data in **Table (8)** indicated that the values of physical analyses of irrigation water (IR) such as [solubility in gm/10ml, refractive index, density in gm/cm^3, surface tension in dyne/cm, viscosity $\times 10^{-6}$ in m^2/s, turbidity in nephelometric turbidity units (NTU) and total hardness in mg/lit] increased with increasing irrigation water salinity levels (SL) except evaporation mm/h decreased with increasing SL for both magnetic (MW) and un-magnetic (UMW) water treatment. In addition, data illustrated a significant superiority of MW compared with UMW (control) for all SL treatments. Applying MW technique decrease the values of physical analyses such as (refractive index, density, surface tension, viscosity, turbidity, total hardness and evaporation) were (1.3287, 1.0051 g/cm^3, 70.08 dyne/cm, 0.769$\times 10^{-6}$ m^2/s, 691.81 NTU, 219.91 mg/lit and 0.493 mm/h) at SL1; (1.3293, 1.0058 gm/cm^3, 71.81 dyne/cm, 0.797$\times 10^{-6}$ m^2/s, 727.69 NTU, 263.43 mg/lit and 0.475 mm/h) at SL2; (1.3326, 1.0075 g/cm^3, 75.42 dyne/cm, 0.802$\times 10^{-6}$ m^2/s, 743.52 NTU, 319.25 mg/lit and 0.438 mm/h) at SL3 respectively, except solubility increased when applying MW technique were (2.83 gm/10ml) at SL1; (3.09 gm/10ml) at SL2; (3.26 gm/10ml) at SL3 if compared with UMW. These results are harmonious with those **Amer et al. (2014), Song and Wang (2015) and Ali et al. (2017).**

Table (8) Effect of MW on physical properties for levels of irrigation water salinity.

Physical proprieties	levels of irrigation water salinity (SL)						LSD (0.05%)
	SL1		SL2		SL3		
	Magnetic water treatment (MW)						
	UMW	MW	UMW	MW	UMW	MW	
Solubility (gm/10ml)	2.37	2.83	2.69	3.09	2.91	3.26	0.03
Refractive index	1.3289	1.3287	1.3295	1.3293	1.3328	1.3326	1.15
Density (gm/cm^3)	1.0056	1.0051	1.0069	1.0058	1.0087	1.0075	0.0007
Surface tension (dyne/cm)	71.93	70.08	73.25	71.81	78.57	75.42	0.75
Viscosity ($\times 10^{-6}$ m^2/s)	0.814	0.769	0.831	0.797	0.858	0.802	0.049
Turbidity (NTU)	749.58	691.81	775.73	727.69	797.31	743.52	3.21
Total Hardness (mg/lit)	241.76	219.91	294.89	263.43	349.98	319.25	2.78
Evaporation (mm/h)	0.531	0.493	0.512	0.475	0.486	0.438	0.024

SL1= 1.21 dS/m SL2= 2.98 dS/m SL3= 4.54 dS/m

2. Effect of MW on chemical properties for levels of irrigation water salinity

Data in **Table (9)** concluded that the values of chemical analyses of irrigation water (IR) such as (acidity (pH), electric-conductivity (Ec) dS/m, total dissolved salts (TDS) ppm, sodium adsorption ratio (SAR), Na^+, K^+, Ca^{++}, Mg^{++}, $CL^=$, HCO_3^-, $CO_3^=$ and $SO_4^=$) increased with increasing SL for both MW and UMW water treatment. Also, data reported a significant superiority for MW compared with UMW (control) for all SL treatments. Applying MW technique increase the values of chemical analyses such as (pH, Ec, TDS, Ca^{++}, Mg^{++} and $SO4^=$) were (7.19, 1.23 dS/m, 389.61 ppm, 3.25, 2.63 and 4.98) at SL1; (7.51, 3.01 dS/m, 561.37 ppm, 8.28, 7.86 and 10.86) at SL2; (7.76, 4.56 dS/m, 761.19 ppm, 12.45, 10.43 and 16.23) at SL3 respectively, except SAR decreased when applying MW technique were 3.18 at SL1, 4.14 at

SL2 and 5.57 at SL3. While the rest of the chemical properties did not affect by application MW technique under all SL treatments if compared with UMW. These results are in agreement with **Mohamed and Ebead (2013), Amer et al. (2014), Hasaani et al. (2015) and Ali et al. (2017).**

Table (9): Effect of MW on chemical properties for levels of irrigation water salinity.

