Foliar Application of Glycine Betaine and Potassium Silicate and Its Effect on Growth Performance of Jerusalem Artichoke Grown on Calcareous Soil Under Water Stress Conditions

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ABSTRACT: This investigation aims to evaluate the effect of water stress and foliar application of two different antitranspirants on growth, yield, quality and water use efficiency of Jerusalem artichoke grown a calcareous soil using drip irrigation system. For this purpose, two field experiments were carried out at soil salinity lab. Res., Agricultural Research Center, Alexandria Governorate, Egypt during the summer seasons of 2017 and 2018 using the split plot design. Jerusalem artichoke plants were irrigated by 100, 75 or 50% of water requirements (ET_C). The antitranspirants included glycine betaine (200 mg/l), potassium silicate (5 cm^3/l) and their combination i.e. potassium silicate (P.S) x glycine betain(G.B) in comparison with spraying distilled water as control treatment. The gained results revealed that increasing irrigation water levels from 50% up to 100% significantly (P<0.05) increase, majority of plant vegetative growth characters Jerusalem artichoke tubers yield/feddan, its component parameters and tubers′ quality during both seasons. Foliar application of antitranspirant treatments; increased irrigation efficiency and potassium silicate was more effective than glycine betaine, in particular, upon irrigation with 50% ET_C treatment**.** In general, spraying Jerusalem artichoke plants with potassium silicate; gave rise to the best results for plant height, No. of main stem/plant and plant fresh weight/plant with 100% ET_C during both seasons. The dry matter percentage was not affected significantly (P>0.05) by the two independent variables. In addition, potassium silicate at 100% ETc; brought about the highest value for tuber yield in both seasons. Jerusalem artichoke plants irrigated with 75% of water requirements gave insignificant decrease in number of tubers/plant, tuber fresh weight and tuber yield than the treatment received 100% of water requirements. The interaction between irrigation tested levels and foliar application treatments was highly effective on tuber yield character in both seasons. The highest average values for tuber yield/feddan were recorded due to the treatments of water level of 75%ETc with spraying potassium silicate at 5cm^3/ l., while the lowest mean values were achieved due to apply at 50 % irrigation level compare with control treatment. Also, the interaction between irrigation levels foliar glycine betaine, potassium silicate, and G.B. x P.S. had a significant (P<0.05) effect on K of tuber content during both seasons. The compositional elements N, P and carbohydrate content in tubers were not significantly affected by this interaction during the two seasons except inulin content during the first season only. The best results were recorded due to apply water irrigation level of 100% ET_C and 75%ET_C with spraying of potassium silicate at 5cm^3 /l. Crop water use efficiency (CWUE) was doubled in the case of 50% ET_C compared with consumptive 100% ET_C. The water use efficiency increased as the irrigation level reduced.

Keywords: Jerusalem artichoke, potassium silicate, glycine betain, foliar application, irrigation, water stress

INTRODUCTION

Jerusalem artichoke (*Helianthus tuberosus L.*) also called as sunchoke, and belongs to family Compositae (Asteraceae). Studies on nutritive value of Jerusalem artichoke tubers have revealed that they contain many important components(Praznik *et al.*, 1998). It is also a better source for inulin and oligofructose, which are types of fibers that act as potent prebiotics, or food for probiotics. Denoroy (1996) reported that inulin is a soluble fiber that balances blood sugar. Moreover, soluble carbohydrates present beside inulin are its derivatives fructooligosaccharides, which are simple sugars (fructose and glucose) and saccharose. It was considered as a biomass crop for ethanol, also. The production of biogas from biomass is economically viable under certain conditions, and the possibility of increasing the cultivation of Jerusalem artichoke has increased the scientific interest about this crop (Gunnarson *et al*., 1985).

Stress caused by water is an increasing environmental constraint in agriculture, cause several damage effects on plant growth and metabolic processes, including water relations, photosynthetic assimilation, and nutrient uptake (Stone *et al.,* 2001). The damage caused by water stress is one of the most important environmental stresses that cause heavy loss to the agriculture worldwide (Kumar *et al*., 2012). Water is essential and the plants should receive at least 1 inch per week to produce better tuber growth. The researchers indicated that vegetables are more sensitive to water stress compared to other crops. Flowering of Jerusalem artichoke begins in August and when the plants begin to brown in September, it's time to harvest its tubers. The main problem that the agricultural production faces is the shortage of irrigation water. Under these conditions, crop water use efficiency, crop water content are seriously affected, leading to low net photosynthetic rate, growth decline, and storage root yield lack (Van Heeden and Laurie, 2008; Yooyongwech *et al*., 2016). Therefore, an effective technique and agricultural practices are required urgently to save water for expansion of agricultural area and other purposes.

One of the approaches to reduce the negative effects of water deficiency is the foliar application by potassium silicate which aimed to improve growth and increase productivity under water stress (Kamal, 2013). Potassium silicate promotes the vegetative growth, yield components and mineral nutrient concentrations such as nitrogen, phosphorus and potassium elements in potato crop (Salim *et al*., 2014). Potassium is very important for both the basic physiological functions of plants, such as the formation of sugars and starch, proteins synthesis, cell division, growth and fruit formation. Potassium, also, affects the synthesis, conversion and storage of carbohydrates as well as the quality of potato tubers (Ebert, 2009; Dkhil *et al*., 2011).

Glycinebetaine(GB) is a quaternary ammonium compound which found naturally in a wide variety of plants, animals and microorganisms. The accumulation of GB is induced and synthesized in the chloroplasts of higher plants under variety of abiotic stress, such as high salt, water stress and cold (Jagendorf and Takabe,2001;Rontein *et al.,*2002), and the exogenous GB could enhance the resistance ability to water stress (Mahouachi *et al.,*2012). Glycinebetaine affords osmoprotection for plants and protects cell components from harsh conditions by functioning as a molecular chaperone (Sakamoto and Murata, 2002). Application an exogenous of

GB improves the growth and survival of a wide variety of plants under several of abiotic stress conditions (Ashraf and Foolad 2007; Hoque *et al.,* 2007; Park *et al.*, 2006 and Chen and Murata, 2008). On the other hand, the antitranspirants reduces the water decrease during vegetative growth period and before or after fruits harvesting (Abd El Aal *et al.*, 2008).

