

Maximizing Water Use Efficiency for Some Plants by Treated Magnetic Water Technique under East Owainat Conditions

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THIS experiment was carried out during the winter season of 2015, at a private farm in East Owainat area, New valley Governorate, Egypt, to study the effect of magnetic field levels (0, 2000, 4000 Gauss) and applied irrigation water regimes (IR_{100%}, IR_{90%}, IR_{80%} and IR_{70%}) under surface (SDI) and sub-surface drip (SSDI) on marketable yield, plant quality parameters, water use efficacy (WUE), irrigation water use efficiency (IWUE) and yield response factor (Ky) of lettuce (*Lactuca Sativa* L.) and potato (*Solanum Tuberosum* L.) crops. The experimental design was a split-split plot design with three replicates. The obtained results indicated that, the values of physical analyses of irrigation water were decreased with increasing MF levels except solubility. While, the values of chemical analyses of IR increased with increasing MF levels except SAR. Meanwhile, the values of (Na⁺, K⁺, Cl⁻ and HCO₃⁻) were recorded non significant at different MF levels. Also, the results revealed that the values of quality parameters for lettuce plant and potato tubers increased with increasing both MF levels and IR under SDI and SSDI except total sugar TS for plant lettuce. The values of lettuce and potato Ya under (MF= 4000 Gauss, IR=100% and SSDI) treatment increased significantly by about 40 and 34 % compared to those under control treatment (MF= 0 Gauss, IR=100% and SDI). Moreover, the maximum values of WUE and IWUE for lettuce plant were 7.08 and 3.88 kg m⁻³ respectively, under MF= 4000 Gauss, IR=80% and SSDI treatment. While, the maximum values of WUE and IWUE for potato tubers were 11.28 and 5.89 kg m⁻³, respectively, under MF= 4000 Gauss, IR=80% and SSDI treatment. This study shows that utilization of magnetized water technology may be considered a promising technique to improve both crops yield productivity and save irrigation water.

Keywords: Water use efficiency, Magnetic field, Irrigation water use efficiency; East Owainat

Introduction

Magnetic water treatment remains a little known in the field of plants metabolism and water relations. One of the harmless technologies which is considered in recent years by researchers of the agricultural science to increase plant yield and also increase the water productivity through a magnetic field before irrigation (Maheshwari and Grewal, 2009). Thus, magnetized water treatment increases plant metabolism in terms of photosynthesis and water uptake (Yano et al., 2004). A plant's metabolism contains 90 to 95% of water which is a diamagnetic compound and the rest contains several para, ferro and diamagnetic metals and non-metals in minute forms (Charan, 2009). The interaction of magnetic fields with flowing water; they measure absorbance, pH, TDS, EC, viscosity, surface tension and thermal conductivity for ordinary tap water before and after applying magnetic fields of strength 6560 G which were generated by proper arrangement

of permanent magnet pieces around the pipe accommodating the flowing water. They found that physical properties of magnetized water were inspected with proper and precise measuring techniques. These include the pH which was increased by 12%, while TDS and EC both decreased by 33% and 36%, respectively. As well, the mechanical parameters like viscosity and surface tension decreased too by a factor of 23% and 18%, respectively. Even, the thermal conductivity decreased by 16% (Hasaani et al., 2015). The magnetic treatment of irrigation water had a positive effect on decreasing salinity of the soil (ECe) after the harvest of plants. Values of relative change (Rc± %) of soil salinity (Ece), sodium adsorption ratio (SAR), Na⁺, Cl⁻ and SO₂₋₄ decreased while (Rc± %) of Ca⁺⁺, Mg⁺⁺, and K⁺ in the soil extraction, after harvesting, increased due to MWT under S1; S2 and S3, as compared with magnetized fresh water (Amer et al., 2014). The results showed that the pH significantly increased under different magnetic

field strength, while EC and TDS significantly decreased by magnetic treatment under different magnetic field strength and time of treatment by 15.60% after 300 min. The results demonstrated that the magnetic treatments improved plant height, yield (kg/m²), fruit length, fruit diameter, and leaves dry matter percentage of cucumber plant compared to control treatment (Shahin *et al.*, 2016). Thus, the present results have shown that irrigation with MTW can be considered as one of the most valuable modern technologies that can assist in saving irrigation water and reducing salt accumulation in plants (Al-Khazan *et al.*, 2011). The combinations between the application of magnetic water and water regimes at 60% or 55% enhanced water use efficiency, tubers quality and yield of potato. Thus, the use of magnetic water and irrigation at 55% or 60% of the field capacity can be recommended to enhance vegetative growth, yield, and the components of potato plants, reduce soil salinity and improve soil fertility (Ahmed and Abd El-Kader, 2016). However, the variable magnetic fields may affect the biological functions of organisms through changes of hormone concentrations, changes of enzyme functions or transport of ions through the cell membrane and through changes in DNA synthesis or transmission (Strasak *et al.*, 2002). The growth and productivity of corn increased by water magnetism under both full and limited irrigation. Both of water use efficiency (WUE) and irrigation water use efficiency (IWUE) increased when irrigation water was magnetized particularly under water deficit conditions. Maximum WUE and IWUE were obtained when ETa/ETm ratio was between 0.65-0.85. Average values of crop ET (ETc) calculated by Blaney-Criddle and Hargreaves equation can be used to estimate the amount of applied irrigation water because of the closeness of ETc values from ETa values. Crop response factor for corn decreased when magnetized water was used for irrigation. Most measured physical and chemical properties of water were slightly affected by magnetism (Aoda and Fattah, 2011). The highest average lettuce yield of 7.8 ton da⁻¹ was obtained from the full-irrigation treatment (Kp1= 1.0). Significant differences were not observed between Kp1= 1.0 and Kp2=0.75 treatments in terms of lettuce yield. Maximum irrigation water use efficiency and total water use efficiency were obtained from Kp4=0.25 treatment, respectively with 0.117 and 0.074 ton da⁻¹ mm⁻¹. Yield response factor (ky) was found to be 0.88. The research results showed that a 7 day

irrigation interval with Kp2=0.75 treatment could be used for irrigating lettuce under the unheated greenhouse conditions without any significant yield loss but increased water use efficiencies (Kirmak *et al.*, 2016). Irrigating potato by drip irrigation with three levels (100%, 75% and 50% of the basin evaporation) gained a significant increase in plant height, number of aerobic stems, leaf area, plant dry weight and total tubers yield by increased irrigation level (Al-Janaby, 2012). The effect of irrigation water level on the yield, tuber height, diameter, weight, dry matter, starch matter, the tuber number per plant and plant height were found significant. The highest yield was 36 t ha⁻¹. Crop yield response factor (ky) was found as 1.13. The highest values for water use efficiency (WUE) and irrigation water use efficiency (IWUE) were found to be 4.84 and 4.29 kg m⁻³ for the K2cp= 75% treatment. When water resources are scarce, it can be recommended that K2cp treatment is most suitable as a water application level for potato irrigation by drip irrigation under unheated greenhouse condition (Ayas, 2013).

This study aimed to investigate the effect of both magnetic field levels and applied irrigation water under surface and sub-surface drip irrigation on lettuce and potato crops production, quality growth parameters, actual evapotranspiration, water use efficiency and yield response factor.

Materials and Methods

Experiments

Field experiments were carried out in East Owainat area, New Valley Governorate, Egypt (23° 41' N: 29° 26' E. 54 m a.s.l) during the winter season of 2015. In split-split plot design with three replicates, the experimental was divided into 30 m² plots; each bounded by 1.5 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. Figure 1 showed the lettuce (*Lactuca sativa* L.) and potato (*Solanum tuberosum* L.) cultivated using four defects of applied irrigation water (IR_{100%}, IR_{90%}, IR_{80%} and IR_{70%}) treated with three magnetic field levels (MF) (0, 2000 and 4000 Gauss) tested under surface (SDI) and sub-surface drip irrigation (SSDI).

Soil management practices were applied using doses of fertilizer as recommended by the Ministry of Agriculture and Land Reclamation.

