Middle East Journal of Agriculture Research
ISSN 2077-4605

Volume : 08 | Issue : 01 | Jan.-Mar. | 2019
Pages:237-254

Physiological Response and Productivity of Potato Plant (*Solanum tuberosum* L.) to Irrigation with Magnetized Water and Application of Different Levels of NPK Fertilizers

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Received: 02 Feb. 2019 / Accepted 20 Mar. 2019 / Publication date: 25 Mar. 2019

ABSTRACT

The objectives of this investigation were to study some physiological characteristics and biochemical aspects as well as yield quantity and quality of potato plants (*Solanum tuberosum* L.cv. Diamant) in response to two types of irrigation (tap and magnetized water) under four NPK fertilizers levels (100, 75, 50 and 25% of the recommended rate) and their interactions during two growing seasons (January 11th in the 1st and 2nd seasons 2016 and 2017). Pot experiments were carried out in a greenhouse at the experimental farm of the Faculty of Agriculture, Menoufia University, Shibin El-Kom, Egypt. The decreases in the fertilizer levels caused a significant decrease in all growth characters, physiological aspects, biochemical constituents and the quantity and quality of tuber yield. Irrigation with magnetized water enhanced most of these characteristics under all fertilizer levels. The leaf area, relative water content, membrane permeability, total chlorophyll (a and b), total carbohydrates concentration in leaves and concentration of N, P and K increased by about 55, 11, 31, 48, 12,16, 59 and 15%, respectively, in the plants fertilized by 50% NPK fertilizer of the recommended rate, compared to the control group. Additionally, irrigation with magnetic water resulted in a significant increase in the yield components i.e., tuber yield/feddan (Kg), NPK use efficiency in potato tuber by about 146 and 203 %, respectively under 25% NPK fertilizer level compared to its control. As the growth and productivity of potato plants increased by using magnetic water for irrigation under the different levels of fertilizer, this study recommends this type of irrigation for potato plants which decrease more than 25% of NPK fertilizer consumption.

Keywords: potato, Magnetic Water, NPK fertilizes, growth, productivity, physiological characteristics

Introduction

In Egypt, potato is one of the most important crops among the vegetable crops because of its high nutritional value and consequently for its consumption in local market and for exportation as well. Potatoes contain a high concentration of carbohydrates and good considerable amounts of fiber, vitamins (A, B and C), amino acids, mineral nutrients such as potassium, phosphorus and iron (Muthoni and Nyamango, 2009). The cultivated areas of potato in Egypt reached about 410 thousand feddans (about 173 thousand hectare) producing about 4.6 million tons with an average of about 11.3 ton/fed (FAO, 2017).

Potato (*Solanum tuberosum* L.) is a plant with high nutrient needs. Fertilization is an essential factor in potato production to give the optimum quantity and quality tuber yield. Maximum potato yields can only be obtained by adding the optimal nutrient doses in balanced proportions (Poljak *et al.*, 2007). Potato production in Egypt depended on the soil mineral fertilization based on three macronutrients i.e. nitrogen, phosphorus and potassium. Nitrogen (N) is an indispensable elementary part of numerous organic compounds *i.e.* amino acids, nucleic acids, protein and formation of protoplasm and new cells. In potato, N is an essential element for protein synthesis, respiration, and growth of tubers (Westermann, 2005; Kavvadias *et al.*, 2012). Nitrogen deficiency reduced dry matter and leaf area and resulted in fewer leaflets that provides less light interception and lower rate of photosynthesis (Marouani*etal*., 2015 and Li *et al*., 2016). Phosphorus (P) and Potassium (K) are essential macro-elements that play critical roles for physiological functions and mechanisms of plant growth. Phosphorus enhances root growth (Aguilar-Acuna*et al*., 2006), formation of tubers and starch synthesis (Perrenoud, 1993). Potassium is necessary for translocation of sugars to the tubers and starch synthesis, essential processes in the tuber growth and filling (Reis and Monnerat, 2000). Devi

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and Zaman (2012) reported that plant height, number of stems and leaves, total dry matter accumulation, crop growth rate of potato plants significantly increased at the recommended NPK rate. Verma *et al.* (2010) found that 75% NPK of the recommended rate plus *Azotobacter* produced the maximum tubers number, total yield and highest percent of potato plant nutrient uptake. However, minimizing the chemical fertilizers used in potatoes fields becomes crucial to reduce production cost, environmental pollution and necessary for human health. One of the new suggesting techniques to reduce consumption of chemical fertilizers is through the use of magnetized water for irrigation.

Magnetic field technology has shown various benefits which can improve the plant growth, the water relations and metabolic processes in plant, the solubility of nutrients in the soil, and crop yields. Several investigators indicated that the magnetic field helps for improvement the germination of seeds (Aladjadjiyan, 2002), the plant growth (Radhakrishnan and Kumari, 2012), the plant water status and relations (Selim, 2016), the concentration and uptake of essential macro- and micro-elements and the chemical composition of plants (Radhakrishnan and Kumari, 2012), saving the irrigation water (Selim and El-Nady, 2011 and Selim *et al*., 2019), and increasing the yield of many economic crops (Doklega, 2017).

The studies concerning the role of magnetized water and its relation with fertilization of the plants is relatively scarce. Selim (2016), on cucumber found that magnetic treated water increased nutrient solubility and mobility in soil and enhances extraction and uptake of NPK and other nutrient elements by plants. Also, Hajer *et al*., 2006 stated that magnetized water increased the efficiency of added fertilizers. Hilal and Hilal (2000) indicated that the behavior of nutrients under magnetic field is a function of their magnetic susceptibility. Magnetically treated water prevents forming white salty deposits near the plant (Ajitkumar, 2014). In addition, some studies stated that irrigation with magnetized water and fertilization with rates less than the recommended doses gave crop growth and yield higher than those irrigated with tap water and fertilized with the recommended doses (Doklega, 2017).

Therefore, the present investigation was done to evaluate the efficiency of irrigation with magnetized water on minimizing the NPK fertilizers rates recommended for potato plants cv. Diamant as well as studying the effect of such treatments on the behavior of growth, physiological and biochemical aspects, yield and NPK use efficiency of potato plants.

Material and methods

Experimental conditions and treatments

Pot experiments were carried out in a greenhouse at the Experimental farm of the Faculty of Agriculture, Shibin El-Kom, Menoufia University, on potato plant cv. Diamant to study the effect of two types of irrigation (tap and magnetized water) under different levels of NPK fertilizers and their interactions on growth, physiological and biochemical aspects as well as yield quantity and quality.

Potato tuber cv. Diamant was planted in polyethylene pots inner diameter 30 cm and 30 cm depth filled with 7 kg sandy clay loam soil on January 11th in the first and second seasons 2016 and 2017. The used soil was analyzed using the methods described by Page *et al*. (1982) to estimate some physical and chemical characteristics of this soil (Table 1).

Table 1: Some physical and chemical properties of the clay loam soil used.

Particle size distribution < 2 mm %					pH	ECe dS/m at 25°C	Soil paste extract analysis (meq / L)							
							Anions				Cations			
Coarse sand	Fine sand	Silt	Clay	Texture grade			$CO_2^{=}$	HCO_3^-	Cl^-	$SO_4^{=}$	Ca^{++}	Mg^{++}	Na^+	K^+
2.35	41.05	29.00	27.60	Clay loam	7.80	2.50	-	4.50	8.30	19.20	14.50	6.39	10.52	0.32

The experimental design involved the following treatments: Two types of irrigation (tap and magnetized water) under four NPK fertilizers levels (100, 75, 50 and 25% of the recommended rate), with 5 replicates of each treatment which arranged in a factorial experiment (2x4) of completely random design. As recommended by the Agric. Res. Center, Egypt, Nitrogen fertilizer was added at three equal portions; the 1st dose was applied after emergence (21 days from planting), in the form of ammonium sulphate (20.5 %), then two and four weeks later in the form of ammonium nitrate (33.5 %) at the rate of 180 Kg N/feddan. Phosphorous at rate of 75 kg P_2O_5/feddan was applied during the soil preparation in the form of calcium superphosphate (15.5% P_2O_5) and potassium sulphate (48 % K_2O) at rate of 80 kg K_2O/feddan was divided into two equal doses to be added during the soil preparation and the vegetative growth stage. The above fertilizers rates were added to the pots according to their surface areas. Irrigation with tap and magnetized water was done immediately. The water was passed through a magnetron, which is a magnetic tube (model U.T.I, 1-inch diameter, output 4–6 m^3/h) produced by Magnetic Technologies L.C.C., Russia, branch United Arab of Emirates. All usual cultural practices of potatoes cultivation were carried out according to the procedures recommended by the Ministry of Agric. Egypt. Harvesting was done after 115 days from planting dates in both seasons. One plant sample from each replicate was taken randomly after 90 days from sowing (14 weeks from sowing) at 8 am during the experimental period of both growing seasons.