This study aims to assess the effect of foliar spraying with potassium silicate, glycine betain as two different antitranspirants and irrigation water stress on growth, yield and tubers' quality of Jerusalem artichoke crop and to determine the actual ET for Jerusalem artichoke plants.

MATERIALS AND METHODS

Field experiments:

Two field experiments were conducted during two successive summer seasons of 2017 and 2018 in the soil salinity lab. Res. Alexandria, Agricultural Research Center. Jerusalem artichoke plant (*Helianthus tuberosus* L.) cultivar Fuseau was used in this investigation. Planting tubers was done on April, 10^{th} and 9^{th} during growing seasons, respectively. Tuber seeds were planted at 60 cm apart on one side of the ridges within rows of 60 cm width and 4 m length. The physical and chemical properties of the experimental soil used were done and shown in Table (1), which had been determined according to Black (1965).

Table (1). Some physical and chemical properties of the experimental soil (average values of both seasons)

Soil type	Particle size distribution (%)			Soil Texture	Soil apparent density (g /cm^3)	Soil moisture content (Volumetric %)		pH	EC dS/m	$CaCO_3$ %	O.M. %
	Sand	Silt	Clay			Field capacity	Witling point				
Calcareous	55	25	20	**sandy clay loam**	1.28	29	16	8.1	1.78	32.6	1.45

Experimental design and treatments

The experimental design used was a split-plot design with three replicates. Three irrigations levels 50%, 75% and 100% of crop evapotranspiration (ET_c) were assigned to main plots. The sub plots were devoted to four foliar applications included sprayed with distilled water as control, liquid potassium silicate (K_2SiO_3) 10 % K_2O and 25% SiO_2 and potassium silicate at rate of 5 cm^3/l, glycin betain [(Carboxymethyl) trimethyl ammonium inner salt,($C_5H_{11}NO_2$, MW**:** 117.146 g/mole) at 200 mg/l and their combination *i.e.,* potassium silicate (P.S.) x glycine betain (G.B.) foliar together. Foliar applied was done twice at 60 and 90 days after planting. Tween-20 (0.1%) was used as a wetting agent for each treatment. Each experimental sub plot consisted of two rows. The irrigation treatments started after 20 days of transplanting. During the first 20 days (initial stage), the Jerusalem artichoke plants were irrigated according to the calculated irrigation requirements, while in other stages (development, mid, and end) the plants irrigated by 100, 75 or 50% of water requirements using drip irrigation method. The following fertilizers were added to the soil at preparation before planting: 20 m^3 organic manure/fed. plus calcium super phosphate fertilizer (15.5% P_2O_5) was base dressed during soil preparations as recommended (150 kg／fed.). Nitrogen fertilizer was added in the form ammonium nitrate (33.5% N) at the rate of 300 kg／fed. at three equal doses ; after four, eight and twelve weeks from planting. Potassium sulphate (48% K_2O) was applied at rate of 90 kg／fed. in two equal doses eight and twelve weeks after planting. During the growing seasons, all other recommended agro-managements such as disease pests and weed control were performed whenever they appeared to be necessary.

The crop evapotranspiration (ET_c) was determined by using CROPWAT 8.0 a computer program and according to Penman-Montieth equation (Allen *et al*., 1998). Meteorological data (2017 and 2018) were obtained online from Weather Station (latitude of 31°11′02″ N, longitude of 29°56′54″ E and altitude of -2 m) in Alexandria-Nouzha Airport, Egypt at 4.5 km from experimental site location (Table 2).

Table(2). Average monthly maximum and minimum temperatures(°C), relative humidity (RH%) and wind speed (km/h) in the experimental location during 2017 and 2018 growing seasons

Month	Minimum temperature (°C)	Maximum temperature (°C)	Relative humidity (%)	wind speed (km/h)	Minimum temperature (°C)	Maximum temperature (°C)	Relative humidity (%)	wind speed (km/h)
	Season 2017				Season 2018			
May	22	29	58	16	21	27	70	18
June	23	28	66	15	24	29	68	16
July	25	29	69	17	25	30	71	18
August	26	31	62	15	26	31	68	16
September	24	29	62	16	25	30	64	16
October	22	27	55	17	23	27	59	17
November	18	23	58	15	17	24	65	13

Calculation of irrigation water requirements (IR)

Based on the climate data in Table (2), the ET_c values for Jerusalem artichoke were calculated in Table (3). The Crop water consumptive use (CU) is the amount of water equal to what is lost by plant while irrigation requirement (IR) depends on Cu, irrigation method and leaching fraction. Both Cu and IR estimation is derived from crop evapotranspiration (ET_c) which can be calculated by the following equation:

$$ET_C = K_C . ET_0$$

Where; K_C is the crop coefficient. Crop coefficients values used for Jerusalem artichoke were 0.35, 0.60, 1.00, 0.35 for growth stages initial, development, mid, and end, respectively as suggested by (Baldini *et al.,* 2011). It is the ratio of the crop ET_c to the ET_0 (Pereira *et al.,* 2015). The K_c coefficient serves as an aggregation of the physical and physiological differences between crops. The daily reference evapotranspiration (ET_o) was estimated using Penman–Monteith's modified equation (Allen *et al.,* 1998). The ET_C and is expressed by the rate of mm/day. The data in Table (3) show the actual evapotranspiration, consumptive water use and irrigation water applied at different water stress during the seasons of 2017 and 2018**.**

Table (3). Average values of reference evapotranspiration (ET_O, mm / day), actual evapotranspiration (ET_C, mm), and crop coefficient (k_C) at plant growth during of 2017 and 2018 seasons

