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Comparison between Organic and Mineral Sources of Potassium and Their Effects on Potassium Fractions in Clay Soil and Productivity of Potato Plants under Water Stress Conditions

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POTASSIUM (K) is an essential element for plant growth that maintains water balance within its cells. Different forms of K were investigated for their effects on potato (*Solanum tuberosum*, cv. Spunta) plants grown under water stress conditions as a kind of adaptation to the climatic changes and water shortage under Egyptian soil conditions. Also, knowledge of different K fractions in the studied clay soil is important to achieve the sustainability in agriculture. Therefore, a field experiment was conducted during the two tested seasons of years 2014 and 2015 at the Faculty of Agriculture, Ain Shams University, Qalubia governorate, Egypt. Two sources of K were tested under three levels of irrigation water in a split-plot design. Results indicated that K fractions in soil were in order of total K > non-exchangeable/ fixed > exchangeable > water soluble. The 50% irrigation level of irrigation requirements (IR) combined with K-humate as ground application increased water soluble and exchangeable K in the studied soil. While there was hardly no changes observed due to the applied treatments on fixed and total amounts of K in the soil. Regarding the studied vegetative growth and yield parameters of the growing potato plants, the treatment 100% of IR combined with K-humate as soil application caused significant increases. The specific gravity of tuber, as an important indicator of potato tuber quality, recorded the highest value by applying 50% of IR combined with K-humate as ground addition, compared to mineral addition which came in the second order. Regarding the nutrient concentrations in potato haulm, results revealed that the 50% of IR combined with K-humate gave the highest content of N, while the same irrigation level with K-humate plus foliar spray gave the highest content of P and K, during the two tested seasons. In tubers, 50% of IR combined with K-humate as soil application gave the highest concentration of N and P during the two tested seasons, while 75% of IR in the first season and 50% of IR in the second season combined with K-humate plus foliar spray gave the highest values of K content. The calculated water use efficiency (WUE) showed that the highest value was obtained by 50% irrigation level of IR combined with soil application of K-humate.

Keywords: Potassium humate, Potassium sulphate, Ground application, Foliar application, Potassium fractions in clay soil, Productivity of potato plants, Irrigation water levels.

Introduction

Potato (*Solanum tuberosum* L.) is one of the common vegetable in Egypt. Their tubers are good sources of carbohydrates, proteins, vitamins and minerals (Blagoeva et al., 2004). The quality of potato tubers as well as their chemical composition are mostly influenced by many factors e.g. soil fertility and the used agro-chemicals (Rytel et al., 2013). Potassium is an essential nutrient for plant growth that influences synthesis, location, transformation and storage of carbohydrates, tuber quality and processing characteristics as well as plant resistance to stresses and diseases (Ebert, 2009). Although, the reserved K in the soil is generally high; however, most of its concentrations are incorporated within the crystal lattice structure of the clay minerals thus being unavailable to plants (Zörb et al., 2014). Therefore, additional K-containing sources are necessary to sustain optimal plant growth performance and yield components (Zörb et al., 2014). In this concern, potassium humate

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(an organic fertilizer) is thought to be a safer K-amendment in food production than potassium sulphate (mineral fertilizer). This amendment not only improves the product quality, but also increases the plant tolerance towards disease, pests and other environmental stresses such as heat, cold and drought (Ajalli et al., 2013). Also, it can increase the nutrient content of soil and growing plants, which is reflected in increasing fertilizer use efficiency (Mosa, 2012).

Egypt has already reached the water poverty limit and needs a much greater share of Nile water in year 2050 to cover the shortage and face the increment in requirements due to increase population. Also, surface freshwater pollution has embarked on a critical path. So, it is necessary to reduce consumption of water irrigation (El-Ramady et al., 2013). Potato is a sensitive crop to water stress (Onder et al., 2005). Thus, the irrigation schedule should be managed in combination with optimized fertilizer applications to ensure high productivity of the potato yields. An application of K fertilizers (120 kg K ha^{-1}) under controlled deficit irrigation (80% of soil field capacity) improved the quantity and quality of potato yield, together with elevated WUE (Abd El-Latif et al., 2011). Moreover, Mosa (2012) reported that amending soils with potassium humate can increase the moisture retention in the root zone, and therefore improves the irrigation efficiency.

Thus, the main objective of this study was to evaluate the effect of K fertilization from different sources (organic and mineral), and applied with different methods (ground and foliar applications) on K fractions and productivity of potato plants grown in clay soil under different irrigation water levels.

Materials and Methods

The current study was carried out during the two successive autumn seasons of the years 2014 and 2015 at the experimental farm of Faculty of Agriculture, Ain Shams University, Qalubia Governorate, Egypt. The average temperature was 20±4.5^{o}C, the relative humidity was 62±7% and the evapotranspiration rate ET_o was 3.5±1.6 mm day^{-1}. The investigated soil was a clayey one (*Vertic Torrifluvents*) and its physical and chemical properties were determined, before cultivation, by the standard methods outlined by Klute (1986) and Page et al. (1982) and the obtained results are shown in Table 1.

TABLE 1. Some physical and chemical properties of the studied soil (0-30 cm)

Particle size distribution, %		**Soluble ions, $mmol_c$ L^{-1}**	
Sand	21.9	Ca^{2+}	3.00
Silt	23.6	Mg^{2+}	2.90
Clay	54.5	Na^{+}	0.93
Textural class	Clay	K^{+}	0.72
Field capacity, %	45.6	HCO_3^-	2.36
Wilting point, %	4.03	Cl^-	1.23
$CaCO_3$, g kg^{-1}	11.4	SO_4^{2-}	2.01
OM, g kg^{-1}	9.40	**Total macronutrient, %**	
CEC, $cmol_c$ kg^{-1}	43.9	N	0.18
pH (1:2.5)	7.45	P	0.03
EC_e, dS m^{-1}	0.46	K	1.49

Carbonate ions were not detected.

