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Impact of different Irrigation Levels and Foliar Spraying with some Potassium Forms on Growth and Productivity of Garlic (*Allium sativum* L.)

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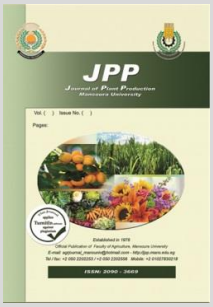

ABSTRACT

A strip-plot experiment was carried out during the two winter seasons of 2018/2019 and 2019/2020 at a private farm located in Demiana village, Belqas District, Dakahlia Governorate, Egypt. This study aimed to investigate the impact irrigation water levels and some potassium forms on garlic (cv. Balady) vegetative growth, water relations and leaves pigments, bulbs physical and chemical quality as well as yield and its components. Irrigation water level treatments were 50%, 75% and 100% full irrigation and different potassium forms (without, potassium citrate, potassium nitrate and potassium thiosulfate) at concentration of 1000 ppm as foliar spray. Results showed that all studied traits of garlic were significantly decreased with water irrigation deficit except electorate leakage, leaves and cloves dry matter, net ratio percentage, water use efficiency for fresh and cured yield and loss weight percent were improved. The highest values of all characters were achieved by potassium thiosulfate. However, the best values for leaves and cloves dry matter and loss weight percentage exhibited by potassium citrate. In addition, the most promising results were obtained from garlic plants treated with potassium thiosulfate interacted with full irrigation treatment which followed by the interaction treatment of full irrigation level with potassium citrate. It can be recommend treating garlic plants with potassium thiosulfate (1000 ppm) to improve yield and water use efficiency. As well as, potassium citrate (1000 ppm) to increase cloves dry matter and eliminate weight loss of cured yield of garlic bulbs under different irrigation levels.

Keywords: Garlic, water irrigation level, potassium forms, yield, water use efficiency and loss weight percentage.

INTRODUCTION

Garlic (*Allium sativum*, L.) is one of the most important vegetable plants that belong to the family *Liliaceae* and the genus *Allium*. Garlic bulbs are ordinarily utilized as a spice or in the medicinal objectives in order to it includes antibiotic substances known as allistatin and garlicin (Agusti, 1990). Also, it is utilized as antifungal, anti-bacterial, anti-cancer, lowering blood lipids and blood sugar. In Egypt, garlic is counted the second cultivated vegetable after onion as a bulbs source together with it is an important provenance of foreign exportation (Shama *et al*., 2016). Thence, rising garlic yield and enhancing bulb quality are major targets for producers to meet the demands of the consumers and the market (Shalaby and El-Ramady, 2014).

Irrigated crop production is substantial for world food security in order that it participates around 40% to the total food supply for the complete global (Garces-Restrepo*et al*., 2007).The incoming water lack caused by climate changes, although it is actually not fully known by the Egyptian agro-public, is a true challenge meeting agricultural evolution and crop production in special (Gebaly *et al*., 2013).Down such urgent threat of water restriction, irrigation water should be efficiently used so that water economies could be utilized in other activities for agricultural. Moreover, Costa *et al*. (2007) indicated that deficit irrigation water, a practice that deliberately lets crops as vegetables plants to tolerate some degree of water deficit with minor yield loss, has the possibility to increase water utilize efficiency and save water.

Potassium (K^+) is a moving element inside plants with little movement in the soil, and it is found inside tissues in the form of dissolved organic or inorganic salt that raises the osmotic pressure of the cellular juice and keeps the cells full so they do not swell (Roy *et al*., 2006).

It is called the quality element for its role as a catalyst in some important biological processes in the cell, such as photosynthesis, the releasing of starch into sugars, and in building protein. So, its deficiency causes the amino acids to accumulate and not be converted into protein (Wiedenhoeft, 2006). However, Benlloch-Gonzalez *et al*. (2008) pointed out that the low plant K state could inhibit water-stress-derived stomatal closure by means of ethylene synthesis, and stomata behavior could be safely decreased in K^+ starved plants. Also, potassium also participates to the survival of plants insecure to various biotic and abiotic stresses (Wang *et al*., 2013).

The main objective of this two-year study was to determine the impact of foliar spraying with different potassium sources on growth, water relations and leaves pigments, bulbs physical and chemical quality, yield and its components as well as water use efficiency and loss weight percentage for yield of garlic (cv. Balady) under irrigation water levels.