The length (L) Cm, diameter (D) Cm, total

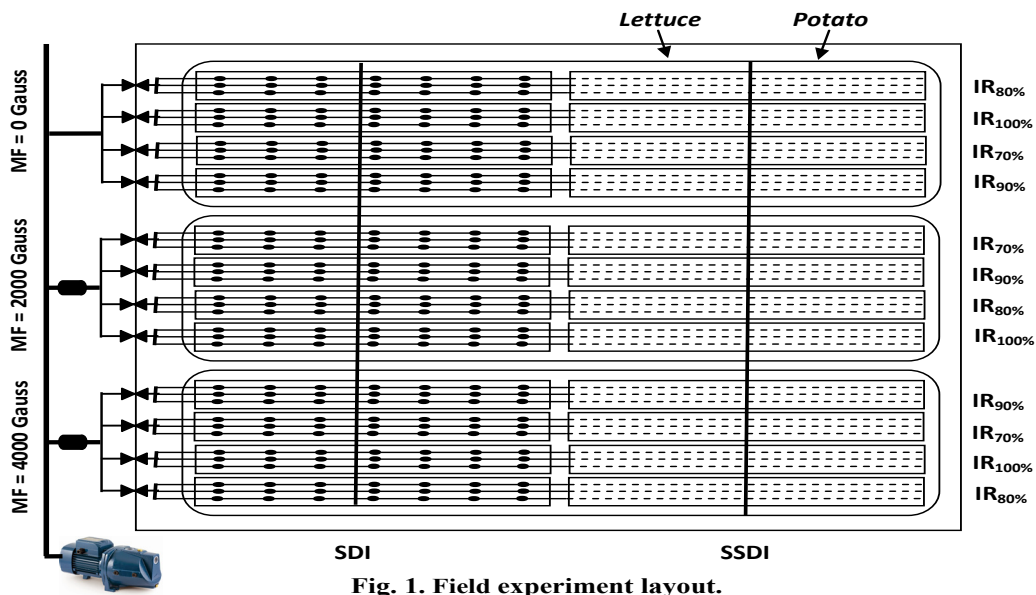


Fig. 1. Field experiment layout.

soluble solid (TSS) %, vitamin C (Vc) mg 100 g⁻¹fw and marketable yield (Ya) g/plant) were determined for lettuce plant. While, height (H) Cm, diameter (D) Cm, total soluble solid (TSS) %, starch (S) %, protein (P) % and specific gravity (SG) were determined for potato tuber. Water use efficiency WUE (kg m⁻³), irrigation water use efficiency IWUE (kg m⁻³) and actual evapotranspiration ETa (mm), were calculated at different MF levels for all IR under SDI and SSDI for lettuce and potato plots.

- Starch percentage was determined according to the method described by Dogras et al. (1991).

- Total soluble solids (TSS %) was determined using the hand refractometer.

- Specific gravity of potato tubers $SG = \frac{W_{air}}{W_{air} - W_{water}}$ (Nessen, 1967)

where: W_{air} : weight of tubers in air, g.

W_{water} : weight of tubers in water, g.

Soil characteristics

Soil samples were collected for some physical and chemical soil characteristics. The methodological procedures were according to methods described by Page et al. (1982) and Klute 1986) (Tables 1&2).

TABLE 1. Some physical characteristics of experimental soil

Soil depth (cm)	Particle size distribution %					Textural class	OM %	ρ_b g/cm ³	Ks cm/h	FC %	WP %	AW %
	C. sand	M. sand	F. sand	Silt	Clay							
0-15	12.61	63.24	4.67	11.42	8.06	LS	0.45	1.51	9.67	10.29	3.12	7.17
15-30	13.38	62.25	5.13	11.26	7.98	LS	0.39	1.53	10.05	9.87	3.04	6.83
30-45	13.82	61.61	5.46	11.18	7.93	LS	0.37	1.54	10.43	9.43	2.98	6.45

TABLE 2. Some chemical characteristics of experimental soil

Soil depth (cm)	ECe (dS m ⁻¹)	pH	CaCO ₃ %	CEC meq/100 g soil	Soluble ions (meq/l) in the saturated soil paste							
					Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	Cl ⁻	HCO ₃ ⁻	CO ₃ ⁻	SO ₄ ⁻
0-15	1.94	8.02	2.51	6.56	9.71	1.06	5.45	3.18	9.45	2.67	-	7.28
15-30	2.06	7.98	2.57	6.09	9.95	1.31	5.78	3.56	10.17	2.89	-	7.54
30-45	2.11	7.96	2.74	5.84	10.07	1.5	5.85	3.68	10.21	3.03	-	7.86

Irrigation water characteristics

Physical and chemical analyses of the irrigation water without magnetic field (MF= 0) were measured according to methods described by Ayers and westcot (1994) (Tables 3&4).

Reference evapotranspiration ETo

The reference evapotranspiration (ETo) shown in Table 5 was calculated using the Cropwate (8) software based on Penman-Monteith equation FAO 56 method (Allen *et al.*, 1998).

TABLE 3. Some physical analysis for irrigation water under no MF = 0 treated

Samples	Solubility (gm/10ml)	Refractive index	Density (gm cm ⁻³)	Surface tension (dyne cm ⁻¹)	Viscosity (m ² s ⁻¹)	Turbidity (NTU)	Total Hardness (mg lit ⁻¹)	Evaporation (mm/h)
mean	3.18	1.3324	1.0056	72.43	0.827× 10 ⁻⁶	761.12	225.36	0.542

TABLE 4. Some chemical analysis for irrigation water under no MF = 0 treated

Samples	pH	EC dS/m	TDS (ppm)	SAR	Soluble cations, meq/l				Soluble anions , meq/l			
					Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	CL ⁻	HCO ₃ ⁻	CO ₃ ⁼	SO ₄ ⁼
mean	7.39	1.53	489.60	6.97	9.76	0.42	2.90	1.04	7.89	3.17	-	2.48

TABLE 5. Calculation reference evapotranspiration (mm day⁻¹) through lettuce and potato growth period.

Month	October	November	December	January	February
ETo, mm day ⁻¹	9.76	6.73	5.68	5.16	6.48

Crop evapotranspiration (ETc)

The crop evapotranspiration (ETc) shown in Table 6 was calculated using the equation:

Leaching requirement LR

$$\bullet \quad \text{ETc} = \text{Kc}_{\text{FAO}} \cdot \text{ETo} \quad (\text{mm day}^{-1}) \quad \text{1998) (Allen et al.,}$$

Where: Kc_{FAO} : crop coefficient from FAO No.(56).

ETo : reference crop evapotranspiration, mm day⁻¹.

TABLE 6. Calculation crop evapotranspiration (mm day⁻¹) through lettuce and potato growth period.

Crops	Stages	Initial	Develop.	Mid	Late	Seasonal
Lettuce	Period length (day)	25	35	30	10	100
	Kc_{FAO} (-)	0.70	0.85	1.00	0.95	-----
	ETo (mm)	216.73	220.85	163.64	51.60	652.82
	ETc _{100%} (mm)	151.71	187.72	163.64	49.02	552.09
Potato	Period length (day)	25	30	30	30	115
	Kc_{FAO} (-)	0.50	0.83	1.15	0.75	-----
	ETo (mm)	216.73	192.45	166.24	164.04	739.46
	ETc _{100%} (mm)	108.37	159.73	191.18	123.03	582.31

The leaching requirement LR was calculated by using the equation:

$$\bullet \quad \text{LR} = \frac{\text{EC}_w}{(5 (\text{EC}_e) - \text{EC}_w)} \times 100 \quad (\%) \quad \text{1998) (Allen et al.,}$$

Where: EC_w : electrical conductivity of the irrigation water, dS m⁻¹.

EC_e : average electrical conductivity of the soil solution extract, dS m⁻¹.

Applied irrigation water IR

The amounts of applied irrigation water (IR) for lettuce and potato crops shown in Table 7 were calculated using the equation:

$$\bullet \text{ IR}_{100, 90, 80, 70\%} = (ET_c - p_e)K_r / E_a + LR \quad (\text{mm period-1})$$

(Keller and Karmeli, 1974)

where: K_r : correction factor for limited wetting at lettuce and potato percent round coverage by canopy 80%, $K_r = 0.90$. (Smith, 1992).

E_a : irrigation efficiency for surface drip (85%) (Allen et al., 1998).

p_e : effective rainfall, 0 mm.

LR : leaching requirements, under salinity levels of irrigation water ($0.17 \times ET_c$), mm.

TABLE 7. Calculation applied irrigation water (IR), mm for lettuce and potato.

Crops	IR (%)	Applied Irrigation water (mm)				
		Initial	Development	Mid	Late	Seasonal
Lettuce	100	187.00	231.38	201.70	60.42	680.50
	90	168.30	208.24	181.53	54.38	612.45
	80	149.60	185.10	161.36	48.34	544.40
	70	130.90	161.97	141.19	42.29	476.35
	100	133.57	196.89	235.64	151.65	717.75
Potato	90	120.21	177.20	212.08	136.48	645.97
	80	106.86	157.51	188.51	121.32	574.2
	70	93.50	137.82	164.95	106.15	502.42

Converted mm to m^3 = water per mm depth, * Area (3.57 not 4.2 for drip irrigation)

$$\bullet \text{ Actual evapotranspiration } ET_a = (M_2 \% - M_1 \%)/100 \cdot db \cdot D \quad (\text{mm})$$

(Doorenbos and Pruitt, 1984)

where: M_2 : moisture content after irrigation %.

M_1 : moisture content before irrigation %.

db : specific density of soil .

D : mean depth, mm.

$$\bullet \text{ Water use efficiency } WUE = Y_a / ET_a \quad (\text{kg } m^{-3}) \quad (\text{Howell et al., 2001})$$

where: Y_a : actual yield of the crop, ($kg \text{ fed}^{-1}$).

$$\bullet \text{ Irrigation water use efficiency } IWUE = Y_a / IR \quad (\text{kg } m^{-3}) \quad (\text{Michael, 1978})$$

where: IR : seasonal amounts of applied irrigation water, (m^3), Table (7).