Studied traits

Growth characters:

Plant height (cm), leaves number per plant, number of aerial stems per plant, dry weights of root, stem and leaves ($g.plant^{-1}$), the shoot /root ratio were recorded, leaf area ($cm^2.plant^{-1}$) was estimated using the disc method according to Bremner and Taha (1966), and leaf area index were calculated with the formula of Simone *et al.* (1993) (LAI= total leaf area, cm^2/ area of pot surface, cm^2).

Physiological characteristics:

Leaf water relations:

-Total water content (TWC, %), leaf water deficit (LWD, %), relative water content (RWC, %).

-Osmotic pressure values (Atm) were calculated using special tables according to the method described by Gosev (1960).

-The succulence degree (SD) was estimated according to the equation of Kreeb (1990): SD = Fresh weight/Dry weight.

-The transpiration rate (TR) (mg/cm2.h) was determined according to the equation of Kreeb (1990): TR = [(Fresh weight – Plant weight after 1 h)/Plant area in cm^2] * 1000.

-Membrane permeability (integrity): the absorption of the leakage of solutes across the cell membrane of tissues was determined at the ultraviolet wavelength 273 nm following the method of Leopold *et al.* (1981).

Chemical measurements:

Photosynthetic pigments were estimated according to Wettestein (1957) in fresh leaves extracted by acetone 80%, calculated as mg. g-1 dry weight.

Total carbohydrates:

Total carbohydrates in fine powder of dry shoot (previously prepared) were estimated using the phenol-sulphuric acid method described by Sadasivam and Manikam (1992).

Mineral elements: 0.2 g of dried ground leaves of the tested plants was digested in H2SO4 (concentrated) and H2O2 (5:1) for chemical analysis of nitrogen (N), phosphorus (P) and potassium (K) according to A.O.A.C. (1995).

The phenoloxidase and peroxidase activities were measured in the fresh leaves. Phenoloxidase activity was determined according the methods described by Broesh (1954). For peroxidase activity, the method of Fehrman and Dimond (1967) was used; enzyme activity was expressed as increase in optical density from 60-120 seconds after the substrate was added.

Data recorded at the harvest time:

Yield and its attributes (quantitative and qualitative): At the harvest time (115 days from sowing), a sample of five plants were chosen at random from each replicate of treatments to determine yield and its quality for the two growing seasons.

Fresh tuber yield was recorded in terms of number of tubers per plant, mean weight of tubers per plant, pots and expected total yield per feddan (Kg/fed) which was calculated according to the equation; total yield (kg/fed.) = (yield of experimental unit, kg x net area of feddan '4200 m^2') /area of experimental unit 'm^2'.

Tuber quality (dry matter, specific gravity, total protein and NPK percentage, starch and vitamin C (vit.C) content as well as total soluble solid percentage) was determined as indicated below.

Specific gravity was calculated according to Abdel-Aal (1971) as follows: Specific gravity (g/cm^3) = Tuber mass (g)/ tuber volume (cm^3);

Dry Matter (%) was determined by drying 100 g of grated tuber tissues at 105 ^{0}C till constant weight, and then DM (%) was calculated.

The NPK use efficiency: Nutrient use efficiency may be defined as yield per unit fertilizer input, or in terms of recovery of fertilizer applied.
It was calculated as kg tuber yield/kg NPK fertilizer applied.

Starch (%) was estimated using the following formula after Burton (1948): Starch%=17.546+199.07(Specific gravity-1.0988)

Total protein percentage was estimated by multiplying total nitrogen value with 6.25.

Vit.C content (mg Ascorbic acid.100 g^{-1}fwt. tuber) were estimated using the methods of A.O.A.C. (1995). Ascorbic acid was extracted from plant material (tuber) with oxalic acid then titrate using 2.6-Dichlorophenol indophenole as described by Sadasivam and Manickam (1992). Potato tuber samples were extracted with 80% cold ethanol (v/v) for three times at 0 C, then put it in water bath for 30 min. The combined extracts were collected and filtered through Whatman No 1 filter paper. Then the volume of sample was raised up to 10 ml with cold ethanol.

Total soluble solids (T.S.S.) was determined in potato juice by refractometer according to AOAC (1990).

For NPK determination, 0.2 g of tuber ground dry matter samples were used and the same methods mentioned before for NPK determination were applied.

Statistical analysis:

The obtained data were statistically analyzed using GLM procedure of SAS software, version 9.2 (SAS Institute, 2008) to conduct the analysis of variance. Differences between the treatments means as well as between the different interactions were tested using the orthogonal comparisons of Duncan's New Multiple Range at 0.05 significance level.

Results and Discussion

Growth characteristics

Table 2 shows vegetative growth characters of potato plants after irrigation by magnetic water under different levels of NPK fertilizers. The results show that growth decreased significantly ($P < 0.05$) as fertilizers levels decreased. The reduction in the dry weight of whole plant and leaf area (cm^2/plant) reached 38 and 36%, respectively at 25% level compared to the control. These results are in agreement with those obtained by Feleafel (2005) in potato plants. Also, Devi and Zaman (2012) reported that plant height, number of stems and leaves, total dry matter accumulation, crop growth rate of potato plants significantly increased at the recommended NPK rate. In this respect, it is known that N is an essential element in biosynthesis of amino acids, nucleic acids, protein and formation of protoplasm and new cells (Marschner, 1995). Marouani *et al*., (2015) and Li *et al*., (2016) stated that N deficiency reduced dry matter and leaf area and resulted in fewer leaflets that provides less light interception and a lower rate of photosynthesis. Also, P and K are essential macro-elements that play critical roles for physiological mechanisms of plant growth and different physiological processes in plant. Regarding the effect of magnetized water treatment, the obtained results indicate that potato plants irrigated with magnetic water recorded highly significant increases in all growth characters which reached about 41 and 24%, respectively in the whole plant dry weight and the leaf area (cm^2/plant) compared to the control. These results are in accordance with those obtained by El-Gizawy *et al.,* 2016 on Potato plants. There was an improvement in most growth characters after using magnetic water under all fertilizers levels, and the highest increase was at the 25% level by about 55% in the leaf area (cm^2/plant). Similar results were observed in the 2nd season (Table 3). The obtained results are in accordance with the findings by by Doklega (2017) in potato plants. The enhancement of growth due to magnetic treatments at the lowest levels of fertilization may be attributed to the physiochemical changes of natural water by weaking the hydrogen bonds between water molecules which leads to reduce surface tension, increase minerals dissolvability and providing adequate nutrients for plant growth, development of roots and shoots (Takashenko, 1995). Selim *et al.* (2009) recorded that the increased in growth may be attributed to the increment in absorption of essential elements, production of photosynthetase enzyme activities, gibberellic acid (GA_3), indole acetic acid (IAA) and cytokinin synthesis and reduced abscisic acid (ABA).

Water relations

Table 4 shows that as the NPK fertilizer level decreased, values of water relations in potato plants decreased significantly compared to the control group except the membrane permeability. Under 25% fertilizer level, the relative water content and osmotic pressure decreased by about 8 and 5%, respectively, in the 1st season. In contrast, compared to the control, irrigation with magnetic water resulted in a significant increase in values of water relations except the transpiration rate. Irrigation with magnetic water caused a marked increment in the relative water content, osmotic pressure and membrane permeability by about 11, 4 and 31%, respectively, compared to the control, under fertilizer level of 50% in the 1st season. The improvement of water relations was more pronounced under fertilizer level of 50%. Similar trend was observed in the 2nd season. These findings are in accordance with those of Abd El–Latif *et al.* (2015) in strawberry plants. The improvement in the water relations of potato plants could be attributed to the reduction of surface tension, viscosity increases permeability through the soil and creates greater water solubility (Takashenko, 1997 and Table, 4). Magnetic treatments increased the concentration of the total carbohydrates and the concentration of minerals (Table, 6) which led to alternation of the osmotic pressure and the membrane permeability to absorb water.