Chemical proprieties	levels of irrigation water salinity (SL)						LSD (0.05%)
	SL1		SL2		SL3		
	Magnetic water treatment (MW)						
	UMT	MT	UMT	MT	UMT	MT	
pH	7.15	7.19	7.42	7.51	7.69	7.76	0.06
Ec (dS/m)	1.21	1.23	2.98	3.01	4.54	4.56	0.01
TDS (ppm)	387.23	389.61	554.15	561.37	746.85	761.19	1.09
SAR	3.19	3.18	4.15	4.14	5.58	5.57	0.03
Na^+	5.46	5.46	11.78	11.78	18.84	18.84	N.S
K^+	0.78	0.78	1.92	1.92	3.76	3.76	N.S
Ca^{++}	3.24	3.25	8.26	8.28	12.39	12.45	0.04
Mg^{++}	2.62	2.63	7.84	7.86	10.41	10.43	0.01
$Cl^=$	3.34	3.34	9.29	9.29	14.06	14.06	N.S
HCO_3^-	3.79	3.79	9.67	9.67	15.13	15.13	N.S
$CO_3^=$	-	-	-	-	-	-	-
$SO_4^=$	4.97	4.98	10.84	10.86	16.21	16.23	0.02

SL1= 1.21 dS/m SL2= 2.98 dS/m SL3= 4.54 dS/m

3. Effect of MW and UMW on actual evapotranspiration of spinach at different SL and IR

Data in **Figs. (1) and (2)** illustrated that the studied quality parameters for spinach leaves such as leaf area (LA) cm^2, calcium content (Ca) mg/100 g FW, vitamin C content (VC) mg/100 g FW and β carotene content (βC) mg/100 g FW decreased with increasing irrigation water salinity levels (SL) and applied irrigation water stresses (IR) for all treatments. Also, data recorded a significant superiority of magnetic water treatment (MW) compared with un-magnetic water (UMW) for all treatments. The results showed the same trend for both seasons 2018/2019 and 2019/2020. The highest values of LA, Ca, VC and βC for spinach leaves were 30.54 cm^2, 63.52 mg/100 g FW, 24.31 mg/100 g FW and 2.57 mg/100 g FW respectively, for the 1st season. While, were 31.31 cm^2, 65.16 mg/100 g FW, 24.93 mg/100 g FW and 2.64 mg/100 g FW respectively, for the 2nd season when applying treatment SL1 =1.21 dS/m and IR = 100 % under MW. The lowest values of spinach leaves LA, Ca, VC and βC were 14.17 cm^2, 34.15 mg/100 g FW, 11.25 mg/100 g FW and 1.38 mg/100 g FW respectively, for the 1st season. While, were 14.55 cm^2, 35.04 mg/100 g FW, 11.57 mg/100 g FW and 1.42 mg/100 g FW respectively, for the 2nd season when applying treatment SL3 = 4.54 dS/m and IR = 55 % under UMW.