Months	ET_O (mm/day)	K_C	ET_C (mm/day)	ETc (mm/month)	ET_O (mm/day)	K_C	ET_C (mm/day)	ET_C (mm/month)
	Season 2017				Season 2018			
May	5.57	0.44	2.45	46.27	5.59	0.44	2.46	55.52
June	6.50	0.58	3.78	83.55	6.47	0.51	3.34	100.29
July	7.07	0.99	6.97	217.09	6.59	0.99	6.49	201.29
August	6.82	1.19	8.12	251.95	6.51	1.19	7.75	240.05
September	6.07	1.18	7.18	215.41	6.08	1.18	7.19	215.63
October	5.57	0.79	4.40	138.00	5.37	0.79	4.27	130.43
November	3.99	0.44	1.76	45.97	3.64	0.48	1.75	22.52
ET_C mm/season				998.24				965.73

Calculation of water use efficiency

In the drip irrigation treatments, daily consumptive use (CU) of water was worked out based on the crop ET and at the end of the season the seasonal consumptive use of water was calculated and expressed in mm. Crop water use efficiency (CWUE) was calculated using the equation CWUE = Y / CU); where Y equals to the marketable tuber yield (kg/fed.), CU equals to the seasonal actual evapotranspiration ET_C (as unit m^3/fed.). Irrigation water use efficiency (IWUE) was estimated using the formula (IWUE = Y / IR) according to Bozkurt *et al.,* (2009), whereas, IR irrigation requirement equals to the seasonal water applied to the field (m^3/fed.) and calculated according to the equation: IR=CU/ [Ea*(1-LF)], where the application efficiency (Ea) for drip irrigation equal 0.85 and the leaching fraction (LF) was considered as 0.10 of water requirement.

Data recorded:

1. Vegetative growth characters :

A sample of three plants from each experimental plot was taken, randomly, at flower initiation stage (150 days after planting) to estimate plant height (cm), number of main stems, plant fresh weight (kg) and plant dry matter percentage.

2. Total tuber yield

Each plant in each experimental unit was taken at harvest time *i.e.* 180 days after planting to yield measure, number of tubers per plant, average tuber fresh weight (g/plant), total yield per plant(kg/plant) and total tubers' yield (ton / fed.).

3. Tuber's quality and mineral content:

Ten tubers per treatment were token randomly, to determine tuber dry matter percentage calculated by drying 100 g of fresh sliced tubers in an electric air – drying oven at 70 °C till constant weight. Inulin content was determined in tubers according to the method of Winton and Winton (1958). Total carbohydrate was determined colorimetrically as gram of glucose /100g dry weight of tubers roots according the methods described by James (1995). In the digested dry matter of tubers nitrogen was determined according to the methods described by Pregl (1945) using micro-kjeldahl apparatus. Meanwhile, phosphorus was determined colorimetrically according to Murphy and Riley (1962). Potassium was determined against a standard using air propane flame photometer according to Chapman and Pratt (1961).

Statistical analysis:

Collected data from the experiments were statistically analyzed, using the analysis of variance method. Comparisons among the means of different treatments were done, using least significant differences (L.S.D) test procedure at $p \leq 0.05$ level of probability, as illustrated by Snedecor and Cochran (1980) using Co-Stat software program (2004).

RESULTS AND DISCUSSION

1- vegetative growth parameters

The results relevant to this research will be presented and dissection as follows:

a. The main effect of irrigation levels

Obtained results in Table (4) exhibit clearly that all the studied vegetative growth parameters *i.e.,* plant height, number of main stems per plant, fresh weight of plant were significantly ($p\leq 0.05$) affected by irrigation levels treatments during both seasons of the growth. In this respect, decreasing the irrigation levels from 100 % of crop evapotranspiration (ET_c) to 50% consistently and continuously; decreased all morphological parameters of plant. However, dry matter percentage of plant foliage did not significantly ($p>0.05$) affected by irrigation levels treatments during both seasons. Such increment in plant morphological parameters due to the reduction of irrigation levels may be due to the main role of irrigation water for increasing the availability and diffusion as well as the uptake of macro and micronutrients by plant, which affect, greatly, the plant growth. Also, the reduction in plant growth due to the deficiency of irrigation water might be due to the lack of water absorption by plant which in turn effect on the role of photosynthetic assimilation insufficient water condition. Moreover, deficit irrigation as a water stress condition eventually reduces plant growth, chlorophyll content, water potential and transpiration rate as well as the free water in plant tissue, leading to deleterious effect on photosynthetic rate, stomatal conductance and intercellular CO_2 (Mingchi *et al*., 2010). Similar results, more or less, were recorded by (Cooper, 1980; Sharma *et al*. 1984; Abo-El Magd *et al*. 2007; Abo-Sedera *et al.* 2004).

