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Improving the Growth and Productivity of Faba Bean (*Vicia faba* L.) under Deficit Irrigation Conditions by Spraying of Potassium Selenate and Potassium Silicate

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A FIELD experiment was elaborated for two seasons (2018/2019 and 2019/2020) under a drip irrigation system in the experimental farm of Department of Soils and Water, Faculty of Agriculture, Al-Azhar University, Cairo, Egypt to investigate the impact of three levels of applied irrigation water: I_1=100, I_2=80 and I_3=60% of irrigation water requirements (IR) and foliar application of potassium selenate (K_2SeO_4: 0.3 and 0.6 mM) and potassium silicate (K_2SiO_3: 5 and 10 mM) on the growth, yield and quality of faba bean (*Vicia faba* L., cv Sakha 3) and also the water use efficiency. The results indicated that increasing the applied irrigation water amount from 2219.75 (I_3) to 3698.77 m^3 ha^{-1} (I1) gave the highest mean values of plant height, number of branches (NB), dry seeds weight, the weight of 100 dry seeds and dry seed yield as well as P and K content in seeds. On the contrary, the highest mean values of water use efficiency (WUE), protein and nitrogen (N) content in seeds occurred with 60% of IR for both seasons. Moreover, foliar spraying with potassium silicate at 10 mM led to a highly significant increase of all the studied parameters followed by foliar spraying with potassium selenate at 0.6 mM compared to the untreated plant's treatment. Consequently, it is recommended to grow faba bean plants (Sakha 3) by applying 80% of IR (2958.02 m^3 ha^{-1}) and foliar spraying with 10 mM potassium silicate and saving 20% of the amount of irrigation water for other uses in agriculture.

Keywords: Drought stress, Foliar spray, Broad bean, Yield and quality.

Introduction

Water stress is one of the vitally essential environmental stresses that directly affect agricultural production, particularly in arid and semi-arid regions that are considered to be a consequence of worldwide of climate change and decreased water availability for crop production (Carrizo et al., 2020 and Rafie & El-Boraie, 2017). Many of the physiological processes within a plant are negatively affected by drought stress i.e., photosynthesis, cell division, nutrient uptake, damage of plant cell membrane and cell wall, however, a homogenous root system may enhance the plant's ability to grow during droughts (Taiz and Zeiger, 2006).

Mitigating the negative effects of drought stress has become very necessary to maintains water balance within the plant, which can be achieved through plant nutrition, especially with the nutrient that is related to osmotic regulation, thus enhancing drought tolerance (Yaseen et al., 2020). Clinical research has shown that about forty forms of human health dangerous illnesses, including, cancer, liver disease, cardiovascular disease and so on, are associated with a deficiency of selenium in the human body (Vinceti et al., 2018). Selenium has antioxidant properties that humans and animals require (Fairweather-Tait et al., 2011). Therefore, there is an urgent need to overcome the status of human selenium deficiency by increasing the selenium content in

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crops and plants. Many studies have shown that the proper supply of selenium could not solely excess the selenium content in plants, but else plant growth promotion and development under stress conditions such as salt, drought and cold stress, etc. (Hartikainen and Xue, 1999 and Yao et al., 2011). Selenium is a required element for human and animal health, it is classified as a trace element. On the other hand, it is not considered an essential nutrient for plant growth, where a specific role in plants is still unclear (Chilimba et al., 2012; Hartikainen et al., 2000; Li et al., 2008 and Tapiero et al., 2003). However, the beneficial effects on growth promotion for many plants are normally observed with the application of selenium even at low concentration, especially under stress conditions (Chu et al., 2013; Habibi, 2013 and Hawrylak-Nowak, 2009).

Silicon is considered a non-essential nutrient, but it is used as an excellent element to growth-promoting, increases plant growth parameters, and stimulates productivity in many crop plants (Ahmed et al., 2007 and Ali et al., 2019). The beneficial effects of silicon are attributed to its deposition in plant tissues, which improves the strength and stiffness of plants, this is positively reflected in the mechanical strength that decreases pest attacks and increases the light-receiving position, increases photosynthesis and finally promoting plant growth (Epstein, 1999). Many scientists have pointed out that the role of silicon under stress conditions (both biotic and abiotic stress) are illustrated by reducing multiple stresses through maintaining water potential within plants, photosynthesis, photosynthetic activity, stomatal conductance and erection of leaves under high rates of transpiration (Crusciol et al., 2009; Das et al., 2017; Shaaban and Abou El-Nour, 2014; Shen et al., 2010). Potassium is one of the macronutrients for several crop plants and plays a main role in basic physiological processes, such as growth, the formation of sugars, starch, photosynthesis, cell division, proteins synthesis, improve yield quality and maintenance of water status in plant tissues (Abbas and Fares, 2009 and Marschner, 2002). Potassium is one of the most important nutrients that affect many vital processes such as the movement of water and sugars and maintaining a water balance (Beg and Ahmad, 2012). Furthermore, it influences synthesis, transformation and storage of carbohydrates as well as it has been shown to promote plant disease reduction, and potassium deficiency can increase the degree of crop damage that subjected to fungal and bacterial diseases (Holzmueller et al., 2007). Also, the application of silicon was associated with osmotic adjustment by accelerating the accumulation of various organic and inorganic substances such as glycine, betaine, proline, and antioxidant activity in stressed plants (Ahmad and Haddad, 2011). Despite, silicon has been described as a non-essential nutrient for plant growth, it plays an important role in ameliorating the negative effects of stress conditions, either abiotic and/or biotic stress (Chanchal Malhotra et al., 2016). Potassium silicate is a highly soluble source of two elements, one is an essential nutrient for plant growth which is potassium and the other is silicon as a non-essential nutrient. Consequently, it is used in the agricultural production system, where K_2SiO_3 is mainly used as a source of silicon, as well as added potassium quantities that help to enhance vegetative plant growth and improves yield quality (Salim et al., 2014 and Tarabih et al., 2014).