Potato tuber seeds (*Solanum tuberosum*, cv. Spunta) were obtained from Agriculture Research Center. Potassium humate solution was purchased from FAM Company for agricultural development (Grandy solution). Potassium humate (powder) and sulphate (granules) were obtained from Agriculture Research Center. Characteristics of the investigated K fertilizers are shown in Table 2. Tuber seeds of potatoes were sown on the 29th and 27th of October 2014 and 2015, respectively, in rows of 80 cm width and 50 cm between hills. The experiment was laid out in a split-plot design with three replications. The main plots were assigned to the irrigation treatments (50, 75 and 100% of IR) and the subplots were assigned to the different sources of K fertilization which were applied after one month of cultivation (*i.e.* potassium humate or sulphate amended to soils at a rate of 1 g/ plant, potassium humate as ground application at a rate of 0.5 g/ plant plus foliar application of potassium humate at a rate of 2.5 cm^3/ L/ plant, and potassium sulphate amended to soils at a rate of 0.5 g/ plant plus potassium sulphate solution sprayed on plants at a rate of 0.25 g/ L/ plant as foliar application). Treatments that contained foliar application were added through two irrigation periods in the same week. All plants received the recommended doses of N and P fertilizers according to the Ministry of Agriculture *i.e.* 240 kg P ha^{-1} in the form of ordinary superphosphate amended before cultivation and 360 kg N ha^{-1} in the form of ammonium sulphate 30 days amended after plant cultivation.

Flow meter was installed for each irrigation level treatment; two meters were left between each two irrigation levels; plants were irrigated by using drippers of 4 L h^{-1} capacity. Calculations of irrigation levels were performed whereas the irrigation control was practiced via manual valves for each experimental plot. The total amount of irrigation requirement was calculated by FAO, Penman-Monteith procedure (Alva, 2008). The potential evapotranspiration was calculated as follows:

$$ET_o = \frac{0.408\Delta\,(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\, u_2)} \quad (1)$$

Where:
ET_o = Daily reference evapotranspiration (mm day^{-1}),
R_n = Net radiation at the crop surface (MJ m^{-2} day^{-1}),
G = Soil heat flux density (MJ m^{-2} day^{-1}),
T = Mean daily air temperature at 2 m height (°C),
u_2 = Wind speed at 2 m height (m s^{-1}),
e_s = Saturation vapor pressure (k Pa),
e_a = Actual vapor pressure (k Pa),
Δ = The slope of vapor pressure curve (k Pa °C^{-1}),
γ = The psychometric constant (k Pa °C^{-1}).

The second step was to obtain values of crop water consumptive use (ET_{crop}) as described by Alva (2008); it was calculated as the following:

$$ET_{crop} = ET_o\ K_c \quad \text{mm/ day……} \ (2)$$

Where:
ET_o = The rate of evapotranspiration from an excessive surface of green cover of uniform height (8 to 15 cm), actively growing, completely shading the ground and did not suffer from water shortage.

K_c = Crop coefficient (ranged from 0.6 to 1.2).

Irrigation requirements (IR) were calculated as follow, see Table 3.
IR = ET_{crop} x % LR x R × 10000/ 1000(m^3/ ha/ day) (3)

Where:
LR % = Leaching requirement percentage (22% of the water requirement based on the leaching fraction equation).

R = Reduction factor for drip irrigation that only covers a part of land and the rest dry leaves. It was recommend by Alva (2008) to use R value which ranged between 0.25 and 0.90 for drip irrigation system.

At the physiological maturity growth stage *i.e.* 10th and 14th of February 2015 and 2016, respectively, whole plants were harvested and the total yield of tubers was estimated in ton ha^{-1} for each treatment. Plant samples were collected to determine the plant height, number of stems per plant, haulm fresh weight, number of tubers per plant and specific gravity of tubers. The specific gravity of tubers was determined following underwater weight method using 2.5 kg of medium sized tuber by the following equation by Nissen (1967):

Specific gravity = the weight of the tuber in air/ (weight of the tuber in air – its weight in water)

Tubers and haulm samples were digested using a mixture of H_2SO_4/H_2O_2 according to the method described by Page et al. (1982). Total nitrogen was determined by Kjeldahl method according to the procedure described by Chapman and Pratt (1961). Phosphorus content was determined using Spectrophotometer according to Watanabe and Olsen (1965). Potassium content was determined photometrically using Flame photometer as described by Chapman and Pratt (1961).

TABLE 2. Some characteristics of the studied treatments

Treatment	pH (1:5)	EC_e, dS m^{-1}	Total N, %	Total P, %	Total K, %
Potassium Humate (Powder)	9.11	21.6	10.5	0.003	2.47
Potassium Humate (Solution)	6.94	0.22	0.98	0.40	0.19
Potassium Sulphate (Granules)	6.50	162	n.d*	n.d	48.0

*n.d means not detected.