b. The main effect of four foliar application

The results of Table (4) demonstrate foliar application of glycine betain, potassium silicate and interaction of them that exerted significant ($p\leq 0.05$) effects on vegetative growth characteristics of Jerusalem artichoke plants except for plant dry matter percentage. It is clear that vegetative growth characteristics, increased significantly *i.e.*, plant height (cm), number of main stems and plant and fresh weight (kg) were recorded when the growing plants sprayed with potassium silicate and the interaction of G.B. x P.S. compared with G.B. and control treatments during both growing seasons. Salim *et al*. (2014) and Abd El-Gawad *et al*. (2017) reported that potassium has an effect on photosynthesis, which is positively affect the vegetative growth of potato plant. It could be taken place due to the role of potassium on plant nutrition, *i.e.* promotion of enzymes activity and enhancing the translocation of assimilates and protein synthesis. Also, Sangakkara *et al.* (2000) ascribed the increase in the vegetative growth of potato plants to the role of K in biochemical pathways in plants and it amplifies the photosynthetic rates, CO_2 assimilation and facilitates carbon movement. Marschner (2012) reported that Potassium is a significant nutrient for numeral of physiological function, counting regulation of water and gas exchange in plants, protein synthesis, enzyme activation, photosynthesis and carbohydrate translocation in plants. Pilon *et al.* (2013) found that leaf area of potato plants increased because of silicon application. Similarly, silicon application reflected an increase in the leaf area and haulm dry weight readings (Abd El-Gawad *et al.,* 2017). The enhancement effect of silicon on the vegetative growth could be attributed to activating antioxidant defense system or through their protective effect on the photosynthetic pigments in salt stressed plant (Ashraf *et al*., 2010). Romero-Aranda and Cuartero (2006) found that treating tomato plants with potassium silicate (K_2SiO_3) as a source of silicon (2.5 mM); improved leaf fresh, weight, area and net photosynthesis rate as well as water storage within plant tissues. Furthermore, Abou-Baker *et al* . (2012) indicated that spraying faba bean plants with silicon at 300 ppm as potassium silicate; recorded the highest significant average values of plant height, root length, shoot and root dry weight. In this respect, Soja *et al*., (1990), Mansour *et al.* (2001), Tawfik *et al.* (2003) and Abo-El Maged *et al*. (2007) recorded, more or less, similar results on Jerusalem artichoke.

The application of glycine betaine; produced the highest average values in the most of vegetative growth parameters during both season. However, this increment did not reach the level of statistical significant when compared with foliar application of potassium silicate and interaction of them on plant fresh weight in the first season and plant dry matter percentage both season of the study. In this content, Osman (2009) found that application of 1 mM glycine betaine increased flag leaf area of rice. In addition, Abbas *et al.* (2010) found also that foliar application of G.B. caused improvement in growth of two eggplant cultivars. The growth improvement could be taken place due to G.B. as enhance for photosynthetic rate and stomatal conductance. In the other words, glycine betaine was effective in stimulating plant growth compared to the control treatment.

Table(4). Average values of some vegetative growth characters as affected by irrigation levels and four foliar applications of glycine betaine, potassium silicate and their interactions on Jerusalem artichoke plant during 2017 and 2018 seasons

Treatments		Vegetative growth characters							
		Season 2017				Season 2018			
Irrigations levels	Foliar application	Plant height (cm)	No. of main stem / plant	Plant fresh weight (kg)	Plant D.M (%)	Plant height (cm)	No. of main stem / plant	Plant fresh weight (kg)	Plant D.M (%)
100% ET_c	control	196d	6.9abc	5.22a	10.56a	232d	8.5b	4.78e	11.80a
	G.B. (200mg/l)	233b	8.2a	5.41a	10.83a	245bc	9.5a	5.98ab	11.61a
	P.S. (5 cm^3/l)	296a	9.8a	5.63a	10.87a	261a	10.9a	6.31a	11.48a
	G.B. x P.S.	215c	8.8a	5.49a	10.69a	234d	8.5b	6.03a	11.75a
75% ET_c	control	188d	7.1ab	3.23c	10.55a	210e	9.4a	5.21c	11.42a
	G.B. 200mg/l	180de	6.6bc	4.03b	11.22a	242b	9.8a	5.47bc	13.40a
	P.S5 cm^3/l	193d	6.5bc	4.36b	11.52a	266a	10.3a	5.89b	12.94a
	G.B x P.S	185de	6.5bc	5.08a	11.56a	256b	9.6a	5.44bc	12.66a
50% ET_c	control	164fg	4.7e	3.02c	11.41a	172gh	7.4c	3.54f	14.51a
	G.B 200mg/l	169fg	5.2cd	4.22b	12.56a	177g	8.0c	4.45ef	14.66a
	P.S5 cm^3/l	173f	4.6e	3.52c	13.74a	198f	8.5b	4.65e	14.58a
	G.B. x P.S.	175f	4.2ef	3.54c	13.40a	178g	8.8b	4.69e	14.98a
Irrigations levels									
100% ET_c		210.16a	7.3a	5.84a	10.78a	288.16a	10.3a	5.89a	13.56a
75% ET_c		195.12b	5.2b	4.43b	11.56a	259.26b	9.6a	5.22a	13.98a
50% ET_c		153.43c	3.6c	3.20c	14.22a	185.33c	7.6b	3.69b	14.33a
Foliar application									
control		166.13c	5.5c	4.23c	12.14a	188.23c	7.8c	5.50c	12.45a
G.B.(200mg/l)		185.65b	6.4b	5.56b	12.66a	243.12b	8.4b	6.78b	12.54a
P.S.(5 cm^3/l)		189.62a	7.5a	5.64b	13.51a	274.36a	11.0a	7.94a	13.55a
G.B. x P.S.		195.48a	7.1a	6.88a	12.87a	268.48a	10.4a	7.98a	13.45a

Values followed by the same letter (s) within column are not significantly different (P<0.05)

C. The effect of tested interaction

The given results of Table (4) indicate that the given interactions exerted significant effect ($p \leq 0.05$) on plant height, No. of main stem / plant and plant fresh weight/plant. In general, foliar application of Jerusalem artichoke plants with potassium silicate of 5 cm^3/l and G.B. x P.S., gave the best results for the characteristics of plant height, No. of main stem/plant and plant fresh weight/plant with 100% of crop evapotranspiration (ETC) of irrigation levels applied during in both seasons. As mentioned -earlier, the characteristic of dry matter percentage was not affected by the two independent variables; this trait was not affected significantly ($P > 0.05$) by the interaction between these two variables.