Results and Discussion

Effect of MF levels on physical and chemical for irrigation water

Data in Table 8 reported that the values of physical analyses of irrigation water (IR) (refractive index, density ($gm \text{ cm}^{-3}$), surface tension ($dyne \text{ cm}^{-1}$), viscosity ($\times 10^{-6} \text{ m}^2 \text{ s}^{-1}$), turbidity (NTU), total hardness ($mg \text{ lit}^{-1}$) and evaporation ($mm \text{ h}^{-1}$) decreased with increasing magnetic field levels (MF) except solubility ($gm/10ml$) which was recorded increased with increasing MF levels. The minimum values

of physical analyses were (1.3323, 1.0048 $gm \text{ cm}^{-3}$, 68.75 $dyne \text{ cm}^{-1}$, $0.687 \times 10^{-6} \text{ m}^2 \text{ s}^{-1}$, 645.31 NTU, 187.53 $mg \text{ lit}^{-1}$ and 0.449 $mm \text{ h}^{-1}$), respectively, except solubility which was (3.46 $gm/10ml$) under MF= 4000 Gauss. While, the maximum values were (1.3324, 1.0056 $gm \text{ cm}^{-3}$, 72.43 $dyne \text{ cm}^{-1}$, $0.827 \times 10^{-6} \text{ m}^2 \text{ s}^{-1}$, 761.12 NTU, 225.36 $mg \text{ lit}^{-1}$ and 0.542 $mm \text{ h}^{-1}$), respectively, except solubility which was (3.18 $gm/10ml$) under MF= 0 Gauss. These results are harmonious with those obtained by Hasaani et al., (2015).

TABLE 8. Effect of MF levels on physical analyses for irrigation water

Physical proprieties	Magnetic Field (Gauss)			LSD (0.05%)
	0	2000	4000	
Solubility (gm/10ml)	3.18	3.34	3.46	0.02
Refractive index	1.3324	1.3323	1.3323	1.17
Density (gm cm ⁻³)	1.0056	1.0053	1.0048	0.0006
Surface tension (dyne cm ⁻¹)	72.43	71.98	68.75	0.83
Viscosity ($\times 10^{-6}$ m ² s ⁻¹)	0.827	0.762	0.687	0.065
Turbidity (NTU)	761.12	708.56	645.31	4.29
Total Hardness (mg lit ⁻¹)	225.36	203.09	187.53	3.05
Evaporation (mm h ⁻¹)	0.542	0.497	0.449	2.41

Moreover, Data in Table 9 concluded that the values of chemical analyses of IR (pH, electric-conductivity Ec (dS m⁻¹), total dissolved salts TDS (ppm), Ca⁺⁺, Mg⁺⁺ and SO₄⁼) increased with increasing MF levels except SAR was recorded decreased with increasing MF levels. The maximum values of chemical analyses were (7.45, 1.56 dS m⁻¹, 499.20 ppm, 2.93, 1.06 and 2.53), respectively, except SAR was 6.92 under MF= 4000 Gauss. While, the minimum values were (7.39, 1.53 dS m⁻¹, 489.60 ppm, 2.90, 1.04

and 2.48), respectively, except SAR which was 6.97 under MF= 0 Gauss. Meanwhile, Data in the same table showed that the values of (Na⁺, K⁺, CL⁻ and HCO₃⁻) were not significant at different MF levels. One can explain the result as; when water flows through the magnetic field, the nuclei of its atoms are polarized, this polarization makes the atoms behave as tiny magnets with north and south poles. These results are in agreement with Amer *et al.* (2014) and Hasaani *et al.* (2015).

TABLE 9. Effect of MF levels on chemical analyses for irrigation water

Chemical proprieties	Magnetic Field (Gauss)			LSD (0.05%)
	0	2000	4000	
pH	7.39	7.42	7.45	0.05
Ec (dS m ⁻¹)	1.53	1.54	1.56	0.02
TDS (ppm)	489.60	492.80	499.20	1.17
SAR	6.97	6.92	6.92	0.03
Na [±]	9.76	9.76	9.76	N.S
K ⁺	0.42	0.42	0.42	N.S
Ca ^{±±}	2.90	2.91	2.93	0.03
Mg ^{±±}	1.04	1.05	1.06	0.01
CL ⁻	7.89	7.89	7.89	N.S
HCO ₃ ⁻	3.17	3.17	3.17	N.S
CO ₃ ⁼	-	-	-	-
SO ₄ ⁼	2.48	2.51	2.53	0.04

Effect of MF and IR under IS on studied quality parameters of crops

Lettuce

Data in Fig. 2&3 showed that the values of studied quality parameters for lettuce plant (length (L) Cm, diameter (D) Cm, total soluble solid (TSS) %, vitamin C (VC) mg 100 g⁻¹fw and marketable yield (Ya) g/plant) increased with increasing both magnetic field levels (MF) and applied irrigation water (IR). While, total sugar (TS) % fw increased with increasing MF and decreased with increasing IR under surface

(SDI) and sub-surface drip (SSDI) irrigation. The maximum values of lettuce plant L, D, TSS, VC and Ya were (17.58 cm, 24.74 cm, 2.19 %, 19.65 mg 100 g⁻¹fw and 425.75 g/plant), respectively, except TS which was (3.83% fw) under MF= 4000 Gauss, IR=100% and SSDI treatment. While, the minimum values were (34.31cm, 69.05cm, 4.97 %, 10.79mg 100 g⁻¹fw and 160.75g/plant), respectively, except TS which was (3.05% fw) under MF= 0 Gauss, IR=70% and SDI treatment. The values of lettuce plant L, D, TSS, TS, Vc and Ya under MF= 4000 Gauss, IR=100% and SSDI

treatment were recorded increased significantly by about 20, 37, 45, 60, 28 and 52% , respectively, compared to that under control treatment (MF= 0 Gauss, IR=100% and SDI). These results are similar to those reported by Shahin et al. (2016).

Moreover, Figures 1&2 revealed that the relationships between IR, mm and the studied quality parameters of lettuce plant were highly significant positively correlated with MF= 0 Gauss, L ($r = 0.996^{**}$), D ($r = 0.995^{**}$), TSS ($r = 0.996^{**}$), VC ($r = 0.996^{**}$) and Ya ($r = 0.998^{**}$) under SDI. Also, L ($r = 0.997^{**}$), D ($r = 0.994^{**}$), TSS ($r = 0.995^{**}$), VC ($r = 0.998^{**}$) and Ya ($r = 0.996^{**}$) recorded highly significant positively correlated with MF= 0 Gauss under SSDI. While, the relationship between IR, mm and TS was highly significant negatively correlated with MF= 0 Gauss, ($r = -0.992^{**}$) and ($r = -0.998^{**}$) under SDI and SSDI, respectively. Meanwhile, the same relationships recorded significant positively correlated with MF= 2000 Gauss, L ($r = 0.955^{*}$), D ($r = 0.987^{*}$), TSS ($r = 0.954^{*}$), VC ($r = 0.974^{*}$) and Ya ($r = 0.983^{*}$) under SDI. Also, L ($r = 0.961^{*}$), D ($r = 0.986^{*}$), TSS ($r = 0.963^{*}$), VC ($r = 0.974^{*}$) and Ya ($r = 0.983^{*}$) recorded significant positively correlated with MF= 2000 Gauss under SSDI. On the other hand, the relationship between IR, mm and TS was significant negatively correlated with MF= 2000 Gauss, ($r = -0.966^{*}$) and ($r = -0.979^{*}$) under SDI and SSDI , respectively. Finally, the relationships between IR, mm and studied quality parameters of lettuce plant were not significantly correlated with MF= 4000 Gauss, under SDI and SSDI. These results may be attributed to that magnetized water treatment increases plant metabolism in terms of photosynthesis and water uptake. These results are in agreement with Yano et al. (2004).

Potato

Data in Fig. 3&4 showed that the values of the studied quality parameters for potato tuber (high (H) Cm, diameter (D) Cm, total soluble solid (TSS) %, starch (S) %, protein (P) % and specific gravity (SG) increased with increasing both magnetic field levels (MF) and applied irrigation water (IR) under SDI and SSDI. The maximum values of potato tuber H, D, TSS, S, P and SG were (9.55 cm, 9.02 cm, 4.45 %, 17.52 %, 2.46 % and 1.079), respectively, under MF= 4000 Gauss, IR=100%, and SSDI treatment. While, the minimum values were (5.04 cm, 4.56 cm, 4.30 %, 11.59 %, 1.41 % and 1.062) respectively,

under MF= 0 Gauss, IR=70% and SDI treatment. The values of potato tuber H, D, TSS, S, P and SG under MF= 4000 Gauss, IR=100% and SSDI treatment increased significantly by about 29, 35, 1, 51, 32 and 0.75% , respectively, compared to those under control treatment (MF= 0 Gauss, IR=100% and SDI). These results agreed with that obtained by Al- Janaby (2012).