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MATERIALS AND METHODS

Two field experiments were carried out during the two winter seasons of 2018 and 2019 under clay loamy soil conditions using drip irrigation system at a private farm located in Demiana village, Belqas District, Dakahlia Governorate, Egypt to study vegetative growth and yield of garlic (cv. Balady) as influenced by irrigation water treatments in three levels *i.e.*, 50%, 75% and 100% from full irrigation and four foliar application with some potassium forms (without, potassium citrate, potassium nitrate and potassium thiosulfate) and their interactions. Physical and chemical analyses of soil were listed in (Table 1).

Table 1. Physical and chemical parameters from the top layer of soil 0-30 cm depth during the two seasons of 2018/2019 and 2019/2020

Seasons	Silt %	Clay %	Sand %	Texture soil	F.C %	W.P %	AW %	PH	E.C (dSm-1)	O.M %	$CaCO_3$ %	N ppm	P ppm	K ppm
2018	41.7	36.2	22.1	Clay loamy	35.5	18.8	16.7	8.17	1.54	1.87	3.38	52.9	5.9	298
2019	41.3	36.8	21.9	Clay loamy	35.1	18.3	16.8	8.19	1.68	2.01	3.43	53.5	6.3	292

F.C : Field Capacity - W.P.: Welting point - AW: Available water - OM: Organic matter

Garlic cloves uniformity in shape and size (cv. Balady) were sowing on 15th of September in both seasons on both sides of each dripper line at 12.5 cm distance. The ridge consists of three dripper lines. The plot area was 27 m^2 which consist of three ridges of 1.8 m wide and 5.0 m long. An alley (1.0 m wide) was left between irrigation water treatments.

Full irrigation (100% level) was calculated according to drip irrigation program which followed in the farm on both seasons. Equal amounts of irrigation water were added to all experimental units during germination period, application of water quantities for different treatments was done by using water counter at 2.0 bar, Water flow through the drippers (4 liter/h.). Irrigation water level treatments were started 10 days after sowing and repeated every 3 days until to 150 days after sowing, water irrigation amounts was determined through water counter (Table 2).

Table 2. Amounts of irrigation water applied (m^3 water/fed.) during the two seasons of 2018/2019 and 2019/2020.

Treatment	First season			Second seasons		
	100 %	75 %	50 %	100 %	75 %	50 %
Total	2315	1736	1157	2410	1807	1205

Foliar application with potassium forms (without, potassium citrate, potassium nitrate and potassium thiosulfate) at 1000 ppm for each type were started 30 days after sowing and repeated every 15 days until 15 days before harvesting time (180 days from sowing date).

Experimental design:

The experiment was arranged in a strip plots design with three replications. Irrigation water level treatments were arranged in horizontal plots, while foliar applications with potassium forms were assigned in vertical plots.

Measurements:

1. **Vegetative growth characters:** After 140 days from sowing date, ten plants were randomly chosen from each plot to determine, plant height, average plant weight, leaves number per plant, leaves area per plant and leaves dry matter percentage of garlic plants.
2. **Water relations and leaves pigments:** After 140 days from sowing date, ten plants were randomly chosen from each plot to determine, leaf relative water content (LRWC) according to Korkmaz *et al*. (2010), electrolyte leakage according to Hayatu *et al*. (2014), chlorophyll a, b and carotenoids contents were measured according to A.O.A.C (1990).
3. **Bulbs physical and chemical quality:** At harvest time (180 days from sowing date) all plants of each experimental plot were harvested and weighed to determine average plant weight. Then, ten plants randomly chosen to determine the net ratio percentage (Cloves weight/plant weight x 100), cloves dry matter percentage, Vitamine C (VC) and TSS in garlic cloves were determined according to A.O.A.C (1990).
4. **Yield and its component:** At harvest time and before curing, fresh yield per feddan and water use efficiency for fresh yield (was estimated according to El-Banna *et al*., 2001) were estimated. After that, all harvested plants per plot placed under shaded place for 15 days for curing then the cured yield per feddan, water use efficiency and loss weight percentage of cured yield were calculated.