2. Yield and yield components

The results outlined in Table (5) indicate that Jerusalem artichoke tuber yield and its component characters were significantly affected ($p \leq 0.05$) by the two studied independent variables (irrigation water levels and foliar spraying with potassium silicate, glycine betain and G.B x P.S) during both seasons.

a. The main effect of irrigation level

regarding to the irrigation levels as a main effect, the results of Table (5) appeared that there is a clear positive relationship between increasing the irrigation levels and the total tuber yield and its components (number and weight of tuber /plant, average tuber weight as well as total yield/fed.) during the two seasons of the growth. In this respect, the highest average values were recorded for such characters were at 100% ET_C followed by75% ET_C, while the lowest average values were recorded at 50%ETc. Total yield per plant (kg) was the only character that affected significantly ($p \leq 0.05$ by irrigations levels in the first season. On the other hand, the tuber dry matter percentage was not significantly affected during the two seasons. It is known that the total yield and its components were highly correlated with the vigorous of the vegetative growth. These results might be attributed to lack of water absorbed and inhibition of photosynthesis efficiency under insufficient water conditions (Abo- El Maged *et al.,* 2007). Similar results, more or less, were obtained by Smittle *et al,* (1990) and Abd –El Aal (2011) on sweet potato.

b. The main effect of foliar application

With regard to the main effect of foliar applicants variable, the result of (Table 5) demonstrate that Jerusalem artichoke tuber yield trait and its component characters were significantly ($p \leq 0.05$) affected with (glycine betain at 200mg/l, potassium silicate of 5 cm^3/l and their interaction compared with control treatment during both seasons. In this respect, No. of tubers per plant, total yield per plant and total yield per fed. were affected significantly($p \leq 0.05$) owing to foliar application of potassium silicate 5cm^3 / l and because the interaction G.B. x P.S. during both seasons. Average tuber fresh weight trait was affected significantly ($p \leq$ 0.05) by four foliar application treatments in the first season only. On the other hand, tuber dry matter percentage was not affected significantly by the four foliar application treatments during the two seasons. In this regard, spraying potassium silicate at 5cm^3/l significantly ($p \leq 0.05$) gave rise to the highest average values, followed by spraying with the interaction (G.B. x P.S.) then spraying glycine betain at 200 mg/l, and finally control treatment, which significantly ($p \leq 0.05$); recorded the lowest average values for the three traits. Abd El-Baky *et al*. (2010) reported that sweet potato total yield per plant and total yield / feddan illustrate positively response to supplying the potassium. The promising effects of four foliar spraying applications with potassium silicate, glycine betain, interaction (G.B. x P.S.) and control treatment on Jerusalem artichoke increasing yield/fed., and its component characters might be attributed to its profound effects on enhancing vegetative growth traits (Table, 4) and the role of potassium as a macroelement in assimilation and translocation of plant synthetic assimilated molecules from the organs of synthesis to the storage organs (tubers). This result is consistent with the confirmed by Soja *et al.*(1990), Mansour *et al.* (2001), Tawfik *et al.* (2003) and Abo-El Magde *et al.* (2007) in their study on Jerusalem artichoke crop.

Table (5). Average values of yield and its components of Jerusalem artichoke as affected by irrigation levels and foliar application of glycine betaine, potassium silicate and their interaction treatments during 2017 and 2018 seasons

Treatments		Season 2017					Season 2018				
Irrigations levels	Foliar application	No. of tubers/ plant	Average Tuber fresh weight (g)	Total yield/plant (kg)	Total Yield/fed. (ton)	Tubers dry matter%	No. of tubers/ plant	Average tuber fresh weight (g)	Total yield/plant (kg)	Total yield/fed. (ton)	Tubers dry matter%
100% ET_c	control	49.23d	33.12e	2.061d	13.690c	16.45f	52.36e	42.89a	3.189b	13.026b	20.45a
	G.B. 200mg/l	65.42b	41.23b	3.556bc	14.813ab	17.72de	66.45c	43.23a	3.838ab	14.254a	20.54a
	P.S.5 cm^3/l	70.02a	38.69c	3.891b	15.023a	18.23d	73.25a	47.55a	4.431a	14.910a	19.87a
	G.B. x P.S.	68.33ab	45.20a	4.030a	15.014a	18.36d	70.45b	46.21a	4.220a	15.451a	20.36a
75% ET_c	control	46.22e	40.23bc	2.800	13.012c	17.52de	50.02f	40.12a	3.012b	13.254b	22.63a
	G.B. 200mg/l	55.80c	42.33b	3.310c	13.456c	19.14cd	55.63d	43.55a	3.226b	13.894b	22.05a
	P.S5 cm^3/l	70.41a	45.51a	4.090a	15.353a	21.56b	74.25a	49.12a	4.626a	15.256a	21.53a
	G.B. x P.S.	68.21ab	42.36b	3.856b	15.162a	20.32bc	69.66b	48.06a	4.312a	14.963a	20.14a
50% ET_c	control	38.54f	39.21c	2.650d	10.456e	22.36b	40.63i	44.54a	2.160c	11.560de	22.58a
	G.B. 200mg/l	45.21e	33.65e	2.881d	12.145d	24.63a	45.23h	43.12a	2.485c	12.681bcd	22.36a
	P.S 5 cm^3/l	49.02d	36.44d	2.764d	12.365d	23.58a	47.21g	45.23a	2.692c	12.873bc	21.45a
	G.B. x P.S.	48.33d	32.55ef	2.536d	12.045d	24.12a	46.23g	43.45a	2.518c	12.895bc	20.14a
Irrigations levels											
100 % ETc		57.21a	56.32a	4.192a	15.456a	20.56a	66.23a	58.63a	4.828a	16..651a	19.22a
75 % ETc		54.23a	53.21a	3.862b	14.253a	22.14a	64.25a	55.36a	4.520a	16.058a	22.51a
50 % ETc		43.54b	48.45b	2.064c	12.687b	23.56a	49.23b	52.14a	3.548a	13.054b	23.17a
Foliar application											
control		50.12c	46.25c	2.300c	12.023d	23.15a	52.63c	48.55a	3.496c	13.526b	20.36a
G.B. (200mg/l)		55.45b	49.89b	3.695b	14.258c	23.52a	58.93b	49.22a	3.842b	14.520a	22.04a
P.S. (5 cm^3 / l)		60.90a	53.76a	4.180a	15.265a	23.88a	62.31a	49.56a	4.036a	15.423a	22.14a
G.B x P.S		60.89a	51.66a	4.060a	14.956a	22.51a	65.32a	48.09a	4.146a	15.210a	22.32a