Moreover, Fig. 3&4 indicated that the relationships between IR, mm and studied quality parameters of potato tuber were highly significant positively correlated with MF= 0 Gauss, H ($r = 0.997^{**}$), D ($r = 0.999^{**}$), TSS ($r = 0.993^{**}$), S ($r = 0.994^{**}$), P ($r = 0.992^{**}$) and SG ($r = 1.000^{**}$) under SDI. Also, H ($r = 0.999^{**}$), D ($r = 1.000^{**}$), TSS ($r = 0.996^{**}$), S ($r = 0.991^{**}$), P ($r = 0.996^{**}$) and SG ($r = 0.996^{**}$) under SSDI. Meanwhile, the relationships revealed that they significant positively correlated with MF= 2000 Gauss, H ($r = 0.950^{*}$), D ($r = 0.952^{*}$), S ($r = 0.968^{*}$) and P ($r = 0.951^{*}$) except TSS ($r = 0.994^{**}$) and SG ($r = 0.997^{**}$) which were the highly significant positively correlated under SDI. Also, H ($r = 0.962^{*}$), D ($r = 0.963^{*}$), S ($r = 0.967^{*}$) and P ($r = 0.983^{*}$) except TSS ($r = 0.996^{**}$) and SG ($r = 0.996^{**}$) were the highly significant positively correlated under SSDI. Generally, the relationships between IR, mm and studied quality parameters of potato tuber were not significantly correlated with MF= 4000 Gauss, except TSS ($r = 0.994^{**}$) and SG ($r = 0.997^{**}$) which were the highly significant positively correlated, under SDI and SSDI. These results may be attributed to the plant's metabolism containing 90 to 95% of water which is a diamagnetic compound and the rest contains several para, ferro and diamagnetic metals and non-metals in minute forms according to Charan (2009).

Effect of MF and IR under IS on marketable yield of crops

Data in Tables 10&11 reported that the values of marketable yield (Ya) for lettuce plant and potato tubers increased with increasing both MF levels and IR under SDI and SSDI. The maximum values of Ya for lettuce and potato crops were 8.17 and 13.21 Mg fed⁻¹ , respectively, under MF= 4000 Gauss, IR=100% and SSDI treatment. While, the minimum values were 3.25 and 5.13 Mg fed⁻¹ for both crops under MF= 0 Gauss, IR=70% and SDI treatment.

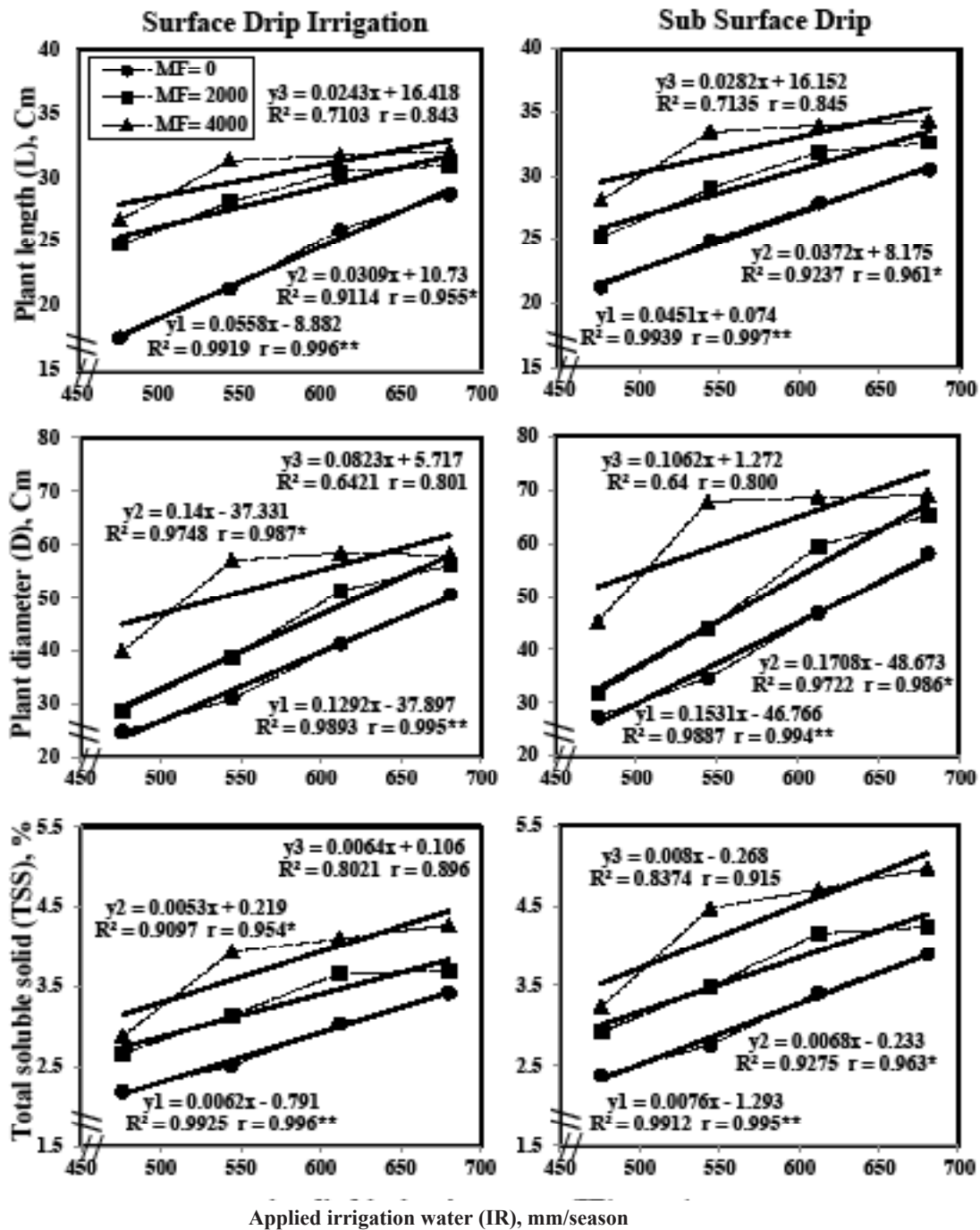


Fig.2. Relationships between applied irrigation water (IR) and studied quality parameters of lettuce