TABLE 3. The average of weekly irrigation water requirements under different irrigation water levels for potato plants at the studied site

Weeks after planting	1st season, 2014/ 2015			2nd season, 2015/ 2016		
	m^3 ha^{-1}			m^3 ha^{-1}		
	50%	75%	100%	50%	75%	100%
1	68	102	136	63	95	126
2	70	106	141	66	100	133
3	74	111	148	70	105	140
4	79	119	159	76	114	152
5	84	127	169	83	124	165
6	96	145	193	90	135	180
7	100	150	200	93	140	187
8	103	155	206	102	154	205
9	119	179	238	112	168	224
10	129	194	259	122	183	243
11	126	189	253	127	190	253
12	125	188	251	124	187	249
13	121	182	243	121	182	242
14	119	179	238	113	169	225
15	127	191	254	115	172	229
16	112	169	225	105	158	211
17	91	137	182	90	135	181
18	76	115	153	77	116	154
19	71	107	143	62	93	125
20	57	85	113	59	88	117
Total	1951	2927	3903	1871	2806	3741

Soil samples (0-30 cm) were collected from the rhizosphere after plant harvest. These samples were air dried and grounded to pass through a 2 mm sieve. The grounded samples were analyzed for their contents of different K fractions, *i.e.* water soluble, exchangeable, non-exchangeable/ fixed in the lattice structure of clay minerals and total K. Water soluble K (H_2O-K) was extracted by shaking 2.5 g soil in 50 mL deionized water for 30 minutes (Habib et al., 2014). Exchangeable K was extracted with 1.0 M NH_4OAC (Knudsen et al., 1982). Non-exchangeable K was extracted with boiling 1.0 M HNO_3 (Martin and Sparks, 1983). Total K in soils was estimated by digesting soil samples using a mixture of H_2SO_4/H_2O_2 according to the method described by Page et al. (1982).

Water use efficiency (WUE) was calculated according to Cantore et al. (2014) as the ratio between the crop yield (Y) and the amount of water for irrigation throughout the growth season (IR).

$$\text{WUE (kg m}^{-3}\text{)} = \text{Y (kg)/ IR (m}^3\text{)}$$

The obtained data were then statistically analyzed using SAS software package. The means that were significant were separated using Duncan's multiple range test at P≤0.05 (SAS, 2000).

Results and Discussion

Potassium fractions in soil as affected by the different K sources and irrigation water levels

Water soluble K

Data illustrated in Fig. 1 showed that the soluble K increased in soils in the following descending order: humate > sulphate > humate plus humate spray > sulphate plus sulphate spray > control. On the other hand, the concentrations of water soluble K decreased in soils with increasing the level of irrigation water. This might be attributed to leachability of K from soil surfaces owing to the increases in irrigation water level. Probably, the dilution effect of soluble soil-K with increasing soil moisture accounted for such reductions. Humate treatment combined with 50% irrigation water level of IR recorded the highest increase in water soluble K (72%), followed by the sulphate treatment combined with 50% of IR, recording 61% increase. Wang and Huang (2001) found that application of humic substances prevent K^+ ions from leaching due to the influence of functional groups commonly present in humic acid (HA), including carboxyl, phenol and hydroxyl, which contributed in K^+ binding by HA.

Exchangeable K

The values of exchangeable K are depicted in Fig. 2. It was found that soils amended with either humate or sulphate under 50% of IR recorded the highest increases in the fraction of exchangeable K. Such increases were 21 and 10%, respectively, compared to the control. This might take place because K-humate is a soluble K source that is readily available to be absorbed by the cultivated plants (Sparks, 2000), while on the other hand, this treatment decreased K fixation by clay minerals (Bansal, 2000). Increasing the irrigation water level from 75 to 100% of IR led to significant reduction in the exchangeable K fraction, while on the other hand, decreasing soil moisture from 75 to 50% of IR recorded no significant effect on this fraction.

Potassium fixed by clay minerals or difficult to exchange

It seems that the soil and foliar applications of humate or sulphate recorded no significant effect on the non-exchangeable K content as compared to the control treatment (Fig. 3). Likewise, increasing the level of water irrigation seemed to be of no further significant effect on the non-exchangeable K content. The forms of soil K can be arranged according to their availability to plants and microbes as follows: solution > exchangeable > fixed/ non-exchangeable (Sparks, 2000). Thus, the non-exchangeable K content is thought to be the soil reservoir of K (Mengel & Uhlenbecker 1993 and Cox et al., 1999) that releases in more available forms when the levels of soluble and exchangeable K decreased in soils by plant uptake and soil leaching (Martin and Sparks, 1983). Higher non-exchangeable contents of K were observed in soils of high clay and silt contents (Tiwari and Nigam, 1994). In such soils, the degree of K fixation depends on many factors *e.g.* the type of clay mineral, its charge density, the degree of interlayering, the moisture content, the concentration of competing cations, and the pH of the ambient solution bathing the clay or soil (Sparks, 2000).

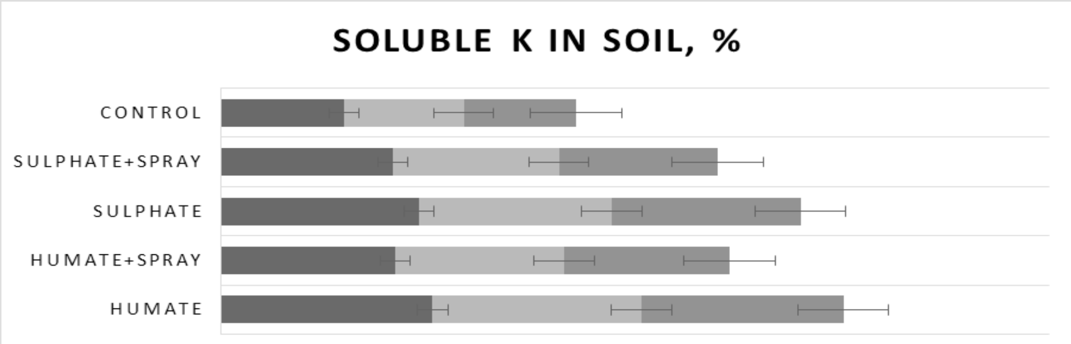
Total K

The results indicated that little changes occurred in the total content of K in the studied soil due to the effect of different applied K sources and irrigation water levels, especially for humate or sulphate plus foliar spray combined with 50 or 75% irrigation water from IR, with the same trend of non-exchangeable K (Fig. 4). Total K depends on the presence of K bearing primary and secondary minerals in the soil. Clay mineralogy is a key factor affecting dynamics of K in the soils (Ghiri and Abtahi, 2011). Also, the results reported that organic source of K increased total K in the studied soil (Fig. 4).