Chemical measurements

Photosynthetic pigments

The data of Table 5 reveal that the concentrations of photosynthetic pigments in potato plants were significantly decreased with reducing NPK fertilizers levels compared to the control. On the other hand, irrigating of the potato plants with magnetic water caused a marked increase in the photosynthetic pigments under all fertilizer levels. The concentration of chlorophyll a, chlorophyll b,

Table 2: Effect of magnetized water, NPK fertilizers levels and their interactions on some vegetative growth characters of potato plants at age of 90 days during the 1st growing season

Treatments / Characters: Magnetic Treatment	NPK Fertilizer levels	Plant height (cm)	Leaves No. per plant	No. of Arial stems /plant	Dry weight (g/plant) Root	Dry weight (g/plant) Stem	Dry weight (g/plant) Leaves	Dry weight (g/plant) whole	Shoot/ root ratio	Leaf area (cm²/plant)	Leaf area index
A. Effect of magnetized water											
Normal water		38.250^{a}	23.583^{a}	2.167^{a}	0.766^{b}	1.216^{b}	5.279^{b}	6.942^{b}	8.498^{a}	2486.488^{b}	3.959^{b}
Magnetic water		47.500^{a}	31.083^{a}	2.667^{a}	1.273^{a}	2.026^{a}	6.521^{a}	9.820^{a}	6.760^{b}	3071.509^{a}	4.891^{a}
B. Effect of NPK levels (% recommended rate)											
	100	50.334^{a}	31.667^{a}	2.500^{a}	1.074^{a}	2.206^{a}	7.268^{a}	10.548^{a}	9.942^{a}	3423.385^{a}	5.451^{a}
	75	50.834^{a}	29.500^{a}	2.500^{a}	1.081^{a}	1.660^{ab}	6.648^{a}	9.389^{b}	7.256^{b}	3131.365^{b}	4.986^{a}
	50	38.834^{b}	28.000^{a}	2.500^{a}	1.044^{a}	1.405^{b}	5.002^{b}	7.078^{c}	6.218^{c}	2355.785^{c}	3.751^{b}
	25	31.500^{b}	20.167^{a}	2.167^{a}	0.878^{a}	1.213^{b}	4.683^{b}	6.508^{c}	7.100^{b}	2205.458^{d}	3.512^{b}
C. **Effect of the interaction between Magnetized water and NPK levels**											
Normal water	**100**	46.667^{ab}	28.667^{ab}	2.667^{ab}	0.763^{a}	1.888^{ab}	7.002^{ab}	9.653^{b}	11.646^{a}	3297.785^{b}	5.251^{ab}
	75	49.667^{a}	24.667^{ab}	2.000^{ab}	1.023^{a}	1.475^{abc}	6.458^{abc}	8.957^{b}	7.752^{bc}	3041.875^{d}	4.844^{ab}
	50	33.000^{bc}	26.000^{ab}	2.333^{ab}	0.747^{a}	0.878^{bc}	3.980^{d}	4.858^{c}	6.507^{d}	1874.580^{g}	2.985^{c}
	25	23.667^{c}	15.000^{b}	1.667^{b}	0.532^{a}	0.622^{c}	3.677^{d}	4.298^{c}	8.085^{b}	1731.710^{h}	2.758^{c}
Magnetic water	**100**	54.000^{a}	34.667^{a}	2.333^{ab}	1.385^{a}	2.523^{a}	7.535^{a}	11.443^{a}	8.238^{b}	3548.985^{a}	5.651^{a}
	75	52.000^{a}	34.333^{a}	3.000^{a}	1.139^{a}	1.845^{ab}	6.838^{ab}	9.822^{b}	6.759^{cd}	3220.855^{c}	5.129^{ab}
	50	44.667^{ab}	30.000^{ab}	2.667^{ab}	1.342^{a}	1.932^{ab}	6.023^{bc}	9.297^{b}	5.929^{d}	2836.990^{e}	4.518^{ab}
	25	39.333^{abc}	25.333^{ab}	2.667^{ab}	1.225^{a}	1.803^{ab}	5.688^{c}	8.717^{b}	6.116^{d}	2679.205^{f}	4.266^{b}

* Means superscripted by different letters within each main factor and the interactions are significantly different, α=0.05.

Table 3: Effect of magnetized water, NPK fertilizers levels and their interactions on some vegetative growth characters of potato plants at age of 90 days during the 2nd growing season

Magnetic Treatment	NPK Fertilizer levels	Plant height (cm)	Leaves No. per plant	No. of Arial stems / plant	Dry weight (g/plant) Root	Stem	Leaves	whole	Shoot/ root ratio	Leaf area (cm^2/plant)	Leaf area index
A. Effect of magnetized water											
Normal water		37.833^{b}	20.792^{b}	2.667^{b}	0.878^{a}	1.401^{b}	4.681^{b}	6.960^{b}	7.569^{a}	2204.869^{b}	3.511^{b}
Magnetic water		50.833^{a}	28.667^{a}	3.250^{a}	1.348^{a}	2.209^{a}	6.138^{a}	9.696^{a}	6.392^{b}	2890.959^{a}	4.603^{a}
B. Effect of NPK levels (% recommended rate)											
	100	50.333^{b}	30.667^{a}	3.333^{a}	1.590^{a}	2.393^{a}	6.658^{a}	10.641^{a}	5.851^{c}	3135.683^{b}	4.993^{a}
	75	52.500^{a}	26.667^{b}	2.500^{b}	1.461^{a}	2.400^{a}	6.721^{a}	10.582^{a}	6.179^{c}	3165.513^{a}	5.041^{a}
	50	41.833^{c}	23.167^{c}	3.167^{ab}	0.714^{b}	1.277^{b}	4.445^{b}	6.436^{b}	8.334^{a}	2093.595^{c}	3.334^{b}
	25	32.667^{d}	18.417^{d}	2.833^{ab}	0.688^{b}	1.149^{b}	3.815^{b}	5.652^{c}	7.557^{b}	1796.865^{d}	2.861^{b}
C. Effect of the interaction between Magnetized water and NPK levels											
Normal water	**100**	46.667^{d}	29.333^{bc}	3.333^{a}	1.442^{ab}	2.232^{a}	6.313^{ab}	9.987^{b}	5.927^{de}	2973.580^{d}	4.735^{ab}
	75	49.667^{c}	23.333^{d}	2.000^{b}	1.255^{ab}	2.178^{a}	6.418^{ab}	9.852^{b}	6.850^{cd}	3023.035^{c}	4.814^{ab}
	50	33.000^{f}	18.000^{e}	3.000^{ab}	0.463^{b}	0.751^{b}	3.535^{d}	4.750^{d}	9.251^{a}	1664.985^{g}	2.651^{c}
	25	22.000^{g}	12.500^{f}	2.333^{ab}	0.352^{b}	0.442^{b}	2.458^{e}	3.252^{e}	8.246^{ab}	1157.875^{h}	1.844^{c}
Magnetic water	**100**	54.000^{b}	32.000^{a}	3.333^{a}	1.739^{a}	2.555^{a}	7.002^{a}	11.295^{a}	5.774^{de}	3297.785^{b}	5.251^{a}
	75	55.333^{a}	30.000^{b}	3.000^{ab}	1.667^{a}	2.622^{a}	7.023^{a}	11.312^{a}	5.509^{e}	3307.990^{a}	5.268^{a}
	50	50.667^{c}	28.333^{c}	3.333^{a}	0.965^{ab}	1.803^{a}	5.355^{bc}	8.123^{b}	7.418^{bc}	2522.205^{e}	4.016^{b}
	25	43.333^{e}	24.333^{d}	3.333^{a}	1.023^{ab}	1.857^{a}	5.172^{c}	8.052^{b}	6.868^{cd}	2435.855^{f}	3.879^{b}

* Means superscripted by different letters within each main factor and the interactions are significantly different, α=0.05.

Table 4: Effect of magnetic water, NPK fertilizers levels and their interactions on water relations in leaves of potatoes plants at age of 90 days during the 1st and 2nd growing seasons