Values followed by the same letter (s) within column are not significantly different ($P<0.05$)

c. The effect of tested interaction

Regarding the effect of the interaction between the independent variable irrigation levels and the second one, i.e., foliar application treatments on the total yield and its components. The results of Table (5) reveal that most of the studied characters were significantly ($p \leq 0.05$) affected. The significantly highest average values for number of tubers/plant, total yield /plant and total yield / fed. were recorded due to the treatments of water level 75% ET_C with spraying potassium silicate 5cm^3/l. With regard to average values of tuber fresh weight (g), the tabulated results appeared that, irrigation with water level of 75% ET_C with spraying potassium silicate 5 cm^3/l significantly; gave rise to the highest average values during the first season. While the tubers dry matter percentage was not significantly affected during both seasons. Similar trend, more or less, was reported by Abo-Sedera *et al.* (2004) on taro and Abo- El Maged *et al*. (2007) and El-Sharkawy and El-Zohiri (2007) on Jerusalem artichoke.

3. Tubers′ quality traits

a. The main effect of irrigation level

As for the tested water irrigation levels, the results of Table (6) divulged that the tested tubers′ quality traits (N%, P%, K%, total carbohydrate% and inulin% tuber content) were significantly affected ($p \leq 0.05$) with the different levels irrigation water during the both seasons. Such results in Table (6) illustrated that nitrogen, phosphorus and potassium as well as inulin and total carbohydrate percentage in produced tuber were significantly ($p \leq 0.05$) increased with increasing irrigation levels up to 100 % ETc compared with 70 or 50 % ETc during growing season. These findings could be attributed to increasing soil moisture of root zone, which leads to such increments in the concentration of macroelements. Increasing of nutrients solubility and their availability to be absorbed and uptaken by plant and in turn increase their accumulation in produced tubers. The obtained results are, more or less, in agreement with those reported by El- sharkawy and El-Zohiri (2007) and Abo-El Maged *et al*. (2007) on Jerusalem artichoke and Abo-Sedera *et al*. (2004) and El-Zohiri and Abd Elal (2014) on taro.

b. The main effect of foliar application

Results obtained in Table (6) indicate that the foliar applicants besides exhibited significant positive effects ($p \leq 0.05$) on increasing the concentration of the estimated elements as N and K tubers contents during the two seasons. While, the phosphorus and inulin contents in Jerusalem artichoke tubers was not significantly ($p > 0.05$) affected during both seasons. Carbohydrate tubers content was positively affected by the four foliar applicants in the first season only. Generally, the maximum increments of nitrogen, phosphorus, potassium total carbohydrates and inulin percentage content were detected for the foliar application of potassium silicate at 5 cm^3 /l and G.B. x P.S. foliar application during both seasons. However, this increment did not reach the level of statistical significant when compared with them except for phosphorus and inulin percentage contents during both season. Shaaban and Abou El-Nour (2014) reported that foliar fertilization of potassium silicate may be more beneficial for silica deposition in the required key points which keep very healthy hairy roots allowing better water, macro- and micronutrient absorption. In this regard, Bhattarai and Swarnima (2016) explained that sugar content in potato tubers increases with the addition of potassium element to a certain level, and then starts to decrease. Low doses of potassium convert starch into sugar and vice versa at high doses. Khan *et al*. (2010) pointed out that increasing the concentration of potassium element has a positive effect on increasing tubers content of both sugars and starch. The recorded results are similar, more or less, to those reported by Abo-El Maged *et al*. (2007) on Jerusalem artichoke and Sameh and Shama, (2019) on potato. Abd El-Baky *et al*. (2010), reported that total yield of sweet potato per plant and total yield per feddan declared a positive response to supply with potassium. The promising effects of four foliar spraying applications with potassium silicate, glycine betain, interaction G.B. x P.S. and control (without spraying) on Jerusalem artichoke increasing yield/fed and its component characters, and these finding might be attributed to its positive effects on enhancing vegetative growth traits (Table 5) and the role of potassium as a macroelement in assimilation and translocation of plant synthetic assimilated molecules from the organs of synthesis to the storage organs (tubers). This result is consistent with those of Soja *et al.,* (1990); Mansour *et al.* (2001); Tawfik *et al*. (2003) and Abo-El Maged *et al*. (2007) in their study on Jerusalem artichoke crop.

C. The effect of the interactions

Results of Table (6) indicate the interaction between irrigation levels and foliar applications of glycine betaine, potassium silicate, G.B. x P.S. and control, had a significant ($p \leq 0.05$) effect on tubers K content during both seasons. The remaining estimated elements N, P and carbohydrate contents in tubers were not significantly ($p > 0.05$) affected by this interaction during both seasons except inulin content during the first season only. Generally, the best results were achieved when irrigation water level was 75%ET_C with spraying of potassium silicate at 5 cm^3/l, followed by irrigations water level at 100% ET_C, while the lowest average values were at irrigation water level of 50% ET_C. It could be indicated that spraying the growing Jerusalem artichoke plants with potassium silicate solution at the rate of 5 cm^3/l significantly ($p \leq 0.05$) alleviated the adverse effects of decreasing irrigation water levels through improving the vegetative growth characters; resulting in increases in total tubers yield, and tubers′ quality characteristic

Table (6). Average values of Jerusalem artichoke tubers chemicals components as affected by irrigation levels and foliar application of glycine betaine, potassium silicate and their interaction during 2017 and 2018 seasons