Statistical analysis:

All data were statistically analyzed using the analysis of variance according to Snedecor and Cochran (1980). Least significant difference (LSD) at the probability of 5 % was used due to the procedure reported by (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Vegetative growth characters:

From data recorded in Table 3 it is obvious that all either 50% or 75% irrigation level treatments significantly decreased all garlic growth parameters compared with the 100% of full irrigation in both seasons. The lowest values of plant height, average plant weight, leaves number and area per plant were achieved by the 50% water level treatment. However, the highest value of leaves dry matter was achieved by 50% irrigation level. The vigorous impact of increasing irrigation up to the full level on plant growth could be demonstrated as a result of promoting cell division and enlargement which require additional water supplies (Hammad, 1991). Similar results were reported by Musa *et al*. (2019) on onion.

Generally, all potassium forms increased vegetative growth characters compared to control in both seasons. The greatest plant height, average plant weight, leaves number and area of garlic plants were noticed with potassium thiosulfate form. While, the best values of leaves dry matter percentage were exhibited by potassium

citrate in both seasons. Where, K^+ has remarkable function in open and closure of stomatal, photosynthesis, protein synthesis, transpiration and enzymes stability (Milford and Johnston, 2007). Likewise, Behairy *et al.* (2015) suggested that spraying onion plants by 2 liter potassium thiosulfate per feddan noticeably improved vegetative growth. Also, Shafeek *et al*. (2018) found similar results on pea plant.

Table 3 reveals that, the interaction of irrigation water levels and potassium forms was found statistically significant for vegetative garlic growth characters. The highest values in plant height, average plant weight, leaves number and leaves area per plant were obtained by the interaction between the full irrigation water (100%) and potassium thiosulfate form at 1000 ppm compared to control and the other interaction treatments under study in both seasons. In contrary, the highest values of leaves dry matter percentage were obtained by interaction between the 50% of full irrigation level and potassium citrate form followed by 75% irrigation level and potassium citrate application in the first and second seasons, respectively.

Generally, potassium (K) plays in particular crucial function in plant growth and metabolism and it donates extremely to the plants survivals that are under several biotic and abiotic stresses (Wang *et al*., 2013). Similar results were found by Ismail *et al.* (2017) on pea and Adhikari *et al.* (2020) on soybean plants.

Table 3. Impact of foliar application with some potassium forms after 140 days from sowing on vegetative growth characters of garlic under irrigation water levels during the two seasons of 2018/2019 and 2019/2020.

Treatments		Plant height (cm)		Average plant weight (g)		Leaves No/ plant		Leaves area / plant (cm^2)		Leaves DM%	
		1st s	2nd s	1st s	2nd s	1st s	2nd s	1st s	2nd s	1st s	2nd s
Irrigation water levels											
100%		87.8	88.5	131.1	134.3	7.87	8.06	458	470	14.42	14.64
75%		73.8	75.8	110.2	113.0	6.62	6.78	385	395	14.92	15.28
50%		54.8	56.1	81.8	83.8	4.91	5.03	286	293	15.21	15.50
LSD 5%		2.8	3.6	1.8	3.9	0.11	0.40	6.3	9.6	0.33	0.61
Foliar applications											
Without		64.6	65.4	96.5	98.5	5.79	5.91	337	344	13.40	13.63
Potassium citrate(PC)		74.0	76.7	110.4	113.5	6.62	6.81	386	397	16.27	16.73
Potassium nitrate (PN)		71.1	70.0	106.2	108.6	6.37	6.51	371	380	14.46	14.66
Potassium thiosulfate(PThs)		78.9	81.8	117.8	120.8	7.07	7.25	412	423	15.26	15.54
LSD 5%		5.4	4.2	9.5	10.4	0.57	0.86	33.0	35.7	1.39	1.47
Interaction											
100%	Without	75.9	76.0	113.4	116.0	6.80	6.96	396	406	13.85	13.89
	PC	90.8	95.0	135.5	138.9	8.13	8.33	474	486	14.96	15.41
	PN	86.1	79.7	128.5	131.1	7.71	7.86	449	458	14.17	14.20
	PThs	98.5	103.5	147.1	151.1	8.82	9.09	514	530	14.71	15.04
75%	Without	64.7	66.0	96.6	98.5	5.79	5.91	338	344	13.37	13.67
	PC	75.7	78.0	113.0	116.4	6.78	6.98	395	407	16.56	16.97
	PN	72.7	74.7	108.8	111.5	6.53	6.69	380	390	14.09	14.37
	PThs	82.2	84.4	122.6	125.5	7.36	7.53	429	439	15.65	16.12
50%	Without	53.2	54.3	79.5	81.1	4.77	4.86	278	283	12.99	13.31
	PC	55.3	57.0	82.7	85.1	4.96	5.11	289	297	17.30	17.82
	PN	54.4	55.7	81.2	83.1	4.87	4.99	284	290	15.12	15.12
	PThs	56.1	57.5	83.7	85.9	5.03	5.15	293	300	15.42	15.47
LSD 5%		8.6	7.2	14.3	16.1	0.86	1.35	50.2	54.0	2.11	2.28