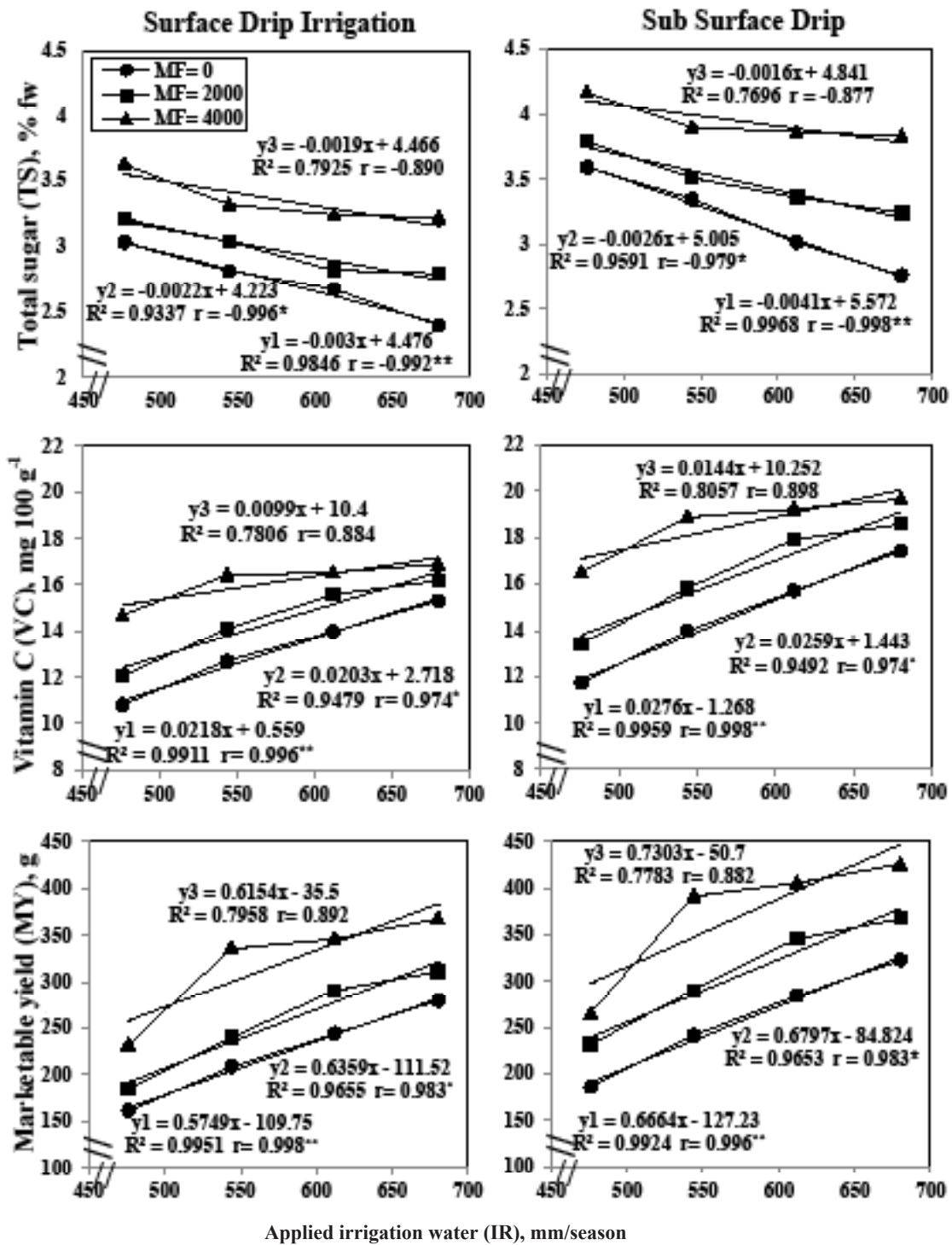


Fig. 3. Relationships between applied irrigation water (IR) and studied quality parameters of lettuce

*y1 at MF = 0 Gauss y2 at MF = 2000 Gauss y3 at MF = 4000 Gauss

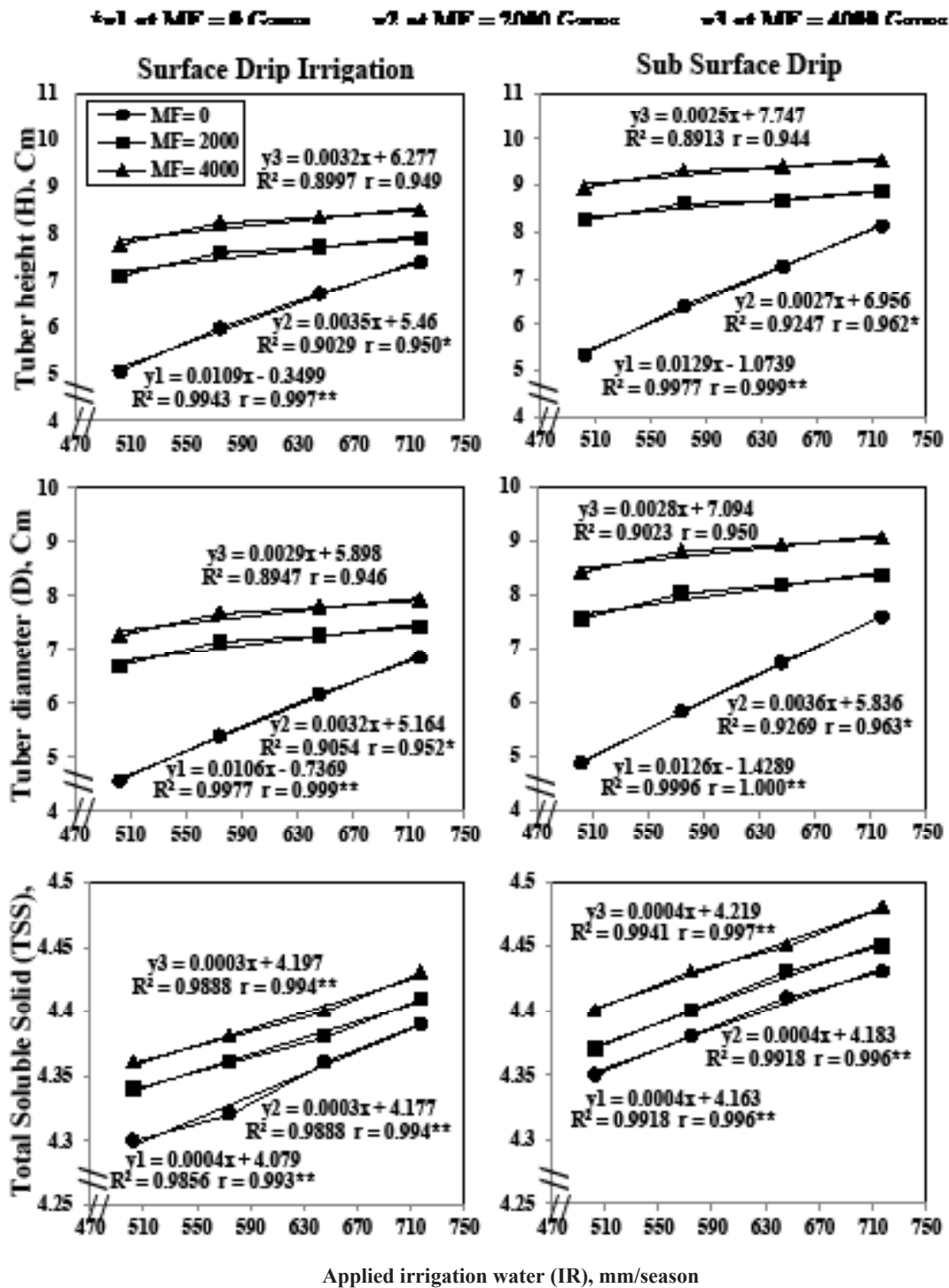


Fig. 4. Relationships between applied irrigation water (IR) and studied quality parameters of Potato tuber

TABLE 10. Effect of MF levels and IR on Ya, ETa, WUE and IWUE of lettuce plant under SDI and SSDI

IS	MF (Gaus)	IR (%)	Ya (Mg fed ⁻¹)	ETa (mm)	WUE (Kg m ⁻³)	IWUE (Kg m ⁻³)	
SDI	0	100	5.84	511.73	3.20	2.40	
		90	4.89	447.51	3.06	2.24	
		80	3.96	382.65	2.90	2.04	
	2000	70	3.25	334.39	2.72	1.91	
		100	6.37	438.69	4.07	2.62	
		90	6.10	397.47	4.30	2.79	
	4000	80	4.92	371.82	3.71	2.53	
		70	4.11	336.15	3.42	2.42	
		100	7.00	406.14	4.83	2.88	
	SSDI	0	90	6.79	368.52	5.16	3.11
			80	6.34	324.16	5.48	3.26
			70	4.71	302.39	4.36	2.77
2000		100	6.69	427.59	4.38	2.75	
		90	5.73	405.17	3.96	2.62	
		80	4.81	371.23	3.63	2.47	
4000		70	3.92	316.60	3.47	2.31	
		100	7.53	374.92	5.63	3.10	
		90	7.26	327.75	6.20	3.32	
LSD (0.05)		0	80	5.92	321.26	5.16	3.05
			70	4.68	261.53	5.01	2.75
			100	8.17	376.37	6.08	3.36
	2000	90	7.98	342.81	6.52	3.65	
		80	7.54	298.45	7.08	3.88	
		70	5.29	249.60	5.94	3.11	
	4000	IS	0.01	1.96	0.03	0.01	
		MF	0.01	3.01	0.03	0.01	
		IR	0.02	2.56	0.04	0.01	
	IS X SL X IR			0.06	6.80	0.18	0.03

TABLE 11. Effect of MF levels and IR on Ya, ETa, WUE and IWUE of potato tuber under SDI and SSDI

IS	MF (Gaus)	IR (%)	Ya (Mg fed ⁻¹)	ETa (mm)	WUE (Kg m ⁻³)	IWUE (Kg m ⁻³)	
SDI	0	100	9.87	564.73	4.90	3.85	
		90	8.35	496.51	4.71	3.62	
		80	6.81	420.65	4.53	3.32	
	2000	70	5.13	355.42	4.04	2.86	
		100	10.34	468.69	6.18	4.04	
		90	9.61	422.47	6.37	4.17	
	4000	80	8.97	363.52	6.91	4.38	
		70	6.89	332.15	5.81	3.84	
		100	11.96	446.14	7.51	4.67	
	SSDI	0	90	11.32	403.56	7.86	4.91
			80	10.64	359.78	8.28	5.19
			70	9.72	315.62	8.63	5.42
2000		100	10.69	480.02	6.24	4.17	
		90	9.04	466.46	5.43	3.92	
		80	7.56	418.25	5.06	3.69	
4000		70	5.71	347.62	4.60	3.18	
		100	11.43	410.07	7.81	4.46	
		90	10.58	359.95	8.23	4.59	
LSD (0.05)		0	80	10.00	321.26	8.72	4.88
			70	7.89	312.17	7.08	4.40
			100	13.21	381.22	9.71	5.16
	2000	90	12.49	343.02	10.20	5.42	
		80	11.61	304.67	10.67	5.66	
		70	10.57	262.52	11.28	5.89	
	4000	IS	0.03	1.32	0.03	0.01	
		MF	0.05	1.72	0.04	0.02	
		IR	0.06	2.18	0.08	0.03	
	IS X SL X IR			0.19	4.57	0.20	0.08

Gauss

Meanwhile, the values of lettuce and potato Y_a under MF= 4000 Gauss, IR=100% and SSDI treatment increased significantly by about 40 and 34 % compared to those under control treatment (MF= 0 Gauss, IR=100% and SDI). This increase may be attributed to the mechanism of magnetic field with the 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. These results are in harmony with the finding of Maheshwari and Grewal (2009) and Kirnak *et al.* (2016).