Productivity of potato plants as affected by the different K sources and irrigation water levels

Vegetative growth parameters

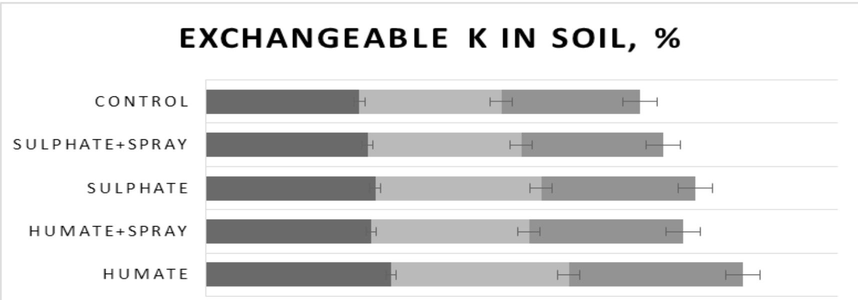
Table 4 reveals that increasing the level of water irrigation was associated to concurrent increases in plant height, number of stems per plant, haulm fresh and dry weights during both seasons of study. Increasing soil moisture content probably decreased soil salinity (via salt leaching), and thus improved soil environmental conditions in the rhizosphere to become more favourable for encouraging plant growth. On the other hand, low irrigation level or drought stress conditions decreased plant growth probably through the reductions that occurred in root extension while increasing leaf thickness as an adaptation mechanisms towards low soil moisture content (Hashem, 2007). Regarding the effect of K sources on plant growth parameters, soil application of K-humate, followed by K-sulphate recorded the highest increases in such vegetative growth characteristics. Humic acid chelate K^+ ions and therefore, minimizes their fast transformations to more complexed forms (Bocanegra *et al.*, 2006). Also, K in form of potassium sulphate is readily available to uptake with plant roots (Ayeni and Adeleye, 2014). The interaction among the studied treatments showed that water irrigation up to 100% of IR with K in the organic form applied as ground application recorded the highest increases in plant growth parameters.



	Humate	Humate+Spray	Sulphate	Sulphate+Spray	Control
50%	0.064	0.053	0.060	0.052	0.037
75%	0.063	0.051	0.058	0.050	0.036
100% of IR	0.061	0.050	0.057	0.048	0.034

*Each value was the mean of 6 replications during the two studied seasons.

Fig. 1. Effect of different K sources and irrigation water levels on soluble K in the studied soil



	Humate	Humate+Spray	Sulphate	Sulphate+Spray	Control
50%	0.47	0.42	0.43	0.41	0.39
75%	0.45	0.40	0.42	0.39	0.36
100% of IR	0.44	0.39	0.39	0.36	0.35

*Each value was the mean of 6 replications during the two studied seasons.

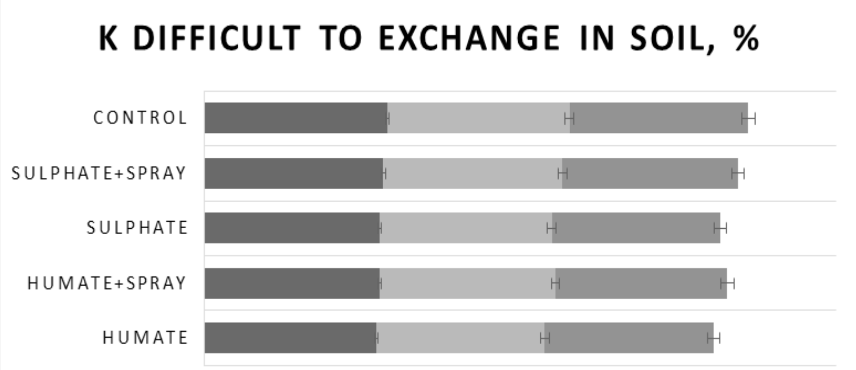
Fig. 2. Effect of different K sources and irrigation water levels on exchangeable K in the studied soil

Elemental content of haulm

Nitrogen, phosphorus and potassium contents in potato haulm decreased significantly during both seasons with increasing the level of water irrigation (Table 5). Such reductions might be because of the increment of nutrient movements toward fruits/ tubers or other plant organs. These results agree with those obtained by Hashem (2007) on cucumber. Regarding the effect of the type of K fertilizers on NPK content within plant haulm, the results indicate that K-humate increase N concentration in potato haulm and this probably attributed to its high content of total N (Table 2). The treatment of K-humate plus humate foliar spray resulted in the highest increases in P and K concentrations in haulm. It is obvious that K in the organic form increased N, P and K concentrations in haulm exceeding those obtained by K in mineral addition. The interaction between the source of K and the irrigation level reveals that the soil application of K-humate recorded the highest increases in N-haulm of soils irrigated with 50% of IR, while the treatment of K-humate plus humate foliar spray under irrigation with 50% of IR recorded the highest contents of P and K in potato haulm. Mosa (2012) found that humic substances can increase the nutrient content of the growing plants, especially of those grown in sandy soils.