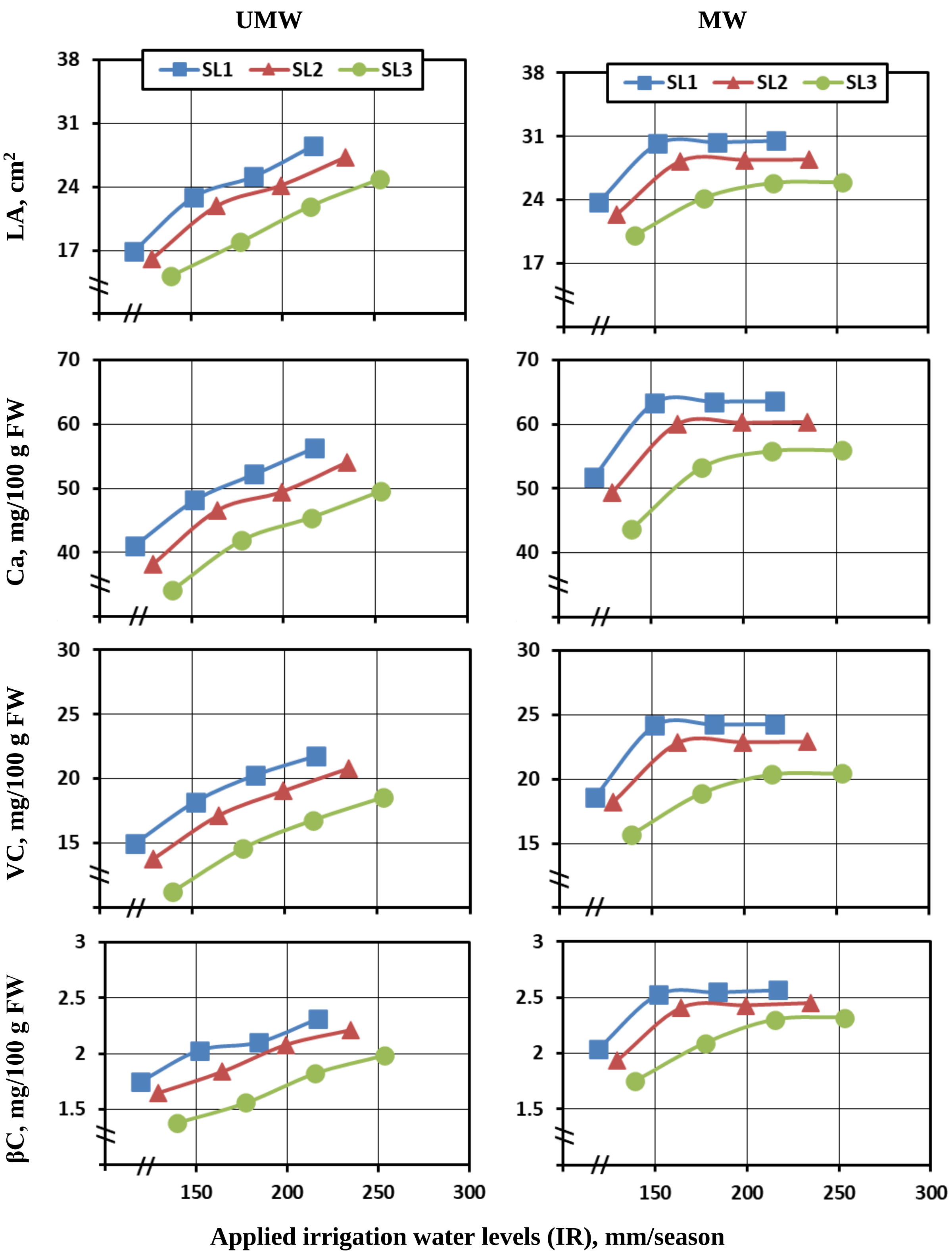

Fig. (1): Effect of salinity irrigation water levels (SL) and applied irrigation water stress (IR) on leaf area "LA" (cm^2), calcium content "Ca" (mg/100 g FW), vitamin C content "VC" (mg/100 g FW) and β carotene content "βC" (mg/100 g FW) of spinach leaves under magnetic (MW) and un-magnetic water treatment (UMW) for season 2018/2019.