Effect of MF and IR under IS on seasonal actual evapotranspiration

Data in Tables 10&11 showed that the values of seasonal actual evapotranspiration ET_a for lettuce and potato crops decreased with increasing MF levels. While, ET_a for both crops increased with increasing IR under SDI and SSDI. The minimum values of ET_a for lettuce and potato crops were 249.60 and 262.52 mm, respectively, under MF= 4000 Gauss, IR=70% and SSDI treatment. While, the maximum values were 511.73 and 564.73 mm for both crops under control treatment (MF= 0 Gauss, IR=100% and SDI). These results agree with Aoda and Fattah (2011).

Effect of MF and IR under IS on WUE and IWUE: Lettuce

Data in Table 10 concluded that the maximum values of water use efficiency (WUE) and irrigation water use efficiency (IWUE) for lettuce plant were 7.08 and 3.88 kg m⁻³, respectively, under MF= 4000 Gauss, IR=80% and SSDI treatment. While, the minimum values were 2.72 and 1.91 kg m⁻³, respectively, for both crops under MF= 0 Gauss, IR=70% and SDI treatment. Meanwhile, the values of WUE and IWUE under MF= 4000 Gauss, IR=80% and SSDI treatment increased significantly by about 121 and 62 %, respectively, compared to those under control treatment (MF= 0 Gauss, IR=100% and SDI). These results may be attributed to that the marketable yield for lettuce plant increased with increasing MF levels for all treatments. While, ET_a and IR decreased with increasing MF levels for all treatments. These results were similar to those reported by Aoda and Fattah (2011) and Kirnak *et al.* (2016).

Potato

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Data in Table 11 reported that the maximum values of WUE and IWUE for potato tuber were 11.28 and 5.89 kg m⁻³, respectively, under MF= 4000 Gauss, IR=70% and SSDI treatment. While, the minimum values were 4.04 and 2.86 kg m⁻³ for both crops under MF= 0 Gauss, IR=70% and SDI treatment. Meanwhile, the values of WUE and IWUE under MF= 4000 Gauss, IR=70% and SSDI treatment increased significantly by about 130 and 53 %, respectively, compared to that under control treatment (MF= 0 Gauss, IR=100% and SDI). These results are in harmony with the finding of Ayas (2013) and Ahmed and Abd El-Kader (2016)

IR and SL on crop yield response factor (Ky):Lettuce

Data in Fig. 6 showed that the crop yield response factor (K_y) for lettuce indicates a linear relationship between the relative reduction in actual evapotranspiration $1-(ET_a/ET_{max})$ and the relative reduction in yield $1-(Y_a/Y_{max})$. These relationships recorded that they highly significant positively correlated with MF= 0 Gauss, ($r = 1.000^{**}$) and ($r = 0.996^{**}$) at different IR under SDI and SSDI, respectively. Also, the same relationships showed that they significantly positively correlated with MF= 2000 Gauss, ($r = 0.955^*$) and ($r = 0.953^*$) at different IR under SDI and SSDI, respectively. Finally, the relationships between $1-(ET_a/ET_{max})$ and $1-(Y_a/Y_{max})$ of lettuce plant were not significantly correlated with MF= 4000 Gauss, at different IR under SDI and SSDI; these results agree with Aoda and Fattah (2011). Moreover, Fig. 7 revealed that the values of K_y for lettuce decreased with increasing both MF levels and IR under SDI and SSDI irrigation. The maximum value of K_y for lettuce plant was 1.12 under MF= 0 Gauss, IR=70% and SDI treatment. While, the minimum value was 0.06 under MF= 4000 Gauss, IR=90% and SSDI treatment. The same figure showed that the relationships between IR, mm and K_y of lettuce plant were high significantly negatively correlated with MF= 0 Gauss, ($r = -0.994^{**}$) and ($r = -0.992^{**}$) under SDI and SSDI, respectively. While, the same relationships recorded that they significantly negatively correlated with MF= 2000 Gauss, ($r = -0.975^*$) and ($r = -0.973^*$) under SDI and SSDI, respectively. Meanwhile, the relationships between IR, mm and K_y of lettuce plant were not significantly correlated with MF= 4000 Gauss, under SDI and SSDI. These results were similar to those reported by Kirnak *et al.* (2016).

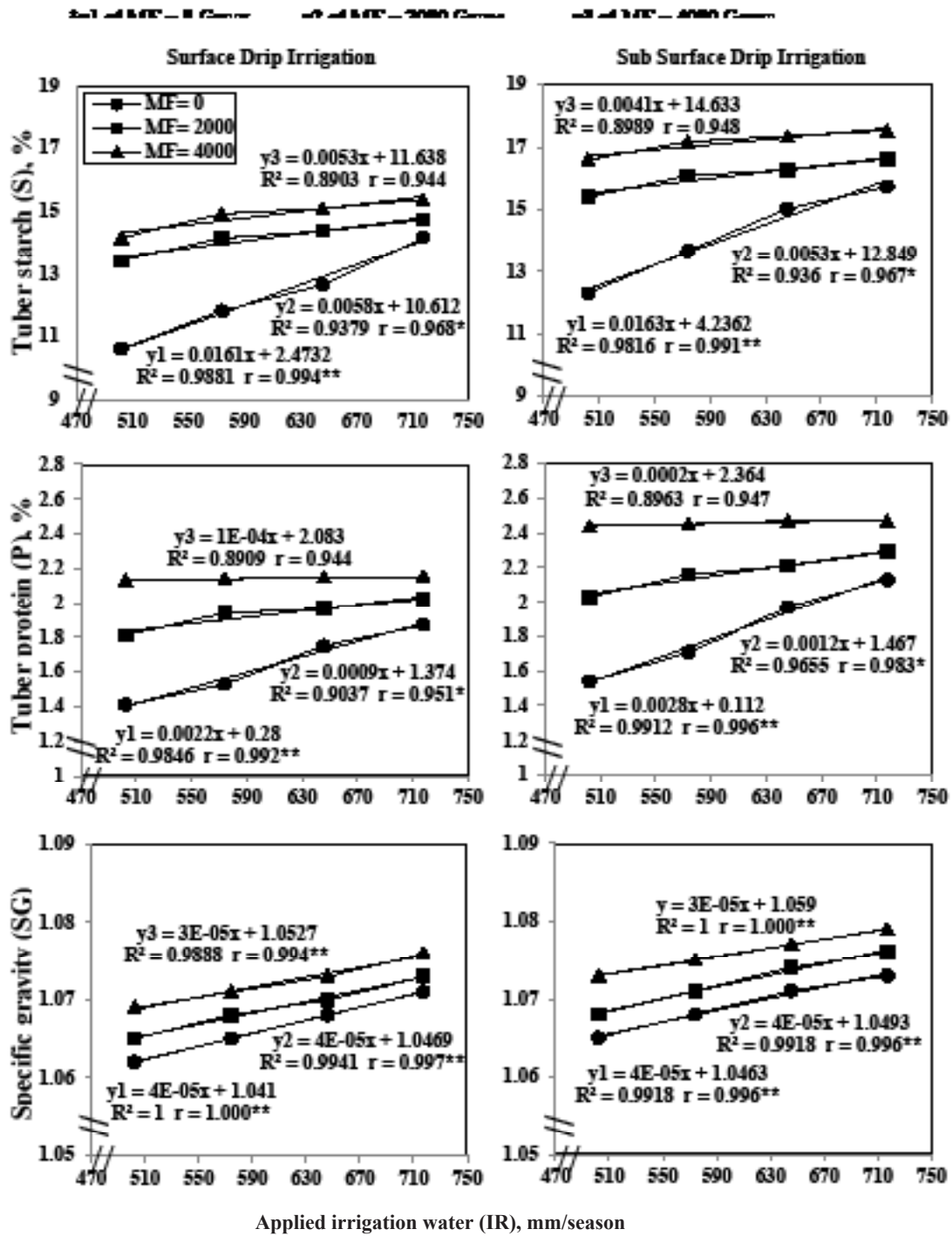


Fig.5. Relationships between applied irrigation water (IR) and studied quality parameters of Potato tuber