Yield measurements

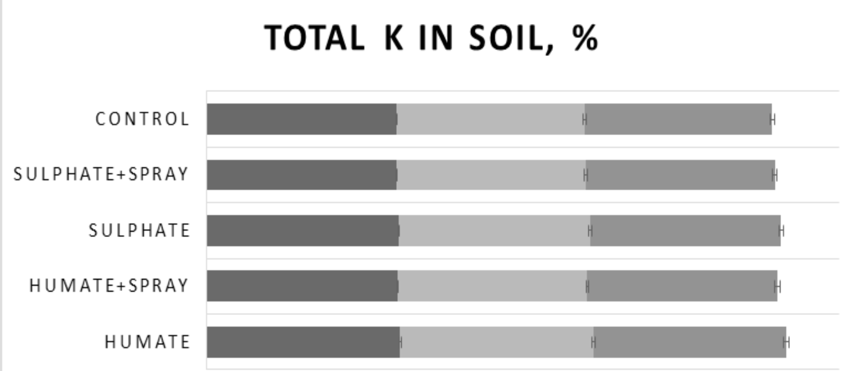
Data clearly showed gradual significant reduction in the yield measures in line with increasing water stress conditions (Table 6).



	Humate	Humate+Spray	Sulphate	Sulphate+Spray	Control
50%	0.49	0.50	0.50	0.51	0.52
75%	0.48	0.50	0.49	0.51	0.52
100% of IR	0.48	0.49	0.48	0.50	0.51

*Each value was the mean of 6 replications during the two studied seasons.

Fig. 3. Effect of different K sources and irrigation water levels on K fixed in clay minerals or difficult to exchange in soil



	Humate	Humate+Spray	Sulphate	Sulphate+Spray	Control
50%	1.53	1.51	1.52	1.50	1.50
75%	1.53	1.50	1.51	1.50	1.49
100% of IR	1.52	1.50	1.51	1.49	1.48

*Each value was the mean of 6 replications during the two studied seasons.

Fig. 4. Effect of different K sources and irrigation water levels on total K in the studied soil

The highest decrease was detected at the highest stress level, when water irrigation was supplied at 50% of IR. Such effect was expected since the adverse effect of decreasing the level of water irrigation was early noticed on most of the plant growth parameters. On the other hand, adequate water supplies up to 100% of IR promoted the plant growth (Table 4) and resulted in higher yield measures (Table 6). Regarding the effect of the source of K fertilizers on the yield measures, results showed that soil application of K in the organic form increased the number of tubers per plant and the outcome yield as compared to the mineral K form, especially during the second season. Also, the increases in the yield measures that obtained from soil application of K-humate plus humate foliar spray exceeded those attained by the soil application of K-sulphate plus sulphate foliar spray. Regarding the interaction among the studied treatments, 100% irrigation water level of IR combined with K-humate in the soil was superior in increasing number of tubers per plant and then yield production.

TABLE 4. Effect of different K sources and irrigation water levels on growth of potato in the two tested seasons of 2014/ 2015 and 2015/ 2016

Irrigation Level of IR	1st season Potassium Source K_1	K_2	K_3	K_4	Control	Mean	2nd season Potassium Source K_1	K_2	K_3	K_4	Control	Mean
	Plant height, cm						Plant height, cm					
50%	44.6 e	34.3 i	41.9 f	33.3 i	31.1 j	37.0 C	39.1 h	30.9 j	38.4 i	30.5 j	27.5 k	33.3 C
75%	51.5 b	41.9 f	45.1 e	39.6 g	36.4 h	42.9 B	46.5 c	43.0 ef	43.5 e	41.9 g	39.3 h	42.8 B
100%	55.9 a	46.7 d	49.4 c	44.1 e	39.2 g	47.0 A	50.3 a	46.6 c	48.0 b	45.6 d	42.7 f	46.6 A
Mean	50.7 A	41.0 C	45.5 B	39.0 C	35.5 D		45.3 A	40.1 C	43.3 B	39.3 C	36.5 D	
	Number of stems/ plant						Number of stems/ plant					
50%	2.88 h	2.56 i	2.48 i	2.52 i	2.48 i	2.58 B	2.98 h	2.80 j	2.88 i	2.66 k	2.56 l	2.78 C
75%	3.68 e	3.87 d	3.95 d	3.58 f	3.48 g	3.71 A	3.61 f	3.75 e	3.88 d	3.51 g	3.45 g	3.64 B
100%	4.42 a	4.18 b	4.39 a	4.06 c	3.90 d	4.19 A	4.55 a	4.28 b	4.31 b	4.09 c	3.86 d	4.22 A
Mean	3.66 A	3.54 B	3.61 AB	3.39 C	3.28 D		3.71 A	3.61 C	3.69 BC	3.42 D	3.29 E	
	Haulm fresh weight, g/ plant						Haulm fresh weight, g/ plant					
50%	340 i	260 k	300 j	220 l	180 m	260 C	402 g	305 k	395 ghi	278 l	250 m	326 C
75%	454 de	444 e	532 a	356 h	340 i	425 B	542 b	387 i	432 f	401 gh	342 j	421 B
100%	521 b	463 d	493 c	429 f	395 g	460 A	578 a	528 c	536 bc	517 d	496 e	531 A
Mean	438 A	389 B	442 A	335 C	305 D		507 A	407 C	454 B	399 C	363 D	
	Haulm dry weight, g/ plant						Haulm dry weight, g/ plant					
50%	29.6 h	25.9 j	26.4 j	23.9 k	16.6 l	24.5 C	33.7 f	22.9 i	33.0 f	21.4 j	19.9 k	26.1 C
75%	38.7 e	33.0 g	43.8 b	33.9 f	29.0 i	35.7 B	44.6 b	37.2 e	36.4 e	29.4 h	30.7 g	35.6 B
100%	44.1 a	43.7 b	41.6 d	42.7 c	33.4 fg	41.1 A	47.8 a	39.1 d	44.4 b	41.0 c	36.3 e	41.7 A
Mean	37.5 A	34.2 B	37.2 A	33.5 B	26.4 C		42.0 A	33.0 C	37.9 B	30.6 D	28.9 D	