Treatments		Season 2017					Season 2018				
Irrigation levels	Foliar application	N%	P%	K%	Total carbohydrates %	Inulin (%)	N%	P%	K%	Total carbohydrates %	Inulin (%)
100% ET_c	control	1.622a	0.213a	2.341e	59.54a	17.22a	1.541a	0.205a	2.331f	58.31a	20.14c
	G.B. 5cm^3/l	1.736a	0.275a	2.670g	56.41a	17.85a	1.687a	0.376a	2.154g	59.41a	20.56c
	P.S. 200 mg/l	1.891a	0.307a	2.764h	62.12a	18.40a	1.932a	0.339a	2.631d	59.66a	21.78b
	G.B. x P.S.	1.842a	0.241a	3.456e	60.20a	18.63a	1.684a	0.366a	2.632d	59.87a	21.22b
75% ET_c	control	1.488a	0.292a	2.026d	54.22a	16.58a	1.890a	0.217a	2.548e	52.71a	19.54e
	G.B. 5cm^3/l	1.548a	0.244a	3.750c	58.63a	16.45a	1.871a	0.275a	3.451b	56.28a	22.14a
	P.S 200 mg/l	1.893a	0.316a	4.691a	64.99a	17.66a	1.843a	0.325a	4.810a	59.63a	22.31a
	G.B. x P.S.	1.365a	0.238a	4.573a	57.36a	17.56a	1.756a	0.345a	4.320a	53.69a	22.01a
50% ET_c	control	1.122a	0.215a	2.077d	51.21a	15.78a	1.465a	0.267a	2.856c	53.69a	18.45f
	G.B. 5cm^3/l	1.045a	0.206a	2.522f	52.12a	16.32a	1.590a	0.268a	2.104g	54.21a	18.54f
	PS 200 mg/l	1.225a	0.245a	3.448c	53.25a	16.54a	1.690a	0.298a	3.156b	56.32a	19.03e
	GB x PS	1.258a	0.285a	3.821c	54.12a	16.84a	1.554a	0.264a	2.876c	55.41a	20.56c
Irrigations levels											
100% ETc		1.961a	0.324a	4.014a	64.23a	20.02a	1.514a	0.248a	4.247a	59.33a	22.61a
75% ETc		1.782b	0.307b	3.226b	62.54b	19.22b	1.357b	0.217b	3.661b	56.87b	22.04b
50% ETc		1.325c	0.259c	2.451c	60.48c	18.11c	1.265c	0.186c	3.098c	51.63c	20.31c
Foliar application											
control		1.461c	0.315a	3.487d	55.23a	17.22a	1.870b	0.26a	2.960c	58.65c	21.36a
G.B. (5cm^3/l)		1.693b	0.335a	3.023c	54.12a	18.65a	1.638b	0.28a	3.126b	59.89b	21.42a
P.S. (200 mg/l)		1.846a	0.365a	4.221a	59.78a	19.22a	2.014a	0.31a	4.235a	62.55a	21.83a
G.B. x P.S.		1.698b	0.354a	4.012b	60.02a	18.96a	2.331a	0.32a	4.215a	59.25b	21.65a

Values followed by the same letter (s) within column are not significantly different ($P<0.05$)

4. Water use efficiency

Irrigation water use efficiency is defined as marketable yield per unit of irrigation water applied of growing plants, and is expressed as kg / m^3. Results of Table (7) express that the estimated 100% ET_c values were 998 and 965 mm in 2017 and 2018, respectively. The water consumptive use (CU) values were 4193 and 4056 m^3 fed^{-1} while the irrigation requirement (IR) were 5426 and 5249 m^3 fed^{-1}; during the two growth seasons of 2017 and 2018, respectively (the application efficiency for drip irrigation equal 85% and the leaching fraction was considered as 10% of water requirement).

Table (7). Consumptive water use efficiency (CWUE) and irrigation water use efficiency (IWUE) by Jerusalem artichoke plant at 2017 and 2018 seasons

	Treatment	Tuber yield (kg/fed)	Crop water consumptive use, CU (m^3/fed)	Consumptive water use efficiency, CWUE (kg/m^3)	Irrigation requirement, IR (m^3/fed)	Irrigation water use efficiency, IWUE (kg/m^3)	Tuber yield (kg/fed	Crop water consumptive use, CU (m^3/fed)	Consumptive water use efficiency, CWUE (kg/m^3)	Irrigation requirement, IR (m^3/fed)	Irrigation water use efficiency, IWUE (kg/m^3)
	Irrigation			Season 2017					Season 2018		
	100% ET_C	15456	4193	3.69	5480	2.82	16651	4056	4.11	5301	3.14
	75% ET_C	14253	3144	4.53	4110	3.47	16058	3042	5.28	3976	4.04
	50% ET_C	12687	2096	6.05	2740	4.63	13054	2028	6.44	2651	4.92
Irrigation levels	Foliar application										
100% ET_C	control	13690	4193	3.27	5480	2.50	13026	4056	3.21	5301	2.46
	G.B	14813	4193	3.53	5480	2.70	14254	4056	3.51	5301	2.69
	P.S	15023	4193	3.58	5480	2.74	14910	4056	3.68	5301	2.81
	G.B x P.S	15014	4193	3.58	5480	2.74	15451	4056	3.81	5301	2.91
75% ET_C	control	13012	3144	4.14	4110	3.17	13254	3042	4.36	3976	3.33
	G.B	13456	3144	4.28	4110	3.27	13894	3042	4.57	3976	3.49
	P.S	15253	3144	4.85	4110	3.71	15256	3042	5.02	3976	3.84
	G.B x P.S	15362	3144	4.89	4110	3.74	14963	3042	4.92	3976	3.76
50% ET_C	control	10456	2096	4.99	2740	3.82	11560	2028	5.70	2651	4.36
	G.B	12145	2096	5.79	2740	4.43	12681	2028	6.25	2651	4.78
	P.S	12365	2096	5.90	2740	4.51	12873	2028	6.35	2651	4.86
	G.B x P.S	12045	2096	5.75	2740	4.40	12895	2028	6.36	2651	4.86

The results of Table (7) demonstrate the effects of irrigation water regime and foliar antitranspirants on the irrigation water use efficiency. Irrigation water use efficiency was significantly decreased when plants were irrigated with 100% and 75% ETc compared to 50% ETc both seasons. Foliar antitranspirants application caused an increase in irrigation efficiency; never the less, potassium silicate was more effective than glycine betaine especially at 50% ET_C treatment. Karam *et al*. (2002) found the impact of deficit irrigation regimes on lettuce yield and water savings. They illustrate that water stress caused by the deficit irrigation; significantly reduced leaf number, leaf area index and dry matter accumulation. They also observed that applying 80 and 60% of ET_C reduced final fresh weight by 20% to 30% with comparison to the control treatment irrigated at 100% of ET_C. Bozkurt *et al.* (2009) reported that water deficit produced significant effect on yield and yield components except for plant dry weight.