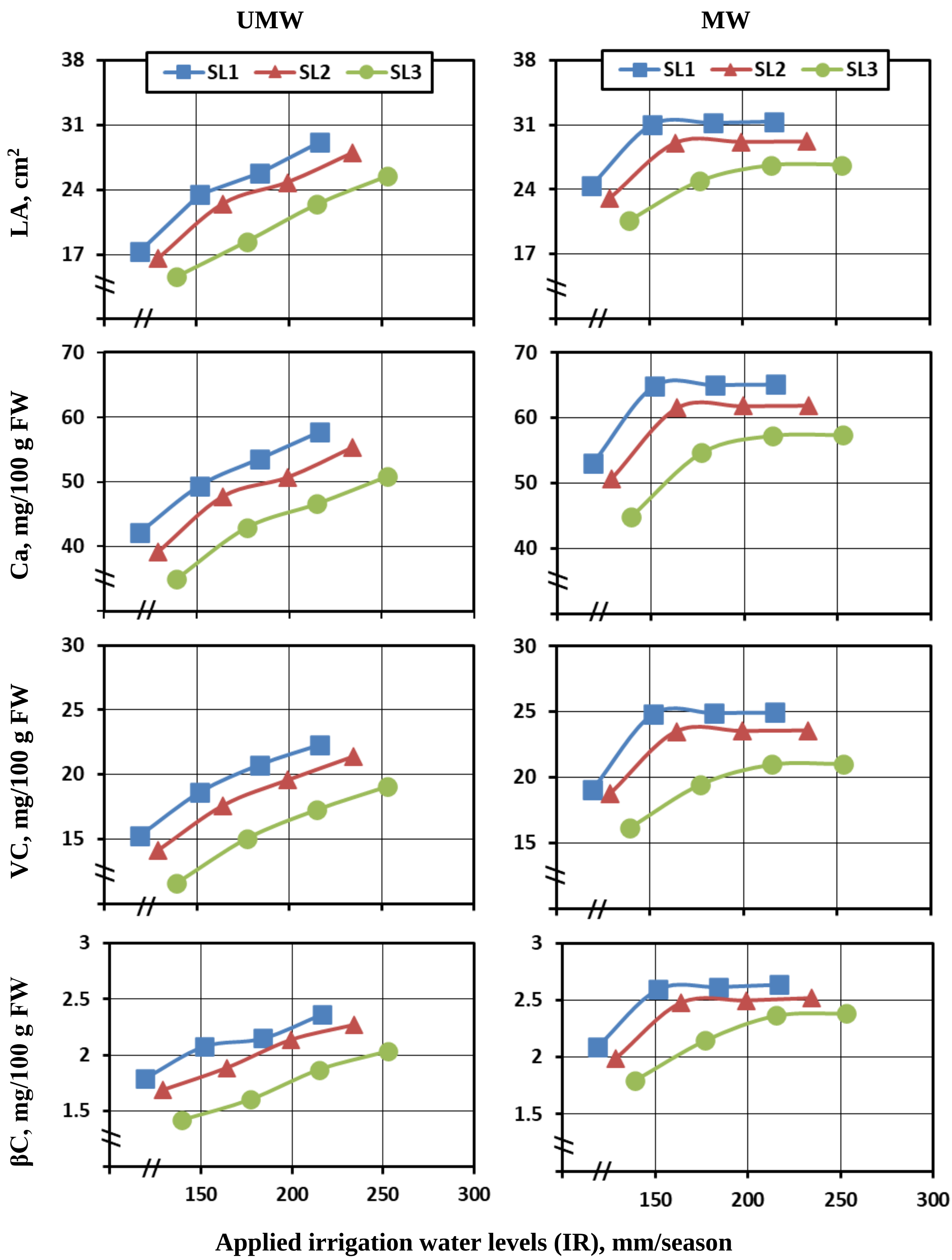

Fig. (2): Effect of salinity irrigation water levels (SL) and applied irrigation water stress (IR) on leaf area "LA" (cm^2), calcium content "Ca" (mg/100 g FW), vitamin C content "VC" (mg/100 g FW) and β carotene content "βC" (mg/100 g FW) of spinach leaves under magnetic (MW) and un-magnetic water treatment (UMW) for season 2019/2020.

These increasing may be attributed to the magnetic water treatment increases plant metabolism in terms of photosynthesis and water uptake. These results are consistent with the findings of **Yano et al. (2004), Grieve et al. (2012), Kuslu et al. (2016) and Ünlükara et al. (2017)**.

4. Effect of MW and UMW on marketable yield of spinach at different SL and IR

Data in **Figs. (3) and (4)** reported that the marketable yield (Ym) Mg/ha of spinach leaves decreased with increasing irrigation water salinity levels (SL) and applied irrigation water stresses (IR) for all treatments. In addition, magnetic water treatment (MW) had a clear effect on all treatments compared to un-magnetic water (UMW) for all treatments. The results confirmed the same trend for both seasons 2018/2019 and 2019/2020. The highest values of Ym for spinach leaves were 7.59 and 7.78 Mg/ha for both seasons respectively, when applying treatment, SL1= 1.21 dS/m and IR = 100 % under MW. The lowest values of Ym for spinach leaves were 1.97 and 2.02 Mg/ha for both seasons respectively, when applying treatment, SL3= 4.54 dS/m and IR = 55 % under UMW. These increasing may be attributed to the mechanism of magnetic field activation of Phyto-hormone such as Gibberellic acid equivalents, Indole-3-acetic acid and Trans-Zeatin as well as activation of the bio-enzyme systems which leads to the growth improvement and increased the crop yield. Moreover that, using MWimproved the physical properties of irrigation water salinity resulting in increased productivity per hectare. These results are in agreement with that found by **Grieve et al. (2012), Hasaani et al. (2015), Fanous et al. (2017) and Ali et al. (2017).**