K_1, K_2, K_3 and K_4 means K-humate, K-humate plus foliar spray, K-sulphate and K-sulphate plus foliar spray, respectively

TABLE 5. Effect of different K sources and irrigation water levels on N, P and K in haulm of potato during the two tested seasons of 2014/ 2015 and 2015/ 2016

Irrigation Level of IR	1st season Potassium Source						2nd season Potassium Source					
	K_1	K_2	K_3	K_4	Control	Mean	K_1	K_2	K_3	K_4	Control	Mean
			N, %						N, %			
50%	3.04 a	2.62 f	2.97 b	2.48 gh	2.34 j	2.69 A	3.13 a	2.41 h	2.90 c	2.74 d	2.23 j	2.68 A
75%	2.73 e	2.58 f	2.85 c	2.44 hi	2.29 j	2.58 B	2.97 b	2.37 h	2.62 f	2.69 e	2.08 k	2.55 B
100%	2.93 b	2.52 g	2.79 d	2.41 i	2.05 k	2.54 B	2.69 e	2.31 i	2.56 g	2.65 ef	2.26 j	2.50 B
Mean	2.90 A	2.57 B	2.87 A	2.44 C	2.23 D		2.93 A	2.36 C	2.69 B	2.69 B	2.19 D	
			P, %						P, %			
50%	0.29 b	0.31 a	0.23 g	0.22 h	0.21 i	0.25 A	0.26 e	0.31 a	0.26 e	0.24 f	0.21 h	0.26 A
75%	0.24 f	0.28 c	0.25 e	0.21 i	0.20 j	0.24 B	0.27 d	0.29 b	0.22 h	0.23 g	0.19 i	0.24 B
100%	0.23 g	0.27 d	0.21 i	0.21 i	0.19 k	0.22 C	0.26 e	0.28 cd	0.24 f	0.19 i	0.19 i	0.23 B
Mean	0.25 B	0.29 A	0.23 C	0.21 CD	0.20 D		0.27 B	0.29 A	0.24 C	0.22 C	0.20 D	
			K, %						K, %			
50%	2.85 d	3.51 a	2.60 g	2.52 h	1.96 k	2.69 A	2.96 d	3.43 a	2.50 i	2.61 g	2.02 j	2.70 A
75%	2.79 e	3.27 b	2.47 i	2.45 i	1.92 k	2.58 B	2.90 e	3.35 b	2.57 h	2.53 hi	1.86 k	2.64 B
100%	2.72 f	3.18 c	2.41 j	2.43 ij	1.86 l	2.52 B	2.82 f	3.26 c	2.51 i	2.51 i	1.81 l	2.58 C
Mean	2.79 B	3.32 A	2.49 C	2.47 C	1.91 D		2.89 B	3.34 A	2.52 C	2.55 C	1.90 D	

K_1, K_2, K_3 and K_4 means K-humate, K-humate plus foliar spray, K-sulphate and K-sulphate plus foliar spray, respectively.

The specific gravity of tuber is an important indicator of potato tuber quality as it indicates the dry matter content of tubers. Generally higher specific gravity indicates higher dry matter content. Elfnesh et al. (2011) found that dry matter content of potato tuber was positively and high significantly correlated with specific gravity (r = 0.99**). The maximum specific gravity (1.09 in the two tested seasons) was recorded by applying K-humate in the soil that was irrigated with 50% of IR, whereas the least ones (1.03 in the two growing seasons) was recorded from control treatment (Table 6). Also, specific gravity of potato tuber increased with increasing nutrient uptake (Table 7). Dasgupta et al. (2017) found that specific gravity of potato tuber was strongly correlated with nutrients uptake (r= 0.85, 0.88 and 0.83 for N, P and K, respectively). Nutrient contents of N, P and specially K promoted dry matter and starch content of tuber (Acharya, 2006) leading to higher specific gravity of potato.

Elemental content of tubers

Data shown in Table 7 reveal that N, P and K concentrations decreased in tubers of potato plants with increasing soil moisture level; however in some cases, no significant differences were detected in P and K contents between irrigation levels 75 and 100% of IR. Regarding the effect of K sources, amending soils with K-humate recorded the highest increases in N and P concentrations, followed by soil application of K-humate plus foliar spray in giving high concentration of N. On the other hand, amending soils with K-sulphate resulted in the highest concentration of P. Similar results were found in both seasons of study. This may occur because of the high contents of the investigated nutrients in the studied sources of K (Table 2). Regarding K concentration in tubers, the treatment of K-humate as soil application plus spray from a solution containing K-humate as foliar application gave the highest values in the two tested seasons, followed by the treatment of K-humate only as ground application. The interaction between irrigation levels and K sources showed that the 50% irrigation level of IR combined with K-humate gave the highest values of N and P. While 75% of IR in the first season and 50% of IR in the second season combined with K-humate plus foliar spray gave the highest values of K concentration in potato tubers.