Treatments / Characters		1st season							2nd season						
Magnetic Treatment	**NPK Fertilizer levels**	**Total Water Content (%)**	**Leaf water def. (%)**	**Rel. water Content (%)**	**Osmotic Pressure C.S. (bar)**	**sclerophylly degree (%)**	**Transpiration rate mg $H_2O.cm^{-2}h^{-1}$**	**Membrane permeability (%)**	**Total Water Content (%)**	**Leaf water def. (%)**	**Rel. water Content (%)**	**Osmotic Pressure C.S. (bar)**	**sclerophylly degree (%)**	**Transpiration rate mg $H_2O.cm^{-2}h^{-1}$**	**Membrane permeability (%)**
A. Effect of magnetized water															
Normal water		71.306^{b}	23.917^{a}	76.083^{b}	4.885^{a}	5.869^{b}	0.201^{a}	14.173^{b}	71.856^{b}	30.899^{a}	69.101^{b}	5.084^{a}	4.318^{b}	0.191^{a}	14.042^{b}
Magnetic water		75.492^{a}	16.746^{b}	83.254^{a}	5.731^{a}	8.941^{a}	0.133^{b}	15.875^{a}	79.703^{a}	21.944^{b}	78.056^{a}	6.013^{a}	8.436^{a}	0.144^{a}	16.125^{a}
B. Effect of NPK levels (% recommended rate)															
	100	76.814^{a}	17.878^{c}	82.122^{a}	5.602^{a}	8.735^{a}	0.198^{a}	13.268^{b}	74.489^{b}	22.701^{b}	77.299^{a}	5.816^{a}	6.932^{a}	0.212^{a}	14.017^{b}
	75	75.793^{ab}	18.402^{bc}	81.598^{ab}	5.428^{a}	7.660^{ab}	0.163^{a}	17.802^{a}	75.348^{b}	24.980^{b}	75.020^{a}	6.300^{a}	6.638^{a}	0.167^{a}	17.013^{a}
	50	73.527^{b}	20.410^{b}	79.590^{b}	4.906^{a}	7.375^{ab}	0.163^{a}	14.730^{b}	78.442^{a}	28.041^{a}	71.959^{b}	4.924^{a}	6.653^{a}	0.152^{a}	14.403^{b}
	25	67.462^{c}	24.638^{a}	75.362^{c}	5.297^{a}	5.850^{b}	0.145^{a}	14.296^{b}	74.840^{b}	29.964^{a}	70.036^{b}	5.155^{a}	5.285^{a}	0.141^{a}	14.901^{ab}
C. Effect of the interaction between Magnetized water and NPK levels															
Normal water	**100**	78.163^{ab}	20.824^{c}	79.176^{c}	5.170^{a}	7.486^{ab}	0.229^{a}	11.683^{d}	67.232^{d}	26.194^{b}	73.806^{b}	5.170^{a}	4.356^{bc}	0.230^{a}	12.477^{c}
	75	76.096^{b}	20.454^{c}	79.546^{c}	4.819^{a}	5.279^{bc}	0.205^{ab}	19.383^{a}	72.135^{c}	28.707^{b}	71.293^{b}	5.923^{a}	5.496^{bc}	0.191^{a}	18.194^{a}
	50	66.640^{d}	24.447^{b}	75.553^{d}	4.819^{a}	7.675^{ab}	0.186^{ab}	12.744^{cd}	75.411^{bc}	29.444^{b}	70.556^{b}	4.923^{a}	3.970^{c}	0.181^{a}	12.362^{c}
	25	64.326^{d}	29.945^{a}	70.055^{e}	4.733^{a}	3.036^{c}	0.186^{ab}	12.880^{cd}	72.648^{c}	39.252^{a}	60.748^{c}	4.319^{a}	3.450^{c}	0.162^{a}	13.133^{bc}
Magnetic water	**100**	75.466^{b}	14.931^{e}	85.069^{a}	6.035^{a}	9.984^{a}	0.168^{ab}	14.853^{bcd}	81.746^{a}	19.208^{c}	80.792^{a}	6.462^{a}	9.508^{a}	0.193^{a}	15.556^{abc}
	75	75.491^{b}	16.349^{de}	83.651^{ab}	6.036^{a}	10.040^{a}	0.122^{ab}	16.221^{abc}	78.561^{ab}	21.254^{c}	78.746^{a}	6.676^{a}	7.780^{ab}	0.142^{a}	15.831^{abc}
	50	80.414^{a}	16.374^{e}	83.626^{ab}	4.992^{a}	7.074^{ab}	0.139^{ab}	16.715^{ab}	81.473^{a}	26.637^{b}	73.363^{b}	4.924^{a}	9.336^{a}	0.123^{a}	16.445^{ab}
	25	70.597^{c}	19.331^{cd}	80.669^{bc}	5.860^{a}	8.665^{ab}	0.104^{b}	15.712^{bc}	77.032^{b}	20.676^{c}	79.324^{a}	5.991^{a}	7.121^{abc}	0.119^{a}	16.668^{ab}

* Means superscripted by different letters within each main factor and the interactions are significantly different, α=0.05.

Table 5: Effect of magnetic water, NPK fertilizers levels and their interactions on the concentrations and the ratios of the photosynthetic pigments in leaves of potato plants during the growing seasons

Treatments / Characters		1st season						2nd season					
		Chlorophyll a	Chlorophyll b	Total Chlorophyll a+b	Carotenoids	Chlorophyll a/b ratio	Total Chlorophyll / Carotenoids ratio	Chlorophyll a	Chlorophyll b	Total Chlorophyll a+b	Carotenoids	Chlorophyll a/b ratio	Total Chlorophyll / Carotenoids ratio
Magnetic Treatment	*NPK Fertilizerlevels*	mg/g DW						mg/g DW					
A. Effect of magnetized water													
Normal water		5.214^{b}	3.514^{a}	8.728^{b}	3.727^{b}	1.973^{a}	2.241^{a}	4.997^{b}	3.404^{b}	8.401^{b}	3.774^{a}	1.649^{a}	2.193^{a}
Mag. water		7.850^{a}	5.187^{a}	13.038^{a}	5.281^{a}	1.826^{a}	2.476^{a}	6.988^{a}	4.135^{a}	11.124^{a}	4.194^{a}	1.666^{a}	2.662^{a}
B. Effect of NPK levels (% recommended rate)													
	100	9.445^{a}	6.382^{a}	15.826^{a}	6.397^{a}	1.618^{a}	2.476^{a}	8.669^{a}	5.573^{a}	14.242^{a}	5.594^{a}	1.554^{a}	2.543^{a}
	75	7.775^{b}	5.186^{b}	12.961^{b}	5.813^{a}	1.764^{a}	2.214^{a}	8.103^{a}	4.406^{b}	12.509^{b}	4.519^{b}	1.864^{a}	2.788^{a}
	50	5.947^{c}	3.859^{c}	9.805^{c}	3.796^{b}	2.254^{a}	2.477^{a}	4.257^{b}	3.116^{c}	7.373^{c}	3.825^{b}	1.361^{a}	2.104^{a}
	25	2.962^{d}	1.977^{d}	4.938^{d}	2.010^{c}	1.961^{a}	2.268^{a}	2.942^{c}	1.983^{d}	4.925^{d}	1.998^{c}	1.851^{a}	2.275^{a}
C. Effect of the interaction between Magnetized water and NPK levels													
Normal water	**100**	8.000^{b}	5.821^{b}	13.821^{b}	5.732^{bc}	1.369^{a}	2.401^{a}	7.553^{b}	5.547^{a}	13.099^{b}	5.492^{a}	1.362^{a}	2.385^{ab}
	75	6.805^{c}	4.953^{b}	11.758^{c}	4.971^{cd}	1.377^{a}	2.388^{a}	7.793^{b}	4.838^{ab}	12.631^{b}	4.158^{bc}	1.611^{a}	3.038^{a}
	50	5.035^{d}	2.873^{c}	7.909^{d}	3.474^{e}	2.611^{a}	2.217^{a}	3.668^{d}	2.808^{c}	6.477^{d}	4.741^{ab}	1.306^{a}	1.366^{b}
	25	1.015^{e}	0.408^{d}	1.423^{e}	0.729^{f}	2.534^{a}	1.960^{a}	0.976^{e}	0.421^{d}	1.397^{e}	0.705^{e}	2.317^{a}	1.981^{ab}
Magnetic water	**100**	10.890^{a}	6.942^{a}	17.832^{a}	7.061^{a}	1.867^{a}	2.550^{a}	9.785^{a}	5.600^{a}	15.385^{a}	5.696^{a}	1.747^{a}	2.701^{a}
	75	8.746^{b}	5.418^{b}	14.164^{b}	6.655^{ab}	2.151^{a}	2.041^{a}	8.413^{b}	3.973^{bc}	12.387^{b}	4.881^{ab}	2.118^{a}	2.538^{ab}
	50	6.858^{c}	4.844^{b}	11.702^{c}	4.117^{de}	1.897^{a}	2.737^{a}	4.846^{c}	3.423^{c}	8.270^{c}	2.910^{d}	1.416^{a}	2.842^{a}
	25	4.908^{d}	3.545^{c}	8.454^{d}	3.291^{e}	1.387^{a}	2.576^{a}	4.908^{c}	3.545^{c}	8.454^{c}	3.291^{cd}	1.384^{a}	2.568^{ab}

* Means superscripted by different letters within each main factor and the interactions are significantly different, $\alpha=0.05$.

total chlorophyll (a+b) and carotenoids increased by about 36, 69, 48 and 19%, respectively, compared to the control, under 50% fertilizer level. Similar results were found in the 2nd season. The previous mentioned results are in accordance with those reported by Abd El–Latif *et al.* (2015) in strawberry plants, used magnetized water plus of 50% NPK and 75% NPK increased significantly total chlorophyll as compared with control. Increasing photosynthetic pigments resulted from the application of the magnetic treatments may be attributed to the increase in gibberellic acid content in plants (Selim *et al.,* 2009), the enhancing of absorption of the essential elements specially the iron (Fe^{++}), magnesium (Mg^{++}), potassium (K^+) and nitrogen (NH_4^+) cations due to dissolvability, that necessary for enzymes activation and formation of both chloroplasts and chlorophyll (Takashenko, 1995; Selim *et al.,* 2019).