Water relations and leaves pigments:

Data of both seasons in Table 4 indicate that the percentages of relative water content as well as the contents of chlorophyll a, b and carotenoids gradually increased with increasing irrigation water level in both seasons. In other words, the water levels of 75% and 50% significantly increased the electrolyte leakage % in both seasons. Chaparzadeh *et al*. (2003) found that the suitable evenness of moisture in plant creates adequate conditions for photosynthesis and metabolites translocation and it is necessary for chlorophyll texture. Also, Xu and Leskovar (2014) on cabbage showed that 75% ETc irrigation had little influence on photosynthetic rate but it temporarily increased chlorophyll and carotenoids content and reduced stomata conductance. Elhindi *et al.* (2016) demonstrated that salt stress impacted adversely the relative content of leaf water and the plant chlorophyll content, while it increased the electrolyte leakage of coriander plant.

Data listed in Table 4 suggest that spraying garlic plants with potassium thiosulfate at 1000 ppm significantly increased relative water content percentage as well as chlorophyll a, chlorophyll b and carotenoids contents without significant differences with potassium citrate, in most cases, compared to control plants during both seasons. In contrarily, the electrolyte leakage % was decreased by using any potassium form compared with untreated plants (control) during two seasons. Moreover, Shafeek *et al.* (2017) found that potassium thiosulfate at a rate of (2%) as foliar application on broad bean plants markedly enhanced pods quality and seeds chemical structure. Similarly, Adhikari *et al.* (2020) pointed out that potassium sulfate presented better positive influence on the carotenoids and chlorophyll contents of soybean leaves compared to those of potassium chloride.

It is evident from the obtained data in Table 4 that the interaction effect between water irrigation levels and potassium form treatments on relative water content % and chlorophyll a, b and carotenoids contents in garlic leaves had significant effect. The highest values of these constituents were achieved with application of potassium thiosulfate under full irrigation level. In most cases, water relations of garlic plant as well as leaves pigments were

gradually decreased under any potassium form when interacted with 100%, 75% then 50% irrigation levels, respectively. Gebaly *et al*. (2013) indicate that spraying cotton plants with potassium citrate under drought conditions tended to increase cotton leaves chemical content *i.e.*, chlorophyll a, b and carotene contents. In the same line, Behairy *et al*. (2015) pointed out that foliar application with potassium thiosulfate on onion plants enhancement growth characters.

Table 4. Impact of foliar application with some potassium forms after 140 days from sowing on water relations and pigments in leaves of garlic under irrigation water levels during the two seasons of 2018/2019 and 2019/2020.

Treatments		Relative water content (%)		Electrolyte leakage %		Chl. a mg/100g FW		Chl.b mg/100g FW		Carotenoids mg/100g FW	
		1st s	2nd s	1st s	2nd s	1st s	2nd s	1st s	2nd s	1st s	2nd s
Irrigation water levels											
100%		64.25	65.82	75.48	77.32	51.14	52.39	26.22	26.87	10.49	10.57
75%		54.03	55.36	83.62	85.68	43.00	44.06	22.05	22.60	8.82	9.04
50%		40.08	41.06	86.31	88.43	31.90	32.68	16.36	16.76	6.54	6.70
LSD 5%		0.88	1.99	3.82	3.98	0.70	0.73	0.36	0.69	0.14	0.24
Foliar applications											
Without		47.28	48.28	85.31	87.83	37.63	38.42	19.30	19.71	7.72	7.88
Potassium citrate (PC)		54.10	55.59	80.20	82.36	43.06	44.45	22.08	22.70	8.83	9.07
Potassium nitrate (PN)		52.04	53.21	83.48	85.17	41.42	42.35	21.24	21.72	8.49	8.68
Potassium thiosulfate (PThs)		57.73	59.25	78.23	79.88	45.95	47.16	23.56	24.18	9.42	9.44
LSD 5%		4.65	5.02	3.58	3.80	3.70	3.99	1.89	1.96	0.76	0.97
Interaction											
100%	Without	55.56	56.84	79.09	81.37	44.22	45.24	22.67	23.20	9.07	9.27
	PC	66.40	68.00	71.94	73.59	52.85	54.16	27.10	27.78	10.84	11.11
	PN	62.97	64.23	79.07	81.05	50.12	51.12	25.70	26.22	10.28	10.49
	PThs	72.05	74.21	71.83	73.27	57.35	59.07	29.41	30.29	11.76	11.43
75%	Without	47.32	48.27	86.62	89.22	37.66	38.41	19.32	19.70	7.72	7.88
	PC	55.39	57.05	83.76	85.68	44.08	45.41	22.61	23.29	9.70	9.31
	PN	53.32	54.65	85.29	87.42	42.44	43.50	21.76	22.31	8.70	8.93
	PThs	60.10	61.48	78.84	80.41	47.83	48.93	24.53	25.09	9.81	10.04
50%	Without	38.96	39.74	90.21	92.92	31.01	31.62	15.90	16.22	6.36	6.49
	PC	40.50	41.72	84.92	87.81	32.24	33.20	16.53	17.03	6.61	6.81
	PN	39.82	40.73	86.09	87.04	31.69	32.42	16.25	16.62	6.50	6.65
	PThs	41.04	42.07	84.04	85.97	32.67	33.48	16.75	17.17	6.70	6.87
LSD 5%		7.03	7.78	6.55	6.91	5.59	6.03	2.87	3.02	1.15	1.48