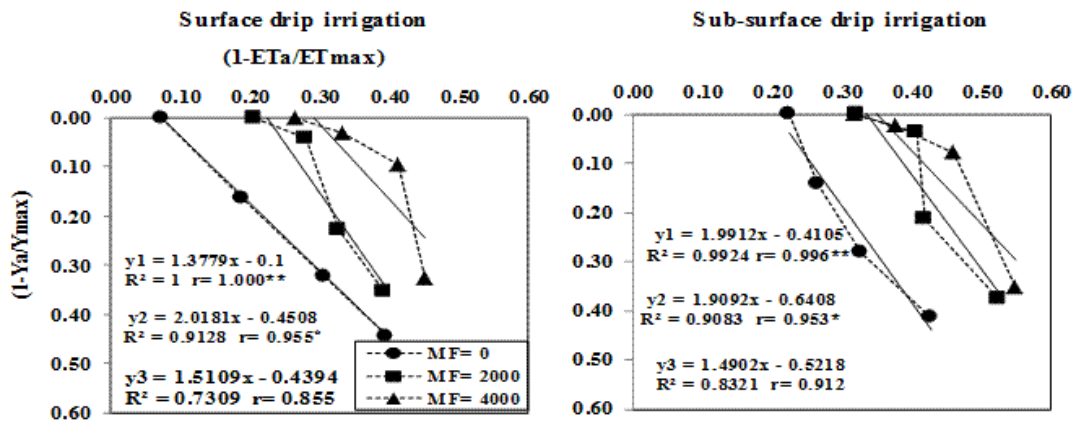


Fig. 6. The relationship between a decrease in marketable yield (Y_a) and crop evapotranspiration (ETc) deficit for lettuce plant

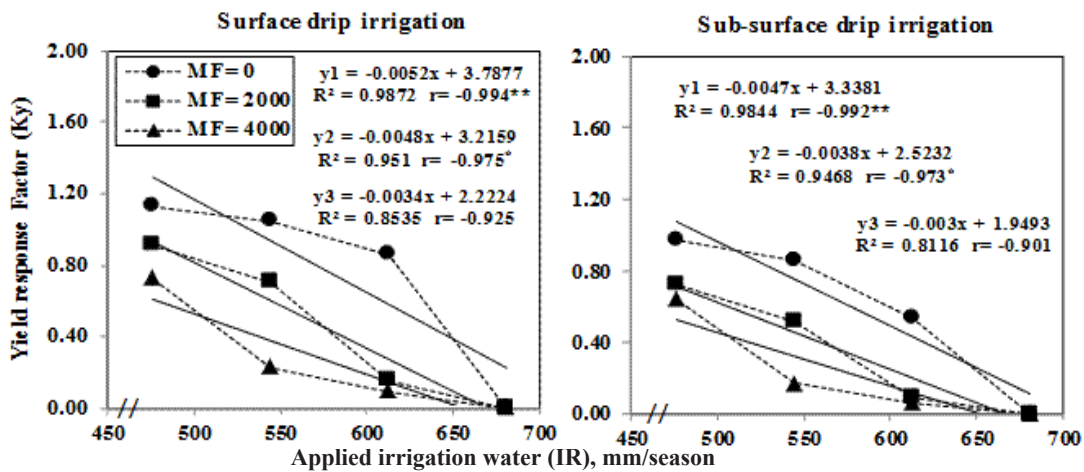


Fig. 7. Effect of magnetic field (MF) at different applied irrigation water (IR) on yield response factor (Ky) for lettuce plant

Potato

Data in Figure 8 reported that the relationships between $1-(E_t/E_{Tmax})$ and $1-(Y_a/Y_{max})$ for potato tuber were high significantly positively correlated with MF= 0 Gauss, ($r = 0.994^{**}$) and ($r = 0.998^{**}$) at different IR under SDI and SSDI respectively. Also, the same relationships showed that they significantly positively correlated with MF= 2000 Gauss, ($r = 0.974^*$) and ($r = 0.972^*$) at different IR under SDI and SSDI, respectively. Finally, the relationships between $1-(E_t/E_{Tmax})$ and $1-(Y_a/Y_{max})$ of potato tuber were not significantly correlated with MF= 4000 Gauss, at different IR under SDI and SSDI. Moreover, Fig. 9 showed that the values of K_y for potato decreased with increasing both MF levels and IR under SDI and SSDI irrigation. The maximum value of K_y for potato tuber was 1.23 under MF=

0 Gauss, IR=70% and SDI treatment. While, the minimum value was 0.13 under MF= 4000 Gauss, IR=90% and SSDI treatment.

The same figure showed that the relationships between IR, mm and K_y of potato tuber were high significantly negatively correlated with MF= 0 Gauss, ($r = -0.996^{**}$) and ($r = -0.999^{**}$) under SDI and SSDI, respectively. While, the same relationships recorded that they significantly negatively correlated with MF= 2000 Gauss, ($r = -0.967^*$) and ($r = -0.962^*$) under SDI and SSDI, respectively. Meanwhile, the relationships between IR, mm and K_y of potato tuber were not significantly correlated with MF= 4000 Gauss, under SDI and SSDI. These results agree with Al-Janaby (2012).

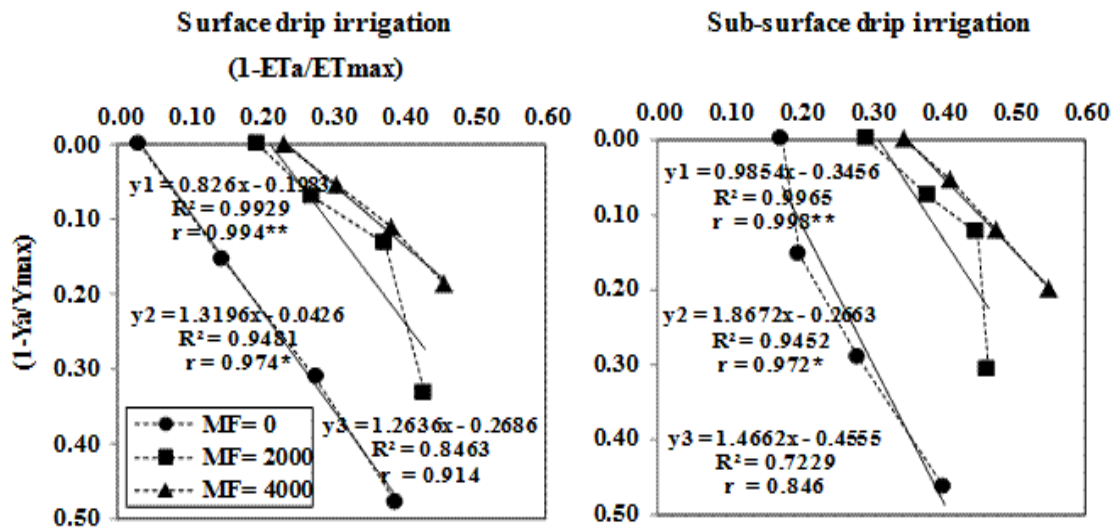


Fig. 8. The relationship between a decrease in marketable yield (Ya) and crop evapotranspiration (ETc) deficit for lettuce plant

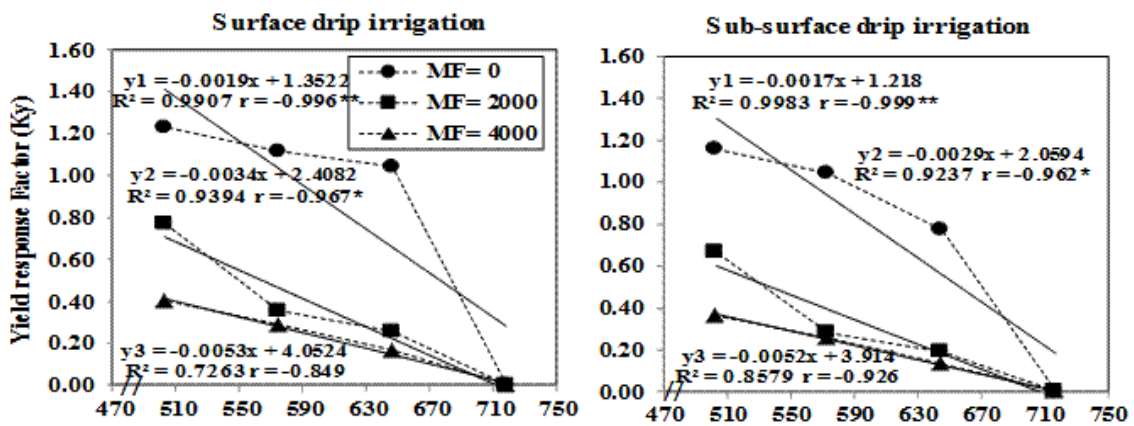


Fig. 9. Effect of magnetic field (MF) at different applied irrigation water (IR) on yield response factor (Ky) for Potato tuber

Conclusion

Results of the current study demonstrated beneficial effects, of MF levels and IR under SDI and SSDI on the Ya, studied quality parameters, seasonal ETa, WUE, IWUE and Ky for lettuce plant and potato tuber under Egyptian sandy soil. This study concluded that:

1. The values of physical analyses of irrigation water decreased with increasing MF levels except solubility. While, the values of chemical analyses of IR increased with increasing MF levels except SAR. Meanwhile, the values of (Na⁺, K⁺, CL⁻ and

HCO₃⁻) were not significant at different MF levels.