Total carbohydrates

The decrease in NPK fertilizers levels resulted in a reduction in the total carbohydrates in leaves of potato plants (Table 6). However, with magnetic water irrigation, the total carbohydrates increased. A significant increase by about 12 % was observed under 50% fertilizer level by using magnetic water compared to the control. The same trend was noticed at the 2nd season (Table 7). These results agreed with those obtained on strawberry plants by Abd El–Latif *et al.* (2015), who found that irrigation with magnetized water plus 50% NPK of the recommended fertilization rate showed the highest values of total carbohydrates as compared with control. Magnetic field contributes to the increase in the rate of photosynthesis which led to increase the synthesized carbohydrates which increase the plant biomass (De Souza *et al.,* 2005).

Mineral concentrations and uptakes

As shown in Table 6, as the NPK fertilizers levels decreased, the concentration and uptake of the elements N, P and K in potato plants decreased significantly compared to the control. The concentration of the elements N, P and K under 25% fertilizer level decreased by about 26, 34 and 28%, respectively, also the decreases in the uptakes of these elements by about 50, 55 and 52%, respectively compared to the control. Similar results were obtained with Feleafel (2005) in potato plants. Conversely, irrigating the potato plants with magnetic water resulted in a marked increase in the concentration and uptakes of all minerals under all fertilizers levels. Under 50% fertilizer level, the concentration of N, P and K increased by about 16, 59 and 15%, respectively, also the increments in the uptakes of these elements reached 75, 141 and 75%, respectively compared to the control plants. The same trend was observed in both seasons (Table 7). These results are in accordance with those of by Doklega (2017) in potato plants. In this concern, Estiken and Turan (2004) reported that, magnetic water decreased pH values of soil layers, dissolving slightly soluble components which led to increase the nutrient mobility and enhancement the uptake of N, P, K and Fe by plants and therefore increase the efficiency of added fertilizers.

Enzymes activity (Phenoloxidase and peroxidase)

The decrease in NPK fertilizers levels resulted in a reduction in the Enzymes activity of phenoloxidase and peroxidase in leaves of potato plants (Table 6). However, with magnetic water irrigation, the activity of phenoloxidase and peroxidase enzymes increased. Similar results were obtained on pepper plants by Selim *et al.* (2009). Under 50% fertilizer level and using magnetic water, the activity of phenoloxidase and peroxidase enzymes increased by about 19 and 40%, respectively compared to the control. The same trend was observed in the two seasons (Table 7).

Yield components

The yield quantity and quality of potato plant using different levels of NPK fertilizers and magnetic water treatments are shown in Table 8 and 9.

Potato yield quantity

As shown in (Table 8), the tuber yield/feddan (Kg) of potato plant was decreased with decreasing fertilizers levels (about 18% at 75% NPK level and 74% at 25% NPK level). These results were in agreement with those of Imamsaheb *et al.* (2011), who found that, total yield tomato plants were gradually increased with increasing NPK fertilizer level. Phosphorus enhances formation of

Table 6: Effect of magnetic water, NPK fertilizers levels and their interactions on some chemical constituents and enzymes activity in leaves of potato plants at age of 90 days during the 1st season

Treatments / Characters		Total Carbohydrates (mg/g DWt.)	Mineral Nutrients						Enzymes activity	
			N		P		K		Phenol-oxidase	Peroxidase
			conc. %	Uptake mg/plant	conc. %	uptake mg/plant	conc. %	uptake mg/plant	O.D./g FW.	
Magnetic Treatment	**NPK Fertilizer levels**									
A. Effect of magnetized water										
Normal water		141.41^{a}	1.42^{b}	77.87^{b}	0.25^{a}	14.11^{b}	1.60^{b}	88.29^{b}	0.69^{a}	0.88^{b}
Magnetic water		156.36^{a}	1.72^{a}	113.10^{a}	0.35^{a}	23.08^{a}	1.88^{a}	123.11^{a}	0.81^{a}	1.11^{a}
B. Effect of NPK levels (% recommended rate)										
	100	171.27^{a}	1.74^{a}	126.44^{a}	0.35^{a}	25.17^{a}	1.93^{a}	140.41^{a}	0.94^{a}	1.15^{a}
	75	159.09^{ab}	1.75^{a}	116.21^{b}	0.35^{a}	23.02^{b}	1.90^{a}	126.51^{b}	0.83^{ab}	1.17^{a}
	50	142.58^{bc}	1.51^{ab}	76.65^{c}	0.29^{a}	14.92^{c}	1.75^{a}	88.56^{c}	0.69^{ab}	0.96^{ab}
	25	122.61^{c}	1.28^{b}	62.65^{d}	0.23^{a}	11.27^{d}	1.38^{b}	67.33^{d}	0.54^{b}	0.70^{b}
C. Effect of the interaction between Magnetized water and NPK levels										
Normal water	**100**	163.38^{ab}	1.61^{ab}	112.73^{c}	0.31^{a}	21.71^{c}	1.88^{a}	131.63^{c}	0.91^{a}	1.05^{ab}
	75	157.13^{ab}	1.64^{ab}	105.92^{d}	0.30^{a}	19.38^{e}	1.80^{a}	116.25^{d}	0.78^{ab}	1.10^{ab}
	50	134.75^{bc}	1.40^{b}	55.72^{g}	0.22^{a}	8.76^{g}	1.62^{a}	64.48^{g}	0.63^{ab}	0.80^{bc}
	25	110.38^{c}	1.01^{c}	37.13^{h}	0.18^{a}	6.62^{h}	1.11^{b}	40.81^{h}	0.42^{b}	0.55^{c}
Magnetic water	**100**	179.16^{a}	1.86^{a}	140.15^{a}	0.38^{a}	28.63^{a}	1.98^{a}	149.19^{a}	0.97^{a}	1.24^{a}
	75	161.05^{ab}	1.85^{a}	126.51^{b}	0.39^{a}	26.67^{b}	2.00^{a}	136.77^{b}	0.87^{a}	1.23^{a}
	50	150.40^{ab}	1.62^{ab}	97.58^{e}	0.35^{a}	21.08^{c}	1.87^{a}	112.64^{e}	0.75^{ab}	1.12^{ab}
	25	134.84^{bc}	1.55^{ab}	88.17^{f}	0.28^{a}	15.93^{f}	1.65^{a}	93.86^{f}	0.66^{ab}	0.85^{abc}

* Means superscripted by different letters within each main factor and the interactions are significantly different, $\alpha=0.05$.

Table 7: Effect of magnetic water, NPK fertilizers levels and their interactions on some chemical constituents and enzymes activity in leaves of potato plants at age of 90 days during the 2nd season

Treatments / Characters		Total Carbohydrates (mg/g DWt.)	Mineral Nutrients						Enzymes activity	
			N		P		K		Phenol-oxidase	Peroxidase
			conc. %	Uptake mg/plant	conc. %	uptake mg/plant	conc. %	uptake mg/plant	O.D./g FW.	
Magnetic Treatment	**NPK Fertilizer levels**									
A. Effect of magnetized water										
Normal water		129.53[b]	1.45[b]	70.53[b]	0.23[a]	11.68[b]	1.60[a]	78.57[b]	0.46[b]	0.64[b]
Magnetic water		163.86[a]	1.78[a]	110.28[a]	0.33[a]	20.75[a]	1.98[b]	122.82[a]	0.67[a]	1.03[a]
B. Effect of NPK levels (% recommended rate)										
	100	173.47[a]	1.79[a]	119.75[a]	0.31[a]	20.78[b]	1.91[a]	127.50[a]	0.67[a]	1.01[a]
	75	158.05[b]	1.72[a]	115.67[a]	0.35[a]	23.32[a]	2.02[a]	136.08[a]	0.65[a]	0.98[a]
	50	134.29[c]	1.59[ab]	72.41[b]	0.26[a]	11.93[c]	1.74[ab]	79.35[b]	0.49[a]	0.76[ab]
	25	120.95[d]	1.36[b]	53.78[b]	0.21[a]	8.83[d]	1.49[b]	59.84[b]	0.46[a]	0.58[b]
C. Effect of the interaction between Magnetized water and NPK levels										
Normal water	**100**	157.18[c]	1.62[abc]	102.28[ab]	0.27[a]	17.05[d]	1.81[bc]	114.27[abc]	0.55[ab]	0.89[abc]
	75	134.88[e]	1.58[abc]	101.41[ab]	0.30[a]	19.26[c]	1.80[bc]	115.53[abc]	0.53[ab]	0.76[bcd]
	50	118.50[g]	1.37[c]	48.43[dc]	0.19[a]	6.72[f]	1.52[cd]	53.73[de]	0.44[ab]	0.51[cd]
	25	107.54[h]	1.22[c]	29.99[d]	0.15[a]	3.69[g]	1.25[d]	30.73[e]	0.32[b]	0.38[d]
Magnetic water	**100**	189.76[a]	1.96[a]	137.23[a]	0.35[a]	24.51[b]	2.01[ab]	140.73[ab]	0.79[a]	1.12[ab]
	75	181.22[b]	1.85[ab]	129.93[a]	0.39[a]	27.39[a]	2.23[a]	156.62[a]	0.76[a]	1.20[a]
	50	150.08[d]	1.80[ab]	96.39[ab]	0.32[a]	17.14[d]	1.96[ab]	104.96[bc]	0.54[ab]	1.00[ab]
	25	134.36[f]	1.50[bc]	77.58[bc]	0.27[a]	13.96[e]	1.72[bc]	88.95[cd]	0.60[ab]	0.78[abcd]