Bulbs physical and chemical quality:

The data given in Table 5 suggest that vitamin C (VC) content and total soluble solids (TSS) significantly improvement by increasing irrigation levels from 50%, 75 % to 100% of full irrigation. While, cloves dry matter percentage and net ratio percentage were significantly increased anticlockwise with irrigation water levels under study in both seasons. Since, Guidaa *et al*. (2017) stated that, as in prospect, deficit irrigation water encouraged higher tomato fruit quality of DM and TSS contents. Also, during tomato flowering with fruit setting, under deficit irrigation situations a close significant positive correlation was noticed between the total chlorophyll value and marketing yield quality and fruits vitamin C content (Nemeskéri *et al*., 2019). On garlic Abd El-Latif and Abdelshafy (2017) cleared that the amounts of applied irrigation water effect on performance of growth parameters which due to maintenance of soil moisture content in the root zone closer to field capacity.

From data presented in Table 5 it is clear that using potassium thiosulfate as foliar spray achieved highly values for net ratio %, VC and TSS compared to the other potassium forms and control but non-significant with potassium citrate under study in both seasons. Whereas, foliar spray with potassium citrate at 1000 ppm significantly increased dry matter of garlic cloves compared to control and the other ones under study. In general, all potassium forms significantly increased garlic bulbs chemical quality parameters compared with control. Lester *et al*. (2005) reported that foliar application of potassium thiosulfate has been connected with enhanced soluble solids and ascorbic acid levels, increased shelf life and shipping quality of muskmelon fruit. John and Gene (2011) indicated that foliar potassium thiosulfate (KTS) treatment result in higher plant tissue K contents, big soluble solids (TSS) and bioactive synthesis (ascorbic acid) on cantaloupe fruits. In the same trend, Afzal *et al*. (2017) noticed that due to positive correlation between potassium nutrition and fruit quality parameters, application of a suitable K rate can contribute to better quality of tomato fruits.

Data presented in Table 5 indicate that the interaction treatment between full irrigation water level and 1000 ppm foliar application of potassium thiosulfate was superior in VC and TSS compared to the other ones under study in the two seasons. In most cases, all interaction treatments between irrigation water levels and potassium forms increased cloves dry matter and net ratio percentages compared to control (full irrigation level interacted without potassium application) in both seasons. In special, application of potassium citrate under each irrigation levels achieved the highest values for cloves dry matter in both season. The highest values of net ratio percentage were represented in combination between 50% water irrigation

level and potassium thiosulfate foliar spray compared to the other interaction treatments. Similarly, Amjad *et al*. (2014) concluded that the application of potassium as foliar spray increases yield and its quality of tomato fruits in saline soil. In the same line, Behairy *et al*. (2015) pointed out that foliar application with potassium thiosulfate on onion plants increased bulb goodness as well as bulb chemical structure.

Table 5. Impact of foliar application with some potassium forms after 180 days from sowing on average plant weight, net ratio, cloves dry matter, VC and TSS of garlic under irrigation water levels during the two seasons of 2018/2019 and 2019/2020.