TABLE 6. Effect of different K sources and irrigation water levels on number of tubers per plant, yield production (t ha^{-1}) and specific gravity of potato tubers during the two tested seasons of 2014/ 2015 and 2015/ 2016

Irrigation Level of IR	1st season						2nd season					
	Potassium Source						Potassium Source					
	K_1	K_2	K_3	K_4	Control	Mean	K_1	K_2	K_3	K_4	Control	Mean
	Number of tubers/ plant						Number of tubers/ plant					
50%	6.60 i	5.34 l	6.38 j	5.59 k	5.43 l	5.87 C	7.11 i	5.79 k	6.19 j	5.49 l	5.19 m	5.95 B
75%	8.59 c	7.86 f	8.05 e	7.78 fg	7.09 h	7.87 B	8.95 b	7.82 g	8.39 d	7.70 h	7.16 i	8.00 A
100%	9.10 a	8.58 c	8.74 b	8.16 d	7.70 g	8.46 A	9.13 a	8.29 e	8.48 c	8.13 f	7.80 g	8.36 A
Mean	8.10 A	7.26 C	7.72 B	7.17 C	6.74 D		8.40 A	7.30 C	7.68 B	7.10 C	6.72 D	
	Yield production, t ha^{-1}						Yield production, t ha^{-1}					
50%	15.6 h	14.0 j	14.6 i	13.2 k	10.8 l	13.6 C	14.9 h	14.2 j	14.5 i	13.9 k	9.91 l	13.5 C
75%	19.3 c	18.0 ef	18.0 ef	17.9 f	16.1 g	17.9 B	17.5 e	15.8 g	16.5 f	15.8 g	15.1 h	16.1 B
100%	22.0 a	19.4 c	21.4 b	18.3 d	18.1 e	19.8 A	21.5 a	20.1 b	20.2 b	18.6 d	19.0 c	19.9 A
Mean	19.0 A	17.1 C	18.0 B	16.5 D	15.0 E		18.0 A	16.7 BC	17.1 B	16.1 C	14.6 D	
	Specific gravity						Specific gravity					
50%	1.086 a	1.080 c	1.083 b	1.077 e	1.073 f	1.080 A	1.085 a	1.083 b	1.081 c	1.080 cd	1.076 e	1.081 A
75%	1.078 de	1.063 g	1.077 e	1.057 h	1.037 l	1.062 B	1.083 b	1.069 f	1.079 d	1.054 h	1.043 hi	1.066 B
100%	1.053 i	1.040 k	1.049 j	1.036 l	1.031 m	1.041 C	1.057 g	1.044 hi	1.042 i	1.035 j	1.032 k	1.042 C
Mean	1.072 A	1.061 B	1.070 A	1.057 C	1.047 D		1.075 A	1.065 B	1.067 B	1.056 C	1.050 D	

K_1, K_2, K_3 and K_4 means K-humate, K-humate plus foliar spray, K-sulphate and K-sulphate plus foliar spray, respectively.

TABLE 7. Effect of different K sources and irrigation water levels on N, P and K in potato tubers during the two tested seasons of 2014/ 2015 and 2015/ 2016

Irrigation Level of IR	1st season Potassium Source K1	K2	K3	K4	Control	Mean	2nd season Potassium Source K1	K2	K3	K4	Control	Mean
	N, %						N, %					
50%	3.13 a	2.55 c	2.04 e	1.64 g	1.50 i	2.17 A	3.16 a	2.48 d	1.83 f	1.48 i	1.40 j	2.07 A
75%	3.08 a	2.50 c	1.99 ef	1.45 ij	1.42 j	2.09 B	2.99 b	2.41 e	1.72 g	1.59 h	1.34 k	2.01 B
100%	2.97 b	2.38 d	1.94 f	1.56 h	1.31 k	2.03 C	2.92 c	2.45 de	1.69 g	1.43 j	1.36 k	1.97 C
Mean	3.06 A	2.48 B	1.99 C	1.55 D	1.41 D		3.02 A	2.45 B	1.75 C	1.50 D	1.37 D	
	P, %						P, %					
50%	0.25 a	0.16 g	0.22 b	0.20 d	0.12 i	0.19 A	0.24 a	0.14 f	0.21 b	0.20 c	0.13 g	0.18 A
75%	0.22 b	0.14 h	0.20 d	0.19 e	0.11 j	0.17 B	0.24 a	0.13 g	0.20 c	0.19 d	0.11 i	0.17 B
100%	0.21 c	0.14 h	0.19 e	0.17 f	0.11 j	0.17 B	0.22 b	0.12 h	0.19 d	0.18 e	0.10 i	0.16 C
Mean	0.23 A	0.15 C	0.20 B	0.19 B	0.11 D		0.23 A	0.13 C	0.20 B	0.19 B	0.11 C	
	K, %						K, %					
50%	2.52 d	2.96 a	1.22 i	1.22 i	1.52 g	1.89 C	2.48 d	2.99 a	1.76 f	1.73 f	1.64 g	2.12 A
75%	2.49 d	2.84 b	1.71 f	1.68 f	1.47 h	2.04 A	2.43 d	2.82 b	1.20 j	1.18 j	1.56 h	1.84 B
100%	2.44 e	2.77 c	1.67 f	1.16 j	1.52 g	1.91 B	2.38 e	2.74 c	1.17 j	1.62 g	1.44 i	1.87 B
Mean	2.48 B	2.86 A	1.53 C	1.35 D	1.50 C		2.43 B	2.85 A	1.37 D	1.51 C	1.55 C	

K_1, K_2, K_3 and K_4 means K-humate, K-humate plus foliar spray, K-sulphate and K-sulphate plus foliar spray, respectively.

TABLE 8. Effect of different K sources and irrigation water levels on water use efficiency (kg m^{-3}) for potato plants during the two studied seasons of 2014/ 2015 and 2015/ 2016

Irrigation Level of IR	1st season Potassium Source K1	K2	K3	K4	Control	Mean	2nd season Potassium Source K1	K2	K3	K4	Control	Mean
50%	7.99 a	7.15 c	7.51 b	6.77 d	5.55 h	6.99 A	7.62 a	7.28 c	7.45 b	7.13 d	5.08 j	6.91 A
75%	6.61 e	6.14 f	6.14 f	6.11 f	5.49 i	6.10 B	5.98 e	5.40 h	5.63 f	5.41 h	5.14 i	5.51 B
100%	5.64 g	4.98 j	5.48 i	4.69 k	4.64 l	5.08 C	5.50 g	5.14 i	5.17 i	4.77 l	4.86 k	5.09 C
Mean	6.75 A	6.09 C	6.38 B	5.86 D	5.22 E		6.37 A	5.94 C	6.08 B	5.77 D	5.03 E	

K_1, K_2, K_3 and K_4 means K-humate, K-humate plus foliar spray, K-sulphate and K-sulphate plus foliar spray, respectively.