5. Effect of MW and UMW on actual evapotranspiration of spinach at different SL and IR

Data in **Figs. (3) and (4)** indicated that the values of seasonal actual evapotranspiration (ET_a) mm/season for spinach leaves increased with increasing irrigation water salinity levels "SL" for all treatments. While, ET_a for spinach leaves decreased with increasing applied irrigation water stresses (IR) for all treatments. Moreover, the data recorded a significant superiority of magnetic water treatment (MW) compared with un-magnetic water (UMW) for all treatments. The results showed the same trend for both seasons 2018/2019 and 2019/2020. The lowest values of ET_a for spinach were 107.91 and 105.10 mm/season for both seasons respectively, when applying treatment, SL1 = 1.21 dS/m and IR = 55 % under MW. While, the highest values of ET_a for spinach leaves were 251.82 and 244.75 2.02 mm/season for both seasons respectively, when applying treatment, SL3 = 4.54 dS/m and IR = 100 % under UMW. These results may be attributed to that using Magnetic treatment of irrigation water improves all physical and some chemical properties which reduces the leaching requirements to remove excess soil salinity which cause reduces yield. Also, MW increases the uniformity and distribution of irrigation water. Finally, MW improves plant absorption of irrigation water and hence reducing the actual water consumption when using levels of irrigation water salinity these entire factors led to increase marketable yield with decrease in actual evapotranspiration (ET_a), these results were similar to those indicated by **Hasaani et al. (2015), Song and Wang (2015), Ali et al. (2017) and Fanous et al. (2017).**