Treatments		Average plant weight (g)		Net ratio %		Cloves DM %		VC mg/100g F.W		TSS %	
		1st s	2nd s	1st s	2nd s	1st s	2nd s	1st s	2nd s	1st s	2nd s
Irrigation water levels											
100%		155.5	159.3	78.05	78.46	22.17	22.73	22.28	22.83	26.22	26.97
75%		125.2	128.2	82.42	82.54	27.27	27.95	18.74	19.21	22.07	22.59
50%		86.3	88.0	82.62	82.97	28.00	28.69	13.92	14.25	16.36	16.76
LSD 5%		6.66	7.17	0.39	0.65	1.05	0.47	0.30	0.52	0.34	1.29
Foliar applications											
Without		115.3	117.8	78.74	79.28	23.92	24.42	16.41	16.74	19.31	19.70
Potassium citrate(PC)		124.3	127.5	81.89	82.08	27.71	28.45	18.76	19.29	22.09	22.81
Potassium nitrate (PN)		119.8	122.4	79.82	80.04	25.41	26.00	18.06	18.47	21.23	21.72
Potassium thiosulfate(PThs)		129.9	132.9	83.68	83.89	26.22	26.94	20.02	20.54	23.57	24.19
LSD 5%		5.78	7.24	ns	ns	1.12	1.24	1.62	2.36	1.90	2.41
Interaction											
100%	Without	148.9	152.9	75.66	76.81	19.54	19.93	19.30	19.73	22.70	23.17
	PC	158.4	162.0	78.37	78.88	24.56	25.17	23.00	23.57	27.10	28.17
	PN	152.3	155.2	77.45	76.99	21.56	22.11	21.83	22.30	25.70	26.23
	PThs	162.2	167.1	80.71	81.18	23.03	23.71	25.00	25.73	29.40	30.30
75%	Without	116.2	118.2	80.00	79.93	25.92	26.44	16.40	16.73	19.33	19.70
	PC	128.4	132.3	84.20	84.23	29.51	30.39	19.23	19.80	22.63	23.27
	PN	123.4	126.3	81.00	81.40	26.68	27.35	18.50	19.00	21.76	22.30
	PThs	132.6	135.8	84.50	84.60	26.98	27.60	20.83	21.30	24.53	25.10
50%	Without	80.8	82.4	80.55	81.10	26.30	26.90	13.53	13.77	15.90	16.23
	PC	86.0	88.2	83.11	83.14	29.06	29.79	14.06	14.50	16.53	17.00
	PN	83.8	85.7	81.00	81.73	27.99	28.55	13.83	14.13	16.23	16.63
	PThs	94.7	95.7	85.83	85.90	28.66	29.52	14.23	14.60	16.77	17.17
LSD 5%		10.85	12.92	6.00	7.31	1.96	1.92	2.44	3.57	2.87	3.82

Yield and its component:

Data recorded in Table 6 reveal that irrigation water levels significantly reduced fresh and cured yield per feddan compared to full irrigation level in both seasons. In other words, water use efficiency for fresh and cured yield significantly increased by irrigation level decreased from 100% to 50%. However, the best values in loss weight percentage were recorded with 50% irrigation level compared to the other two ones under study in the two consecutive seasons. Furthermore, the reduction in average potato tuber yield resulted from drought stress may be attributed to its hazardous influence on plant growth especially total leaves area and fresh and dry weights of leaves/plant (Leilah, 2009). Abd El-Latif and Abdelshafy (2017) cleared that fresh bulb yield and cured bulb yield of garlic were increase in parallel with amount of water irrigation. On other hand, It was also noticed that WUE increased with deficit irrigation water quantity under drip irrigation system. Also, showed that values of average weight loss percent of cured yield was decreased in parallel with more decreasing irrigation water quantity.

The data illustrated in Table 6 show that fresh and cured yield per feddan and water use efficiency for fresh and cured yield were improved due to the application of any potassium form compared to control, however, the same parameters were significantly increased under potassium thiosulfate and citrate foliar spray compared to the other one under study in both seasons. Likewise, foliar application of potassium to carrot plants improved the yield components compared to untreated plants (El-Tohamy *et al*., 2011). Also, Amjad *et al*. (2014) and Liu *et al*. (2019) on tomato plants have found similar results. In contrast, loss weight percentage after curing was decreased when potassium treatments was applied compared without application one in both seasons. Whenever, loss weight percentage of garlic yield after curing recorded the lowest rates under 1000 ppm potassium citrate application compared to control and the other potassium forms.