* Means superscripted by different letters within each main factor and the interactions are significantly different, α=0.05.

tubers and starch synthesis (Perrenoud, 1993). Potassium is necessary for translocation of sugars to the tubers and starch synthesis, essential processes in the tuber growth and filling (Reis and Monnerat, 2000). While, potato plants irrigated with magnetic water recorded highly significant increases in tuber yield/feddan (Kg) under all fertilizers levels which reached about 114 and 146%, respectively at 50 and 25% levels, respectively compared to the control. Similar trend was observed in the 2nd season (Table 9). These findings are in agreement with those of Neshev and Manolov (2016) in potato plants, who found that, the yield of variant NPK was 25 % higher than the yield from variant NP and 68 % higher than control.

Potato yield quality

Table 8 shows that as the NPK fertilizer level decreased, the values of chemical contents (Starch (%), Total Protein (%), Vitamin C mg/100 g fresh weight and NPK minerals content) in potato tuber decreased significantly compared to the control. Under 25% fertilizer level, the percentage of starch, total protein, N, P and K content decreased by about 36, 28, 28, 34 and 32%, respectively. These findings are in agreement with those of Feleafel (2005) in potato plants. On the other hand, using magnetic water caused a marked increase in the values of chemical contents in the potato tuber under all fertilizer levels. The content of starch, total protein, vitamin C, N, P and K increased by about 61, 11, 27, 11, 34 and 22%, respectively, compared to the control, under 50% fertilizer level. Similar results were found in the 2nd season (Table 9). Similar results were obtained with Abd El–Latif *et al.* (2015), who reported that, using 50 % of the recommended NPK fertilization rates plus magnetized water resulted in enhancing yield and quality of strawberry plants. These results may be attributed to that the application of magnetic treatments can affect plant growth as follow; firstly, magnetic field enhanced the activation of the enzymes (Tables, 6 and 7) and increasing IAA, cytokinins and GA_3 syntheses and decreased the synthesis of ABA as indicated in Selim *et al.* (2009). Secondly, the membranes become more permeability which increase the absorption of elements and water as shown in (Table, 4) (Eşitken and Turan, 2004). Thirdly, an energetic excitement of one or more parameters of the cellular substratum (proteins and carbohydrates) (Table, 6) or water inside the dry seeds, changes the natural water properties and improves the moisture supply of plant (Rokhinson and Baskin, 1996) which led to avoid the use of a big amount of mineral fertilizers and enhance yield.

NPK use efficiency

The data recorded in Table 8 indicate that irrigation the potato plants with magnetic water caused a significant increase in the NPK fertilizer use efficiency for potato tuber yield by about 91% compared to the control. The interaction between magnetic technique and NPK fertilizer in different doses showed marked increase in NPK use efficiency for potato tuber yield. NPK use efficiency for potato irrigated with magnetizes water and supplemented by 50 and 25% NPK fertilizer levels increased by about 98 and 203%, respectively, compared to their corresponding controls. Similar results were found in the 2nd season. This indicates that the magnetized treated water played an important role in enhancing the efficiency of potato plants to use the mineral fertilizers at lower rates which led to saving considerable amounts of mineral fertilizer and reducing the production cost, as well as reducing the environmental pollution. This may be due to that the magnetic water significantly increased the tuber potato yield at the lower rates of NPK fertilizers as show in Table 8.

Conclusion

It could be concluded that irrigation with magnetized water improved the growth, physiological and biochemical behavior, NPK use efficiency in potato plant, gave higher potato tuber yield and minimized the NPK fertilizers rates recommended for potato plants cv. Diamant by more than 25%.

Table 8: Effect of magnetic water, NPK fertilizers levels and their interactions on potato yield quantity and quality in the 1st growing season

Magnetic Treatment	NPK Fertilizer levels	Tuber No./ plant	Mean Tuber weight (g)	Dry weight (%)	Specific gravity (g/cm³)	Tuber Yield: Plant (g)	Tuber Yield: Pots (g)	Tuber Yield: Feddan (Kg)	NPK Fertilizer Use Efficiency (kg potato yield/Kg Fert.): N	P	K	NPK	Chemical constituents of tuber: Starch (%)	Total Protein (%)	Vit. C Mg/100 g Fresh weight	Total soluble solids (%)	NPK minerals content: N (%)	P (%)	K (%)
A. Effect of magnetized water																			
Normal water		3.92^{b}	14.23^{b}	16.50^{a}	1.07^{a}	58.93^{b}	117.87^{b}	7006.84^{b}	70.12^{b}	140.24^{b}	131.48^{b}	34.49^{b}	11.81^{b}	8.44^{b}	57.15^{b}	6.20^{b}	1.35^{a}	0.31^{a}	1.59^{b}
Magnetic water		5.42^{a}	16.80^{a}	20.09^{b}	1.10^{a}	94.98^{a}	189.95^{a}	11292.34^{a}	124.63^{a}	249.26^{a}	233.68^{a}	61.29^{a}	16.79^{a}	10.75^{a}	79.62^{a}	7.54^{a}	1.72^{a}	0.41^{a}	2.12^{a}
B. Effect of NPK levels (% recommended rate)																			
	100	6.67^{a}	18.22^{a}	19.25^{b}	1.10^{a}	121.45^{a}	242.90^{a}	14439.72^{a}	96.267^{c}	192.53^{c}	180.50^{c}	47.34^{c}	16.79^{a}	10.88^{a}	76.38^{a}	7.29^{a}	1.74^{a}	0.41^{a}	1.98^{a}
	75	5.33^{b}	18.56^{a}	20.56^{a}	1.10^{a}	99.37^{b}	198.73^{b}	11814.30^{b}	105.02^{a}	210.03^{a}	196.91^{a}	51.65^{a}	16.79^{a}	10.47^{a}	74.85^{b}	7.36^{a}	1.68^{a}	0.41^{a}	2.23^{a}
	50	3.83^{c}	14.14^{b}	17.26^{c}	1.08^{a}	55.28^{c}	110.55^{c}	6572.17^{c}	87.63^{d}	175.26^{d}	164.31^{d}	43.10^{d}	12.81^{b}	9.22^{b}	63.15^{c}	6.74^{a}	1.48^{a}	0.34^{a}	1.89^{ab}
	25	2.83^{d}	11.14^{c}	16.11^{d}	1.07^{a}	31.73^{d}	63.45^{d}	3772.17^{d}	100.59^{b}	201.18^{b}	188.61^{b}	49.47^{b}	10.82^{c}	7.81^{c}	59.15^{d}	6.11^{b}	1.25^{a}	0.27^{a}	1.33^{b}
C. Effect of the interaction between Magnetized water and NPK levels																			
Normal water	**100**	6.67^{a}	14.77^{cd}	18.15^{d}	1.08^{a}	98.46^{c}	196.91^{c}	11706.10^{c}	78.04^{f}	156.08^{f}	146.33^{f}	38.38^{f}	13.80^{d}	9.69^{b}	61.88^{e}	6.74^{cd}	1.55^{ab}	0.38^{a}	1.81^{ab}
	75	4.67^{bc}	17.94^{abc}	19.45^{bc}	1.09^{a}	83.72^{d}	167.45^{d}	9954.37^{d}	88.48^{e}	176.97^{e}	165.91^{e}	43.52^{e}	15.79^{c}	9.38^{bc}	61.92^{e}	6.80^{cd}	1.50^{ab}	0.37^{a}	1.85^{ab}
	50	2.67^{d}	13.21^{d}	14.85^{e}	1.06^{a}	35.22^{g}	70.43^{g}	4187.12^{g}	55.83^{h}	111.66^{h}	104.68^{h}	27.46^{h}	9.82^{e}	8.75^{c}	55.74^{f}	6.02^{de}	1.40^{ab}	0.29^{a}	1.70^{ab}
	25	1.67^{e}	11.00^{d}	13.55^{f}	1.05^{a}	18.33^{h}	36.67^{h}	2179.76^{h}	58.13^{g}	116.25^{g}	108.99^{g}	28.59^{g}	7.83^{f}	5.94^{d}	49.04^{g}	5.25^{e}	0.95^{b}	0.20^{a}	1.00^{b}
Magnetic water	**100**	6.67^{a}	21.67^{a}	20.34^{b}	1.11^{a}	144.44^{a}	288.88^{a}	17173.33^{a}	114.49^{d}	228.98^{d}	214.67^{d}	56.31^{d}	19.78^{a}	12.06^{a}	90.88^{a}	7.83^{ab}	1.93^{a}	0.44^{a}	2.15^{a}
	75	6.00^{a}	19.17^{ab}	21.67^{a}	1.10^{a}	115.01^{b}	230.02^{b}	13674.23^{b}	121.55^{b}	243.10^{b}	227.90^{b}	59.78^{b}	17.78^{b}	11.56^{a}	87.78^{b}	7.92^{a}	1.85^{ab}	0.45^{a}	2.60^{a}
	50	5.00^{b}	15.07^{bcd}	19.67^{b}	1.09^{a}	75.34^{e}	150.67^{e}	8957.23^{e}	119.43^{c}	238.86^{c}	223.93^{c}	58.74^{c}	15.79^{c}	9.69^{b}	70.55^{c}	7.45^{abc}	1.55^{ab}	0.39^{a}	2.07^{a}
	25	4.00^{c}	11.28^{d}	18.67^{cd}	1.08^{a}	45.12^{f}	90.240^{f}	5364.59^{f}	143.06^{a}	286.11^{a}	268.23^{a}	70.36^{a}	13.80^{d}	9.69^{b}	69.25^{d}	6.97^{bc}	1.55^{ab}	0.34^{a}	1.66^{ab}