Water use efficiency (WUE)

Increasing irrigation level over 50% of IR led to significant reductions in WUE (Table 8). These results agree with those obtained by Hashem et al. (2016). There was a significant interaction between irrigation water treatments and applied K fertilizer for WUE. The highest WUE value was obtained by 50% irrigation level of IR combined with K-humate as soil application. Importance of these fertilizers for good yield and better utilization of water can be attributed to the role of K in improving crop resistance to water stress by playing a vital role in osmotic adjustment (Cantore et al., 2014). Mosa (2012) reported that humic substances when applied to soil, they tend to increase moisture retention in the root zone, and therefore can increase WUE.

Conclusion

The results showed that potassium application improved the water soluble and exchangeable K in soil. Organic source of K improved potassium fractions in the studied clay soil. No considerable trend of non-exchangeable and total K in soil was found among various sources/ methods of application. The treatment of 100% followed by 75% irrigation level of IR, with no significant differences in most trials between them, combined with K-humate as ground application improved the vegetative growth and yield parameters of potato plants, compared to mineral source of applied K. Also, K in the organic form applied to the soil tend to increase moisture retention in the root zone, and therefore increased WUE.

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مقارنة بين المصادر العضوية والمعدنية للبوتاسيوم وتأثيرها على صور البوتاسيوم في أرض طينية وإنتاجية نباتات البطاطس تحت ظروف الإجهاد المائي

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من المعروف أن البوتاسيوم (K) هو عنصر غذائي أساسي لنمو النبات ويلعب دوراً هاماً في الحفاظ على توازن المياه داخل خلاياه. لذلك تم دراسة تأثير صوره المختلفة على نباتات البطاطس (*Solanum tuberosum,* cv. Spunta) النامية تحت ظروف الإجهاد المائي كنوع من أنواع التكيف مع التغيرات المناخية ونقص المياه تحت ظروف الأراضي المصرية. كما أن معرفة الصور المختلفة للبوتاسيوم في التربة الطينية تحت الدراسة مهمة لتحقيق الإستدامة في الزراعة. لذلك أُجريت تجربة ميدانية خلال موسم الخريف من عامي ٤١٠٢ و ٥١٠٢ في رحاب كلية الزراعة بجامعة عين شمس- محافظة القليوبية، مصر. تم اختبار مصدرين من البوتاسيوم مع ثلاثة مستويات من مياه الري في تصميم القطع المنشقة. وأشارت النتائج إلى أن الصور الكيميائية للبوتاسيوم في التربة كانت تتبع الترتيب التالي: الكلي > المثبت > القابل للتبادل > الذائب في الماء. معاملة مستوى الري ٠٥٪ من الإحتياجات الإروائية جنباً إلى جنب مع هيومات البوتاسيوم المضافة للأرض أدت إلى زيادة الكمية القابلة للذوبان والمتبادلة من البوتاسيوم في الأرض تحت الدراسة. في حين لم يكن هناك بالكاد أي تغييرات ملحوظة نتيجة المعاملات المُطبقة على الكميات المثبتة والكلية من البوتاسيوم في الأرض. وفيما يتعلق بمعايير النمو الخضري والمحصول لنباتات البطاطس المنزرعة بالأرض تحت الدراسة، فقد أدت معاملة مستوى مياه الري ٠٠١٪ من الإحتياجات الإروائية جنباً إلى جنب مع هيومات البوتاسيوم المضافة للأرض إلى زيادة معنوية في هذه الصفات. وسجلت الكثافة النوعية للدرنات كمؤشر هام لجودة درنات البطاطس أعلى قيمة من خلال تطبيق ٠٥٪ مستوى ري من الإحتياجات الإروائية مع إضافة هيومات البوتاسيوم كإضافة أرضية مقارنة مع الإضافة المعدنية التي جاءت في الترتيب الثاني. أما فيما يتعلق بتركيز المغذيات في المجموع الخضري للبطاطس فقد بينت النتائج أن معاملة مستوى الري ٠٥٪ من الإحتياجات الإروائية مع هيومات البوتاسيوم قد أعطت أعلى نسبة من النيتروجين، بينما أعطى نفس مستوى الري مع هيومات البوتاسيوم كإضافة أرضية + الرش الورقي على أوراق النبات أعلى محتوى من الفوسفور والبوتاسيوم، وذلك خلال الموسمين المختبرين. أما عن محتوى المغذيات في الدرنات، فقد أعطت معاملة مستوى الري ٠٥٪ من الإحتياجات الإروائية مع هيومات البوتاسيوم كتطبيق أرضي أعلى تركيز من النيتروجين والفوسفور خلال الموسمين المختبرين، في حين أن مستوى الري ٥٧٪ من الإحتياجات الإروائية في الموسم الأول و ٠٥٪ من الإحتياجات الإروائية في الموسم الثاني جنباً إلى جنب مع هيومات البوتاسيوم المضاف أرضاً + الرش الورقي قد أعطت أعلى قيم لمحتوى البوتاسيوم. وقد أظهرت كفاءة استخدام المياه المحسوبة (WUE) أن أعلى قيمة تم الحصول عليها عن طريق استعمال مستوى الري ٠٥٪ من الإحتياجات الإروائية جنباً إلى جنب مع هيومات البوتاسيوم كتطبيق أرضي.