Table 6 reveals that, all potassium forms significantly increased garlic fresh and cured yield per feddan (ton) as well as water use efficiency for fresh and cured yield (kg/m^3 water) under any irrigation water deficit level. The best interaction treatments in increasing total yield per feddan after were potassium thiosulfate interacted with full irrigation level followed by potassium citrate interacted with full irrigation level compared to the other interaction treatments under study. As well as, potassium thiosulfate and citrate exhibited good values 9.17 and 8.90 for WUE fresh yield as well as 6.82 and 6.79 for WUE cured yield under sever irrigation level which superior than WUE under full irrigation without foliar spray of potassium. Moreover, Lester *et al*. (2006) found that foliar application of potassium thiosulfate has been connected with improved yields and fruit size of cantaloupe plants compared to control. In addition, Aboelill *et al*. (2012) stated that foliar spray of potassium (at 800 cm^3/feddan) recorded the highest values of yield attributes (number of pods per plant, weight of pods and seeds per plant, and

seed index) of peanut plants under water stress conditions in both seasons. In the same trend, Sapt *et al*. (2019) indicated that spraying garlic plants with potassium silicate at 500 ppm under water stress conditions caused improved of yield parameters. Generally, loss weight percentage of garlic yield after curing recorded the lowest rates under 1000 ppm potassium citrate application compared to control and the other potassium forms under different levels of irrigation, with significant differences between them, in both seasons. Moreover, the treatment with potassium citrate under 50% irrigation level gave the least weight loss (23.5 and 21.2%) in 1st and 2nd season, respectively. Furthermore, Costa *et al*. (2007) reported that moderate water stress could be beholden an efficient practice that may upgrade vegetable quality with probable yield loss. Potassium citrate is citric acid potassium salt which counted one of the most serious organic acids in the respiratory pathways into cells of plant (Taiz and Zeiger, 2002). In addition, citric acid plays a remarkable role in plant metabolism, it's as non-enzymatic antioxidant in chelating free radicals and preserving plant from damage could result in extending the shelf life of plant cells and improving yield quality (Sadak and Orabi, 2015).

Furthermore, Ibrahim *et al*. (2015) found that the application potassium citrate at 2000 ppm was the most favorable treatments for increasing number of potato tuber, yield per plant and feddan and marketable yield in both seasons. In the same line, Behairy *et al*. (2015) pointed out that foliar application with potassium thiosulfate on onion plants increased yield.

Table 6. Impact of foliar application with some potassium forms on garlic yield and its components under irrigation water levels during the two seasons of 2018/2019 and 2019/2020

Treatments		Fresh yield/ fed. (ton)		Cured yield/ fed. (ton)		WUE fresh yield (kg / m^3 water)		WUE cured yield (kg / m^3 water)		Loss weight % after curing	
		1st s	2nd s	1st s	2nd s	1st s	2nd s	1st s	2nd s	1st s	2nd s
Irrigation water levels											
100%		17.41	17.84	11.55	12.13	7.52	7.40	4.99	5.03	33.70	32.07
75%		14.02	14.35	10.18	10.68	8.07	7.94	5.86	5.91	27.47	25.69
50%		9.67	9.86	7.13	7.45	8.35	8.18	6.16	6.18	26.31	24.50
LSD 5%		0.75	0.80	0.54	0.59	0.36	0.42	0.28	0.32	0.40	0.41
Foliar applications											
Without		12.92	13.20	8.76	9.12	7.51	7.36	5.15	5.16	31.46	30.09
Potassium citrate(PC)		13.92	14.28	10.10	10.67	8.09	7.97	5.94	6.03	26.71	24.51
Potassium nitrate (PN)		13.42	13.71	9.30	9.71	7.81	7.67	5.47	5.49	30.14	28.53
Potassium thiosulfate(PThs)		14.55	14.88	10.33	10.84	8.52	8.36	6.12	6.15	28.34	26.55
LSD 5%		0.65	0.81	0.45	0.57	0.36	0.39	0.26	0.28	0.29	0.29
Interaction											
100%	Without	16.38	17.12	10.65	11.15	7.21	7.11	4.60	4.63	36.13	34.85
	PC	17.74	18.15	12.11	12.76	7.66	7.53	5.23	5.30	31.72	29.67
	PN	17.06	17.39	11.21	11.69	7.37	7.21	4.84	4.85	34.26	32.75
	PThs	18.17	18.71	12.23	12.91	7.85	7.76	5.28	5.36	32.68	31.00
75%	Without	13.02	13.24	9.14	9.48	7.50	7.33	5.27	5.25	29.78	28.37
	PC	14.39	14.82	10.80	11.46	8.29	8.20	6.22	6.34	24.90	22.65
	PN	13.82	14.14	9.90	10.36	7.96	7.83	5.70	5.73	28.39	26.74
	PThs	14.86	15.22	10.87	11.41	8.55	8.42	6.26	6.31	26.82	24.99
50%	Without	9.05	9.23	6.47	6.73	7.82	7.66	5.59	5.59	28.48	27.05
	PC	9.64	9.88	7.37	7.78	8.32	8.20	6.37	6.46	23.50	21.20
	PN	9.39	9.60	6.78	7.10	8.11	7.97	5.86	5.89	27.76	26.10
	PThs	10.61	10.72	7.90	8.19	9.17	8.90	6.82	6.79	25.52	23.66
LSD 5%		1.21	1.45	0.85	1.03	0.65	0.72	0.47	0.53	0.48	0.60