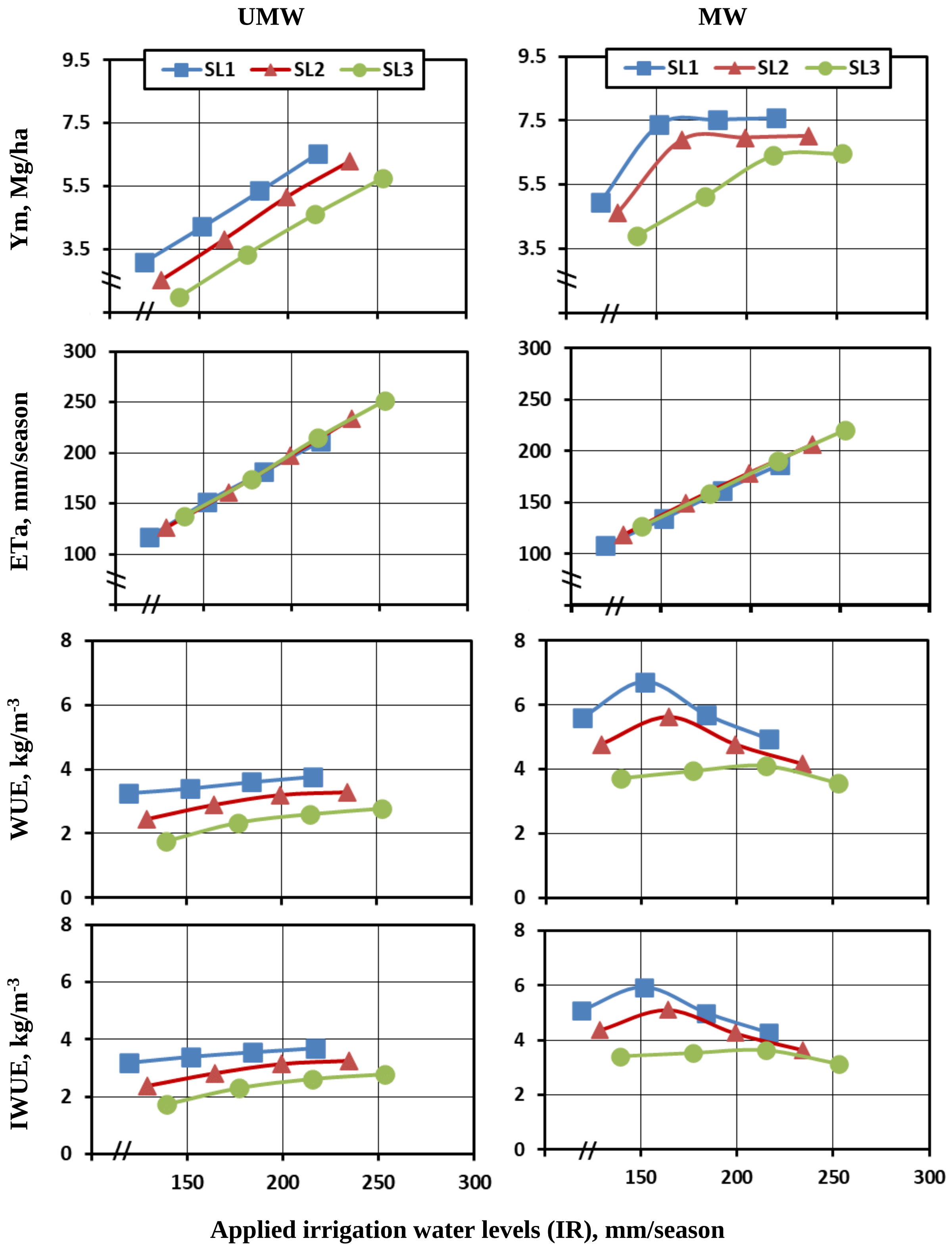

Fig. (3): Effect of salinity irrigation water levels (SL) and applied irrigation water stress (IR) on marketable yield "Ym" (Mg/ha), seasonal actual evapotranspiration "ETa" (mm/season), water use efficiency "WUE" (kg/m) and irrigation water use efficiency "IWUE" (kg/m) of spinach leaves under magnetic (MW) and un-magnetic water treatment (UMW) for season 2018/2019.