* Means superscripted by different letters within each main factor and the interactions are significantly different, α=0.05.

Table 9: Effect of magnetic water, NPK fertilizers levels and their interactions on potato yield quantity and quality in the 2nd growing season

Treatments: Magnetic Treatment	NPK Fertilizer levels	Tuber No./ plant	Mean Tuber weight (g)	Dry weight (%)	Specific gravity (g/cm^3)	Tuber Yield: Plant (g)	Tuber Yield: Pots (g)	Tuber Yield: Feddan (Kg)	NPK Fertilizer Use Efficiency (kg potato yield/Kg Fert.): N	P	K	NPK	Chemical constituents of tuber: Starch (%)	Total Protein (%	Vit. C Mg/100 g Fresh	Total soluble solids (%)	NPK minerals content: N (%)	P (%)	K (%)
A. Effect of magnetized water																			
Normal water		4.33^{b}	13.25^{b}	14.82^{b}	1.07^{a}	59.45^{b}	118.89^{b}	7067.97^{b}	76.36^{b}	152.73^{b}	143.18^{b}	37.56^{b}	10.82^{b}	7.95^{b}	53.74^{b}	4.89^{b}	1.27^{b}	0.30^{a}	1.51^{b}
Magnetic water		6.75^{a}	14.21^{a}	18.26^{a}	1.09^{a}	96.05^{a}	192.09^{a}	11419.46^{a}	146.06^{a}	292.13^{a}	273.87^{a}	71.83^{a}	15.30^{a}	11.17^{a}	75.43^{a}	6.61^{a}	1.79^{a}	0.42^{a}	2.09^{a}
B. Effect of NPK levels (% recommended rate)																			
	100	6.50^{a}	15.97^{a}	17.96^{a}	1.09^{a}	101.40^{a}	202.79^{a}	12055.65^{a}	80.37^{d}	160.74^{d}	150.70^{d}	39.53^{d}	14.80^{b}	10.78^{a}	72.32^{a}	6.06^{a}	1.73^{a}	0.42^{a}	2.05^{a}
	75	6.17^{a}	14.57^{b}	17.65^{a}	1.09^{a}	90.11^{b}	180.22^{b}	10713.52^{b}	95.23^{c}	190.46^{c}	178.56^{c}	46.84^{c}	15.79^{a}	10.78^{a}	70.71^{b}	6.38^{a}	1.73^{a}	0.41^{a}	2.00^{ab}
	50	5.33^{b}	12.69^{c}	15.51^{b}	1.07^{a}	69.11^{c}	138.23^{c}	8217.30^{c}	109.56^{b}	219.13^{b}	205.43^{b}	53.88^{b}	12.31^{c}	9.50^{b}	59.44^{c}	5.45^{b}	1.52^{a}	0.34^{a}	1.78^{ab}
	25	4.17^{c}	11.67^{d}	15.05^{b}	1.06^{a}	50.37^{d}	100.73^{d}	5988.39^{d}	159.69^{a}	319.38^{a}	299.42^{a}	78.54^{a}	9.32^{d}	7.19^{c}	55.87^{d}	5.11^{b}	1.15^{a}	0.28^{a}	1.38^{b}
C. Effect of the interaction between Magnetized water and NPK levels																			
Normal water	**100**	5.00^{c}	17.60^{a}	16.25^{d}	1.07^{a}	88.00^{d}	176.01^{d}	10463.24^{d}	69.75^{h}	139.51^{h}	130.79^{h}	34.31^{h}	11.81^{c}	9.06^{cd}	59.82^{f}	5.45^{c}	1.45^{ab}	0.36^{a}	1.80^{ab}
	75	6.00^{b}	13.06^{de}	16.95^{cd}	1.09^{a}	78.33^{e}	156.67^{e}	9313.52^{e}	82.79^{e}	165.57^{e}	155.23^{e}	40.71^{e}	15.79^{b}	9.38^{c}	61.24^{e}	5.80^{bc}	1.50^{ab}	0.37^{a}	1.70^{ab}
	50	4.00^{d}	11.61^{f}	13.34^{e}	1.06^{a}	46.44^{g}	92.88^{g}	5521.53^{g}	73.62^{g}	147.24^{g}	138.04^{g}	36.21^{g}	8.83^{d}	8.38^{d}	51.42^{g}	4.25^{d}	1.34^{ab}	0.27^{a}	1.55^{ab}
	25	2.33^{e}	10.72^{g}	12.75^{e}	1.05^{a}	25.01^{h}	50.02^{h}	2973.59^{h}	79.30^{f}	158.59^{f}	148.68^{f}	39.00^{f}	6.84^{e}	5.00^{e}	42.48^{h}	4.05^{d}	0.80^{b}	0.21^{a}	1.00^{b}
Magnetic water	**100**	8.00^{a}	14.35^{c}	19.67^{a}	1.10^{a}	114.79^{a}	229.58^{a}	13648.07^{a}	90.99^{d}	181.97^{d}	170.60^{d}	44.75^{d}	17.78^{a}	12.50^{a}	84.82^{a}	6.67^{ab}	2.00^{a}	0.47^{a}	2.30^{a}
	75	6.33^{b}	16.09^{b}	18.34^{b}	1.09^{a}	101.88^{b}	203.77^{b}	12113.52^{b}	107.68^{c}	215.35^{c}	201.89^{c}	52.96^{c}	15.79^{b}	12.19^{a}	80.18^{b}	6.95^{a}	1.95^{a}	0.45^{a}	2.30^{a}
	50	6.67^{b}	13.77^{cd}	17.67^{bc}	1.09^{a}	91.79^{c}	183.57^{c}	10913.06^{c}	145.51^{b}	291.02^{b}	272.83^{b}	71.56^{b}	15.79^{b}	10.63^{b}	67.45^{d}	6.65^{ab}	1.70^{ab}	0.40^{a}	2.00^{a}
	25	6.00^{b}	12.62^{e}	17.34^{c}	1.07^{a}	75.72^{f}	151.45^{f}	9003.20^{f}	240.09^{a}	480.17^{a}	450.16^{a}	118.07^{a}	11.81^{c}	9.38^{c}	69.25^{c}	6.17^{abc}	1.50^{ab}	0.35^{a}	1.75^{ab}

* Means superscripted by different letters within each main factor and the interactions are significantly different, α=0.05.

References

A.O.A.C.,1995. Association of official agriculture chemists. Official Methods of Analysis 12th Ed. Washington, D.C.

Abd El-Latif, Amany. A., A.A. Abdelshafy and T.A. Eid, 2015. Minimizing strawberry mineral fertilization and enhancing water use efficiency by using magnetized irrigation water. J. Plant Production, Mansoura Univ., 6 (9): 1581 – 1593.

Abdel-Aal R.M., 1971. Effect of groundwater and parent material on different soil characteristics in the North Nile Delta. Ph.D. Thesis, Fac. of Agric., Cairo Univ., Egypt.

Aguilar-Acuna, J.L., J. Martinez-Hernandez, V. Volke-Haller, J. Etchevers-Barra, H. Mata-Vazquez, and M. Hernandez-Martinez, 2006. Distribucion del fosforo en suelo, raices y materia seca de tuberculos de papa cultivada con fertirriego. Terra Latinoam. 24(2): 269-276.

Ajitkumar, G. P., 2014. Device for magnetic treatment of irrigation water and its effects on quality and yield of banana plants. International Journal of Biological Sciences and Applications, 1(4): 152-156.