Irrigation treatments affected significantly both the CWUE and IWUE during the two growth seasons. Under water stress, water was used efficiently more than normal irrigation. The higher values of water use efficiency observed under water stress treatment as compared to regular irrigation; was mainly due to less water applied for these treatments and the high obtained grain yield. These results are in agreement, more or less, with those reported by Mansour *et al*. (2001) and Bozkurt *et al*. (2009). Zhang *et al.* (2004) found that it is feasible to reduce irrigation amount in a certain growing stage of plant to maximize the irrigation water productivity.

CONCLUSION

An experimental investigation for two years was conducted to evaluate the response of drip irrigated Jerusalem artichoke to water stress. Increasing the irrigation water to 100%; increased the plant growth, nutrients uptake, and biological yield of plant. The tuber yield of Jerusalem artichoke plants irrigated with 75% of water requirements was lower by about 8% than that received 100% of water requirements. Irrigation Jerusalem artichoke by 100% of water requirements; increased the vegetative growth and lead to a slightly increasing in the tuber yield. Under drip irrigation system Jerusalem artichoke plants can be irrigated by only 75% of water requirements without any loss in the tuber yield.

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الملخص العربي

الرش بالجلايسين بيتايين وسيليكات البوتاسيوم وتأثيرهما على سلوك نمو نبات الطرطوفة المنزرعة في الأراضي الجيرية تحت ظروف الاجهاد المائي

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٢. معمل بحوث الأراضي الملحية و القلوية– معهد بحوث الأراضي و المياه و البيئة

اجريت تجربتان حقليتان على نبات الطرطوفة بالمزرعة البحثية لمعمل بحوث الاراضى الملحية والقلوية بالإسكندرية – مركز البحوث الزراعية – جمهورية مصر العربية. تمت الزراعة باستخدام صنف الفيوزا بغرض التعرف على تأثير كميات الرى المستخدمة فى ري نباتات الطرطوفة (١٠٠%، ٧٥%،٥٠% من البخرنتح الفعلى للنبات ET_C) ، وايضا دراسة تأثير الرش بسليكات البوتاسيوم وجلايسين البوتايين والتداخل بينهما والكنترول (الرش بماء مقطر) على عدد من الصفات الهامة لمحصول الطرطوفة، استخدم فى اجراء التجربتين نظام القطع المنشقة فى تصميم القطاعات الكاملة العشوائية وذلك فى ثلاث مكرارات حيث تم التوزيع العشوائى لمعاملات الري على القطع الرئيسية ومعاملات الرش على القطع تحت الرئيسية . تشير النتائج المتحصل عليها الى الاتى:

- تأثرت ايجابيا الصفات الخضرية لطول النبات ، وعدد الفروع الرئيسية/ للنبات، ووزن المجموع الخضرى الطازج مع معدلات الرى حيث اعطت المعاملة ١٠٠% ET_C اعلى المتوسطات بالمقارنه بمعدلات الرى الاخرى ، كما اعطت معاملة الرش بسيليكات البوتاسيوم بتركيز ٥سم^{3}/لتر اعلى قيم متوسطات كذلك اعطت معاملة التداخل الري عند مستوى٧٥% ET_C مع الرش بسيليكات البوتاسيوم بتركيز ٥سم^{3}/لتر اعلى قيم متوسطات لصفات االنبات الخضرية خلال موسمى الدراسة.
- اشارت النتائج التى تم الحصول عليها الى ان صفة المحصول الكلى من الدرنات (كجم/للنبات أو طن/الفدان) وصفات مكونات المحصول تأثرت ايجابيا بمستويات الري حيث كانت علاقة طرديه من المستوى ٥٠% الى المستوى ١٠٠% ET_C.
- سجلت اعلى قيم لمتوسط المحصول الكلى وصفاته من الدرنات عند معاملة الرش بسيليكات البوتاسيوم بتركيز ٥سم^{3}/لتر والرش بسلكات البوتاسيوم جلايسين البيتاين معا خلال موسمى الدراسة
- بالنسبة لمستويات الرى المختبرة اظهرت النتائج بوضوح علاقة طردية و معنوية مع المكونات الكيميائية للدرنات (النتروجين ،الفوسفور،البوتاسيوم ،محتوى الدرنات من الكربوهيدرات والانيولين) خلال موسمي الدراسة.
- لم يكن هناك اى تأثير معنوي للتداخل بين معدلات الرى و معاملات الرش على محتوى الدرنات من النسبة المئوية للنتروجين والفوسفور الكربوهيدرات خلال موسمى الدراسة باستثناءالانيولين خلال الموسم الاول من الدراسة .

- الاجهاد المائى يؤدى الى زياة كفاءة استخدام مياة الرى و قد وجد عند الرى بالمعاملة ٧٥ % من الاحتياجات المائية ادى ذلك الى انخفاض ضئيل فى المحصول و خصوصا عند استخدام مضادات النتح وقد أظهرت الدراسة تفوق للرش بسليكات البوتاسيوم على باقي معاملات الرش.

- توصى الدراسة بامكانية تطبيق تقليل كمية مياة الري المستخدمة لتوفير مياة الرى مع الاخذ فى الاعتبار اقتصاديات المحصول.