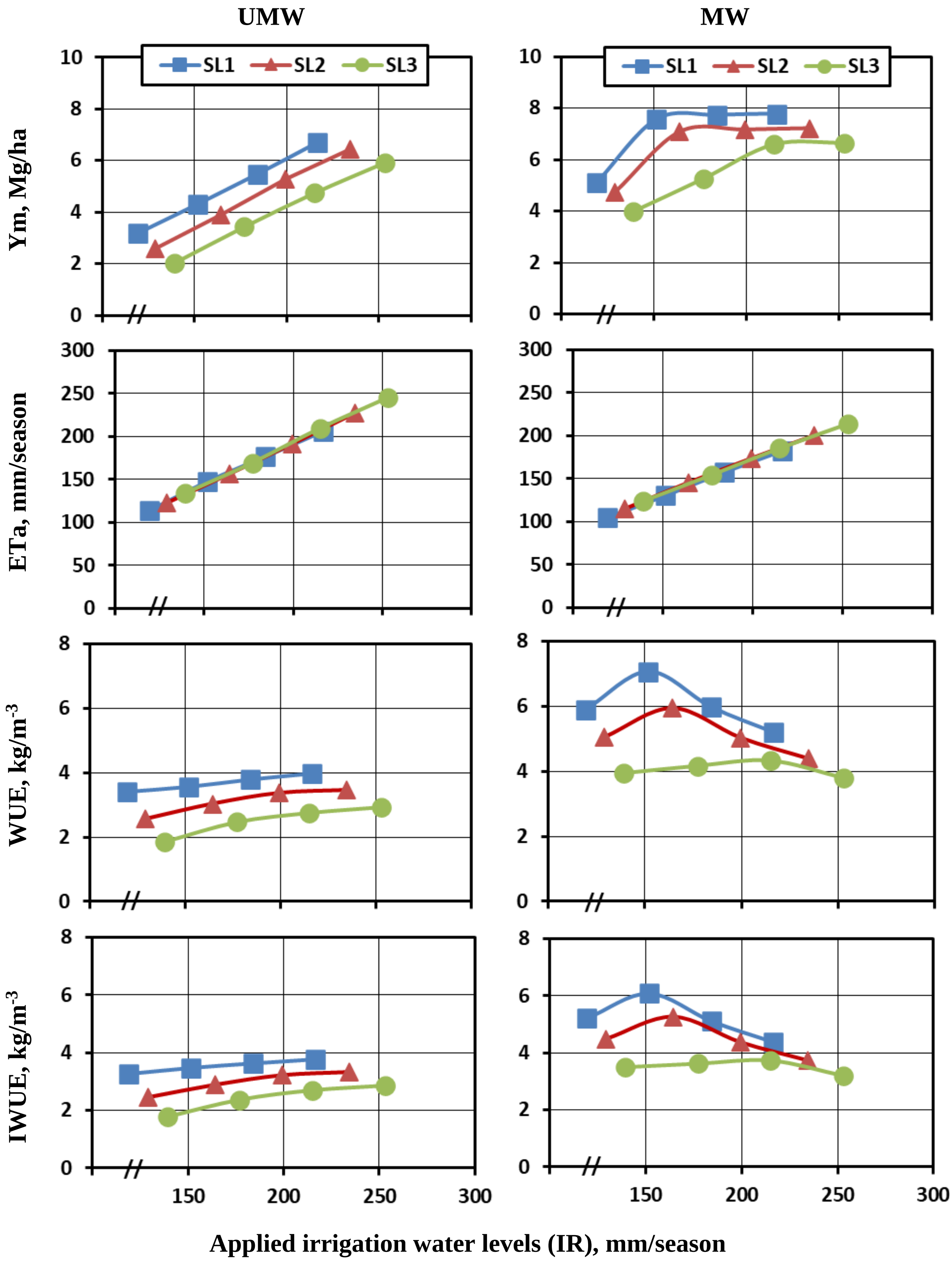

Fig. (4): Effect of salinity irrigation water levels (SL) and applied irrigation water stress (IR) on marketable yield "Ym" (Mg/ha), seasonal actual evapotranspiration "ETa" (mm/season), water use efficiency "WUE" (kg/m) and irrigation water use efficiency "IWUE" (kg/m) of spinach leaves under magnetic (MW) and un-magnetic water treatment (UMW) for season 2018/2019.

6. Effect of MW and UMW on water use efficiency and irrigation water use efficiency of spinach at different SL and IR

Data in **Figs. (3) and (4)** indicated that the highest values of water use efficiency (WUE) and irrigation water use efficiency (IWUE) for spinach were (6.71 and 5.94 kg/m^3); (7.07 and 6.09 kg/m^3) for both seasons respectively, when applying treatment, SL1 = 1.21 dS/m and IR = 70 % under MW. While the lowest values of WUE and IWUE were (1.75 and 1.73 kg/m^3); (1.84 and 1.77 kg/m^3) for both seasons respectively, when applying treatment, SL3 = 4.54 dS/m and IR = 55 % under UMW. Meanwhile, applying treatment, SL1 = 1.21 dS/m and IR = 70 % under MW led to a significant increase in the values of WUE and IWUE for spinach leaves by about (77.92 and 61.20 %); (78.13 and 61.41 %) for both seasons respectively, if compared to that under the control treatment (SL1 = 1.21 dS/m and IR = 100 % under UMW). These results may be attributed to that applying MW technique increased the marketable yield of spinach leaves for all treatments. On the other hand, applying MW and IR techniques decreased the actual evapotranspiration these results were similar to those indicated by **Kuslu et al. (2016), Ünlükara et al. (2017) and Ali et al. (2017)**.

4. CONCLUSION

This study evaluated the effectiveness of irrigation water salinity levels (SL) and applied irrigation water stress (IR) under magnetic (MW) and un-magnetic water treatment (UMW) on spinach leaves of studied quality parameters, Ym, seasonal ET_a, WUE and IWUE under North Sinai sandy soil. The study reported that the Ym and studied quality parameters for spinach leaves gave the highest values when applying treatment, SL1= 1.21 dS/m and IR = 100% under MW. While, the seasonal ET_a for spinach leaves gave the lowest values when applying treatment, SL1 = 1.21 dS/m and IR = 55% under MW. Finally, the values of WUE and IWUE for spinach leaves when applying treatment, SL1= 1.21 dS/m and IR = 70% under MW increased significantly by about (6.71 and 5.94 kg/m^3); (7.07 and 6.09 kg/m^3) for both seasons respectively, compared with that under the control treatment (SL1 = 1.21 dS/m and IR = 100% under UMW). So, it is recommended to applying magnetic water treatment technique to irrigate spinach under North Sinai conditions to save about 30% of irrigation water added at salinity levels SL1 and SL2. While, save about 15% of applied irrigation water added at salinity levels SL3. On the other hand, applying treatment IR=70% under MW increased the marketable yield of spinach by about 13% and 6% at SL1 and SL2 respectively. While, applying treatment IR=85% under MW increased marketable yield of spinach by about 7% at SL3 compared with control treatment (SL1 = 1.21 dS/m and IR = 100% under UMW).