2. The values of quality parameters for lettuce plant and potato tuber increased with increasing both MF levels and IR under SDI and SSDI except total sugar TS for plant lettuce. The relationships between IR, mm and studied quality parameters of lettuce plant and potato tuber were not significantly correlated with MF= 4000 Gauss, under SDI and SSDI.
3. The maximum values of Ya for lettuce and potato crops were 8.17 and 13.21 Mgfed⁻¹ respectively, under MF= 4000 Gauss, IR=100% and SSDI treatment.

4. The values of ETa for lettuce and potato crops decreased with increasing MF levels. While, ETa for both crops increased with increasing IR under SDI and SSDI.
5. The values of WUE and IWUE for lettuce plant under MF= 4000 Gauss, IR=80% and SSDI treatment increased significantly by about 121 and 62 % , respectively, compared to those under control treatment. While, The values of WUE and IWUE for potato tuber under MF= 4000 Gauss, IR=70% and SSDI treatment increased significantly by about 130 and 53 % , respectively compared to those under control treatment.
6. Finally, the minimum values of Ky of lettuce and potato tuber were 0.06 and 0.13, respectively, under (MF= 4000 Gauss, IR=90% and SSDI) treatment compared to that 0.00 under control treatment.

So, it is recommended to use (MF= 4000 Gauss at IR_{80%} under SSDI) treatment for Ya of lettuce plant. This treatment could save about 20% of irrigation water and increased significantly by about 29% compared to that under control treatment. While, (MF= 4000 Gauss at IR_{70%} under SSDI) treatment for Ya of potato tuber could save about 30% of irrigation water and increased significantly by about 7% compared to that under control treatment. This means that this technology can be recommended to farmers to improve their production and save irrigation water.

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رفع كفاءة الأستهلاك المائي لبعض النباتات بتقنية الماء المعالج مغناطيسيا تحت ظروف شرق العوينات

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أجريت هذه التجربة في منطقة شرق العوينات بمحافظة الوادي الجديد – جمهورية مصر العربية وكانت حداثياتها كالتالي (٢٦ ٥٢٩ شمالا : ٤١ ٥٢٣ شرقا) وأرتفاع ٥٤ متر فوق مستوى سطح البحر خلال الموسم الشتوي ٢٠١٥ تم استخدام التصميم الأحصائي القطع المنشقة مرتين بثلاث مكررات لكل معاملة وتم زراعة محصولي الخس والبطاطس بأستخدام أربع نسب من كميات مياه الري المضافة (١٠٠ ، ٩٠ ، ٨٠ ، ٧٠٪) المعاملة بثلاثة مستويات من شدة المجال المغناطيسي (٠ ، ٢٠٠٠ ، ٤٠٠٠ جاوس) تحت نظامي الري بالتنقيط السطحي والتحت سطحي. وقد تم دراسة تأثير هذه المتغيرات على كل من أنتاجية وقياسات الجودة لكل من نبات الخس ودرنات البطاطس وكذلك الأستهلاك المائي الفعلي وكفاءة الأستهلاك المائي والأروائي ومعامل أستجابة المحصولين للنقص. وقد أوضحت النتائج المتحصل عليها الأتي :

١. انخفاض قيم الخواص الفيزيائية لمياه الري بزيادة مستويات المغنطة ماعدا خاصية الذوبانية. بينما زادت قيم الخواص الكيميائية بزيادة مستويات المغنطة ماعدا نسبة الصوديوم الممتص SAR. سجلت قيم الصوديوم والبوتاسيوم والكلوروكربونات تأثيرا غير معنويا بزيادة مستويات المغنطة.
 ٢. زيادة قيم قياسات الجودة لنبات الخس ودرنات البطاطس بزيادة مستويات المغنطة وكميات مياه الري المضافة تحت نظامي الري بالتنقيط السطحي والتحت سطحي ماعدا السكريات الكلية لنبات الخس.
 ٣. سجلت علاقات الارتباط بين كميات مياه الري المضافة (م/موسم) وقياسات الجودة محل الدراسة لنبات الخس ودرنات البطاطس ارتباط معنوي جدا عند مستوى شدة مجال مغناطيسي (٠ جاوس) وأرتباط معنوي عند (٢٠٠٠ جاوس) وأرتباط غير معنوي عند (٤٠٠٠ جاوس) لكلا نظامي الري بالتنقيط.
 ٤. انخفاض قيم الأستهلاك المائي الفعلي لنبات الخس ودرنات البطاطس بزيادة مستويات المغنطة بينما تزيد للمحصولين بزيادة كميات مياه الري المضافة لكلا نظامي الري بالتنقيط.
 ٥. زيادة قيم الأنتاجية الكلية لنبات الخس ودرنات البطاطس بزيادة مستويات المغنطة وكميات مياه الري المضافة لكلا نظامي الري بالتنقيط. سجلت المعاملة المروية (بمستوى مغنطة = ٤٠٠٠ جاوس وكمية مياه ري مضافة ١٠٠٪ تحت نظام الري بالتنقيط السطحي) أعلى أنتاجية لكلا من نبات الخس ودرنات البطاطس (٨,١٧ و ١٣,٢١ طن/فدان) على الترتيب بزيادة تقديروالي ٤٠ و ٣٤٪ مقارنة بالمعاملة التقليدية (مستوى مغنطة = ٠ وكمية مياه ري ١٠٠٪ تحت نظام الري بالتنقيط السطحي).
 ٦. سجلت المعاملة المروية (بمستوى مغنطة = ٤٠٠٠ جاوس وكمية مياه ري مضافة ٨٠٪ تحت نظام الري بالتنقيط السطحي) أعلى قيم لكفاءة الأستهلاك المائي والأروائي لنبات الخس (٧,٠٨ و ٣,٨٨ كجم/م^٣) على الترتيب بزيادة تقدر بحوالي ١٢١ و ٦٢٪ مقارنة بالمعاملة التقليدية. بينما سجلت المعاملة المروية (بمستوى مغنطة = ٤٠٠٠ جاوس وكمية مياه ري مضافة ٧٠٪ تحت نظام الري بالتنقيط السطحي) أعلى قيم لكفاءة الأستهلاك المائي والأروائي لدرنات البطاطس (١١,٢٨ و ٥,٨٩ كجم/م^٣) على الترتيب وتزيد هذه المعاملة بحوالي ١٣٠ و ٥٣٪ مقارنة بالمعاملة التقليدية.
 ٧. انخفاض معامل أستجابة محصولي الخس والبطاطس بزيادة مستويات المغنطة وكميات مياه الري المضافة لكلا نظامي الري بالتنقيط. سجلت علاقات الارتباط بين كميات مياه الري المضافة (م/موسم) ومعامل أستجابة المحصول لنبات الخس ودرنات البطاطس ارتباط معنوي جدا عند مستوى شدة مجال مغناطيسي (٠ جاوس) وأرتباط معنوي عند (٢٠٠٠ جاوس) وأرتباط غير معنوي عند (٤٠٠٠ جاوس) لكلا نظامي الري بالتنقيط. بينما سجلت المعاملة المروية (بمستوى مغنطة = ٤٠٠٠ جاوس وكمية مياه ري مضافة ٩٠٪ تحت نظام الري بالتنقيط السطحي) أقل قيم لمعامل أستجابة المحصول لكلا من الخس والبطاطس (٠,١٣ و ٠,٠٦) مقارنة بالمعاملة التقليدية .
- لذا يمكن التوصية بأستخدام المعاملة عند (مستوى مغنطة = ٤٠٠٠ جاوس وكمية مياه ري مضافة ٨٠٪ تحت نظام الري بالتنقيط السطحي) لأنها أعطت أعلى أستهلاك مائي وأروائي لري نبات الخس هذه المعاملة يمكن أن توفر حوالي ٢٠٪ من كمية مياه الري المضافة وتحقق زيادة معنوية في الأنتاجية تقدر بحوالي ٢٩٪ مقارنة بالمعاملة التقليدية. بينما يمكن التوصية بأستخدام المعاملة (عند مستوى مغنطة = ٤٠٠٠ جاوس وكمية مياه ري مضافة ٧٠٪ تحت نظام الري بالتنقيط السطحي) لأنها أعطت أعلى أستهلاك مائي وأروائي لري درنات البطاطس هذه المعاملة يمكن أن توفر حوالي ٣٠٪ من كمية مياه الري المضافة وتحقق زيادة معنوية في الأنتاجية تقدر بحوالي ٧٪ مقارنة بالمعاملة التقليدية. هذا يعني أنه يمكن التوصية بأستخدام تقنية مغنطة مياه الري في المزارع لرفع أنتاجية المحاصيل وتوفير كميات مياه الري المضافة.