Aladjadjiyan A., 2002. Study of the influence of magnetic field on some biological characteristics of *Zea maiz*. J. of Centr. Eur. Agric., 3 (2): 89-94.

Bremner, R.A. and M.N. Taha, 1966. Studies in potato agronomy: the effect of variety, seed size and spacing on growth, developed and yield. J. Agric. Sci., 66, 241–252.

Broesh, S., 1954. Colorimetric assay of phenoloxidase. Bull. Soc. Chem. Biol., 36: 711-713.

Burton, W.G., 1948. The Potato, Chapman and Hall, London, 319p.

De Souza, A., D. García, L. Sueiro, L. Licea and E. Porras, 2005. Pre-sowing magnetic treatment of tomato seeds: effects on the growth and yield of plants cultivated late in the season. Spanish-J. of Agricultural Research. 3(1): 113-122.

Devi, W.P. and A. Zaman, 2012. Effect of organic and inorganic sources of nutrients in potato (*Solanum tuberosum* L.) production and soil fertility buildup. J. of Crop and Weed, 8(1):145-148.

Doklega, Samar M.A., 2017. Impact of Magnetized Water Irrigation, Soil Mineral Fertilization and Foliar Spraying with Nanomaterial on Potato Plants. J. Plant Production, Mansoura Univ., Vol. 8(11): 1113 – 1120.

El-Gizawy A.M., M. E. Ragab, Nesreen A.S. Helal, A. El-Satar and I. H. Osman, 2016. Effect of Magnetic Field Treatments on Germination of True Potato Seeds, Seedlings Growth and Potato Tubers Characteristics. Middle East J. Agric. Res., 5(1):1-8.

Eşitken, A. and M. Turan, 2004. Alternating magnetic field effects on yield and plant nutrient element composition of strawberry (Fragaria x ananassa cv. Camarosa), Acta. Agric. Scand., Sect. B-Soil Plant Sci., 54 (2004):135-139.

FAO, 2017. Food and agriculture organization. Faostat, FAO Statistics Division, October 2017.

Fehrman, H. and A. E. Dimond, 1967. Peroxidase activity and phytophthora resistance in different organs of the potato. Plant Pathology, 57: 69-72.

Feleafel, M.N., 2005. Effect of NPK and Bioertilizer Types on Vegetative Growth, Tuber Yield and Quality of Potato. J.Agric. & Env.Sci.Alex.Univ.,Egypt, Vol.4 (2)2005.

Gosev, N. A., 1960. Some methods in studying plant water relation leningrade. Aced. of Science USSR.

Gomez K.A. and A.A. Gomez, 1984. Statistical procedures for agricultural Research. 2nd ed. John Wiley Sons, New York, U.S.A. pp. 680.

Hajer, A.S., A.A. Malibari, H.S. Al-Zahrani and O.A. Almaghrabi, 2006. Responses of three tomato cultivars to sea water salinity 1. Effect of salinity on the seedling growth. African Journal of Biotechnology 5: 855-861.

Hilal, M. and M. Hilal, 2000. Application of magnetic technologies in desert agriculture. I-Seed germination and seedling emergence of some crops in a saline calcareous soil. Egyptian Journal of Soil Science, 40(3):413-422.

Imamsaheb, S.J., M.G. Patil and D.K. Harish, 2011. Effect of different levels of fertigation on productivity and nutrients uptake in processing Tomato (*Solanum lycopersicum*) genotypes. Research Journal of Agricultural Sciences, 2(2): 217-220.

Kavvadias, V., C. Paschalidis, G. Akrivos, and D. Petropoulos. 2012. Nitrogen and potassium fertilization responses of potato (*Solanum tuberosum*) cv. Spunta. Com. Soil Sci. Plant Anal. 43(1-2), 176-189. Doi: 10.1080/00103624.2012.634711

Kreeb K.H., 1990. Methoden Zur Pflanzenökologie und Bioindikationen. Gustav Fisher, Jena, 327 pp.

Kushwah V.S., S.P. Singh and S.S. Lal, 2005. Potato Journal, 32(3-4), 157- 158.

Leopold, A.G.; M.E. Musgrave and K.M. Williams, 1981. Solute leakage, resulting from leaf desiccation. Plant Physiol., 68: 1222-1225.

Li, W., B. Xiong, S. Wang, X. Deng, L. Yin, and H. Li, 2016. Regulation effects of water and nitrogen on the source-sink relationship in potato during the tuber bulking stage. PloS one 11(1), e0146877. Doi: 10.1371/journal.pone.0146877

Marouani, A., O. Behi, H.B.H. Salah, and O.A. Quilez, 2015. Establishment of chlorophyll meter measurements to manage crop nitrogen status in potato crop. Com. Soil Sci. Plant Anal. 46(4), 476-489. Doi: 10.1080/00103624.2014.997386.

Marschner, H., 1995. Mineral Nutrition of Higher Plants.2nd edition. Academic press, New York Tokio, London, pp889.

Muthoni, J. and D. O. Nyamango, 2009. A review of constraints to ware Irish potatoes production in Kenya. J. Hort. Forestry, 1 (7): 98 102.

Nesho Neshev and Ivan Manolov, 2016. Effect of Fertilization on Soil Fertility and Nutrient Use Efficiency at Potatoes. Geophysical Research Abstracts. Vol. 18, EGU2016-139, 2016.

Page, A.L.; R.H. Miller and D.R. Keeney, 1982. Methods of Soil Analysis. Part 1&2 American Society of Agronomy, Madison, W.I.

Perrenoud, S., 1993. Fertilizing for high yield potato. IPI Bulletin 8. 2nd ed. International Potash Institute, Basel, Switzerland.

Poljak, M., M. Herak-Ćustić, T. Horvat, L Ĉoga,., A Majić,., 2007. Effects of nitrogen nutrition on potato tuber composition and yield. Cereal Research Communications, 35: 937-940.

Radhakrishnan, R. and B.D.R. Kumari, 2012. Pulsed magnetic field: A contemporary approach offers to enhance plant growth and yield of soybean. Plant Physiology and Biochemistry, 51: 139-144.

Reis, Jr, R.d.A. and P. Monnerat. 2000. Nutrient concentrations in potato stem, petiole and leaf let in response to potassium fertilizer. Sci. Agric. 57, 251-255. Doi: 10.1590/S0103-90162000000200009

Rokhinson, E.E. and V.V. Baskin, 1996. Magnetic treatment of irrigation water. Zeszyty Problemowe Postepow Nauk Rolniczych, 436: 135-141. 18.

Sadasivam, M. and A. Manikam, 1992. Biochemical methods for agricultural sciences. Wiley Eastern Limited 246 pp.

Selim, A.H. and M.F. El-Nady, 2011. Physio-anatomical responses of drought stressed tomato plants to magnetic field. Acta Astronautica 69: 387–396.

Selim Dalia A.F.H., M.A. Nassar Rania, M.S. Boghdady and M. Bonfill, 2019. Physiological and anatomical studies of two wheat cultivars irrigated with magnetic water under drought stress conditions. Plant Physiology and Biochemistry 135:480-488.doi.org/ 10.1016/ plaphy.2018 .11.012.

Selim, Dalia A., A.A. Gendy, A.M Maria and E.M. Mousa, 2009. Response of pepper plants to magnetic technologies. In: 1st Nile Delta Conf on Export Crops Fac of Agric Minufiya Univ, pp. 89–104.

Selim, Dalia A.H., 2016. Physiological response of cucumber plants (*Cucumis sativum* L.) to magnetized field treatments. The 6th International Conference of The Egyptian Botanical Society, Held on Faculty of Science, Menoufia University, 11-12 May 2016, Egypt.

Simone, B., J.M. Peacock and D.C. Struik, 1993. Differences in developmental plasticity and growth rate among drought resistant susceptible cultivars of durum wheat (*Triticum trugidum* L., var. durum). Plant and Soil, 157: 155-166.

Takashenko, Y., 1995. The application of magnetic technology in agriculture (Magnetizer). Abu-Dhabi, UAE, Fax: 781265.

Takashenko, Y., 1997: Hydromagnetic systems and their role in creating microclimate. Intrenational Symposium on Sustainable Management of Salt Affected Soils, Cairo, Egypt, 22-28 Sept.

Verma, S. K., B. S. Asati, S. K. Tamrakar, H. C. Nanda and C. R. Gupta, 2010. Response of potato to organic sources with inorganic fertilizers under Chhattisgarh plain. Advances in Plant Sci., 23(2):645-647.

Westermann, D., 2005. Nutritional requirements of potatoes. Am. J. Pot. Res. 82, 301-307. Doi: 10.1007/BF02871960

Wettestein D., 1957. Chlorophyll-letale und der submikroskopische Formwechsel der Plastiden. Experimental Cell Research 12: 427–506.