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تأثير الماء الممغنط على كفاءة استخدام المياه للسبانخ تحت ظروف شمال سيناء

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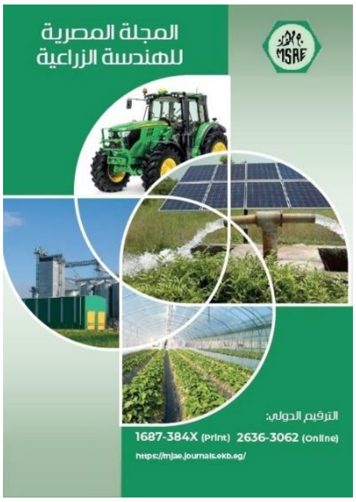

الملخص العربي

أجريت التجربة بمنطقة بالوظة بمحافظة شمال سيناء، مصر، خلال موسمي زراعة شتوية ٢٠١٨/٢٠١٩م و٢٠١٩/٢٠٢٠م. تم ري محصول السبانخ بثلاثة مستويات من ملوحة مياه الري من ثلاثة آبار مختلفة الملوحة بالمزرعة (١,٢١ و٢,٩٨ و٤,٥٤ ديسيسيمنز/م) وأربع نسب من كميات مياه الري المضافة (١٠٠% و٨٥% و٧٠% و٥٥% من الاحتياجات المائية) وذلك تحت معالجة مياه الري مغناطيسياً بتركيب وحدة مغناطيسية عند كل بئر بقطر ٢ بوصة وبشدة مجال مغناطيسى ٧٠٠٠ جاوس ومقارنتها بمياه الري غير الممغنطة لجميع المعاملات. وتم دراسة تأثير هذه المتغيرات على الإنتاجية وقياسات الجودة والاستهلاك المائي الفعلي وكفاءة الاستهلاك المائي والإروائى للسبانخ. وأوضحت النتائج الآتي:

- أعلى قيم لقياسات الجودة للسبانخ عند مغنطة مياه الري ذات ملوحة ١,٢١ ديسيسيمنز/م وإضافة١٠٠% من الاحتياجات المائية وذلك للموسمين.
- أعلى إنتاجية للسبانخ ٧,٥٩ و٧,٧٨ ميجاجرام/هكتار للموسمين على الترتيب عند مغنطة مياه الري بملوحة ١،٢١ ديسيسيمنز/م وإضافة ١٠٠% من الاحتياجات المائية.
- أعلى قيم لكفاءة الاستهلاك المائي والإروائى ٦,٧١ و٥,٩٤ كجم/م٣ للموسم الأول و٧,٠٧ و٦,٠٩ كجم/م٣ للموسم الثاني عند مغنطة مياه الري بملوحة ١,٢١ ديسيسيمنز/م وإضافة ٧٠% من الاحتياجات المائية.

لذا يُوصَى بتطبيق تقنية مغنطة مياه الري لزراعة السبانخ تحت ظروف شمال سيناء لأنها توفر حوالى٣٠% من كميات مياه الري المضافة عند مستويات ملوحة للمياه ١,٢١ و٢,٩٨ ديسيسيمنز/م وتوفر١٥% من كميات مياه الري المضافة عند مستوى ملوحة للمياه ٤,٥٤ ديسيسيمنز/م. كما أدى تطبيق تقنية معالجة المياه مغناطيسياً عند إضافة ٧٥% من الاحتياجات المائية إلى زيادة المحصول بحوالى١٣% و٦% عند مستويات ملوحة للمياه ١,٢١ و٢,٩٨ ديسيسيمنز/م بينما زادت إنتاجية المحصول عند إضافة ٨٥% من الاحتياجات المائية بحوالي ٧% عند مستوى الملوحة ٤,٥٤ ديسيسيمنز/م.

الكلمات المفتاحية:
معالجة المياه مغناطيسياً، ملوحة مياه الري، كفاءة استخدام المياه، كفاءة استخدام مياه الري، كميات مياه الري المضافة.