CONCLUSION

From the obtained results, it could be concluded that the best growth characters, water relations, leaves pigments, bulb physical and chemical quality were enhancement with full irrigation (100% level) interacted with potassium thiosulfate and potassium citrate except leaves dry matter, cloves dry matter and net ratio percentage were improvement with decreasing irrigation level. As well as, fresh and cured yield were improvement with potassium thiosulfate and potassium citrate under all irrigation levels where, water use efficiency showed best values with decreasing irrigation levels with potassium thiosulfate. lowest loss weight percentage after curing period were belonged to 50% and 75% irrigation levels sprayed with 1000 ppm potassium citrate. It is preferable to conduct more scientific studies on the importance of using potassium thiosulfate to maximize the yield of garlic and potassium citrate to extend storage period of garlic bulbs.

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تأثير مستويات الري المختلفة والرش الورقي ببعض صور البوتاسيوم على نمو وإنتاجية الثوم

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أجريت تجربة قطعة منشقة مرة واحدة خلال فصل الشتاء لعامي 2019/2018 و 2020/2019 في مزرعة خاصة بقرية ديميانا، مركز بلقاس، محافظة الدقهلية، مصر. هذه الدراسة تهدف الى بحث تأثير مستويات مياه الري وبعض صور البوتاسيوم على النمو الخضري للثوم (الصنف بلدي)، العلاقات المائية وصبغات الأوراق، الأبصال وجودتها الطبيعية والكيميائية وكذلك المحصول ومكوناته. كانت معاملات مياه الري عبارة عن ثلاث مستويات (50%، 75% و 100% من الري الكامل) وصور مختلفة من البوتاسيوم تشمل (بدون رش، سترات البوتاسيوم، نترات البوتاسيوم وثيوسلفات البوتاسيوم) بتركيز 1000 جزء في المليون رشاً على الأوراق. أظهرت النتائج أن جميع صفات الدراسة للثوم انخفضت معنوياً مع نقص ماء الري عدا التوصيل الكهربى، المادة الجافة للاوراق والفصوص، نسبة التصافى وكفاءة استخدام مياه الرى للمحصول الطازج والمعالج ونسبة الفقد فى وزن الابصال المعالجة قد تحسنت. تم الحصول على أعلى قيم لصفات النمو باستخدام ثيوسلفات البوتاسيوم. ومع ذلك افضل القيم لصفات المادة الجافة للاوراق والفصوص ونسبة الفقد فى الوزن كانت باستخدام سترات البوتاسيوم. بالاضافة لذلك، تم الحصول على أكثر النتائج الواعدة من نباتات الثوم المعاملة بثيوسلفات البوتاسيوم عند التفاعل مع معاملة مستوى الري الكامل والتي تبعت بمعاملة التفاعل بين الري الكامل وسترات البوتاسيوم. يمكن ان نوصى بمعاملة نباتات الثوم بثيوسلفات البوتاسيوم (1000 جزء فى المليون) لتحسين المحصول وكفاءة استخدام مياه الرى. وبالمثل سترات البوتاسيوم (1000 جزء فى المليون) لزيادة المادة الجافة للفصوص والحد من الفقد فى وزن محصول الثوم المعالج تحت مستويات الرى المختلفة.