Faba bean (*Vicia faba*, L.) is one of the most significant leguminous crops cultivated in Egypt. At the same time, dry and green bean seeds are used as human food, also it is a permanent component of major feeds of animal (Crépon et al., 2010; Dawood et al., 2019; Fouda, 2017; Khalifa, 2019). Faba bean is used for the nutrition of human and animal because it is a good source of protein (almost 25% in dry seeds), starch, cellulose, minerals and vitamin C. (Crépon et al. and 2010 and Ismail & Fayed, 2020) and it plays a role in the rotation of crop. Like all legume crops, faba bean plays an important role in enhancing soil fertility. Also, growing it increases soil nitrogen (N) by fixation (Hungria and Vargas, 2000). In Egypt, broad bean production is affected by different factors for example water supply and fertility of the soil (Bakry et al., 2011).

This study study aims to investigate the impact of spraying different concentrations of potassium selenate and potassium silicate on plant growth, yield and its components and water use efficiency of faba bean grown under irrigation water deficit conditions.

Materials and Methods

Description of experimental site and climatic condition

A field experiment was elaborated in the experimental field of Soils and Water Department, Faculty of Agriculture, Al-Azhar University, Nasr City, Cairo, Egypt, (30° 03'19.49" N and 31°19'10.19" E) in two successive winter seasons of 2018/2019 and 2019/2020. The soil samples were collected from the experimental field cultivation, air dried, crushed and sieved through a 2.0 mm sieve for analysis. Some physical and chemical propertiesfor samples of soil and used farmyard manure were shown in Table 1 according to Klute & Page (1986) and Page et al. (1982). Meteorological data which were obtained from the automated weather station of Center Laboratory for Agricultural Climate (CLAC) allocated at the experimental site during the two seasons of growthare shown in Table 2.

TABLE 1. Some physical and chemical properties of the experimental soil and farmyard manure used (Average of two seasons)

Practical size distribution				
Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture class
49.84	25.41	14.70	10.05	Sandy loam

Moisture content (%) at:			pH[4]	EC[5] (dS m^{-1})	CEC[6] (cmol$_c$ kg^{-1})	O.C[7] (%)	O.M[8] (g kg^{-1})	$CaCO_3$ (g kg^{-1})
FC[1]	PWP[2]	AW[3]						
12.55	4.63	7.92	7.92	1.79	3.00	0.24	4.10	21.10

Soluble ions (mmol$_c$ l^{-1})							
Cations				Anions			
Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$CO_3^{=}$	HCO_3^{-}	Cl^{-}	$SO_4^{=}$
2.20	3.00	12.25	0.50	0.00	2.95	11.30	3.70

Available macronutrients (mg kg^{-1})		
N	P	K
35	8	50

Farmyard manure							
pH[9]	EC[10] (dS m^{-1})	O.C (%)	O.M (%)	C/N ratio	Total macronutrients (%)		
					N	P	K
6.85	3.84	19.00	32.86	12.02	1.58	0..75	1.20

[1]Field capacity, [2]Permanent wilting point, [3]Available water, [4]1:2.5 w/v soil water suspension, [5]Soil paste extract, [6] Cation exchange capacity, [7]Organic carbon, [8]Organic matter, [9]1:10 w/v farmyard manure water suspension and [10] farmyard manure water extract (1:10).

TABLE 2. The mean climatic data at the experimental location during the two seasons of 2018/2019 and 2019/2020 (Average of two seasons)

Month	Temperature		Relative humidity		Wind speed (m s^{-1})	Sunshine (h)
	T_{max} (C)	T_{min} (C)	RH_{max} (%)	RH_{min} (%)		
Nov.	24.1	13. 5	74.7	35.8	1.87	7.2
Dec.	23.5	12.3	75.1	35.9	1.89	7.3
Jan.	19.5	10.6	76.0	39.1	1.74	7.5
Feb.	22.0	12.4	67.5	26.6	2.85	7.8
Mar.	23.2	12.7	63.8	30.6	3.20	8.8

Treatments

Designed factorial experiments under the study were coordinated in a randomized complete block design. The first factor included irrigation regimeat three levels (I_1=100, I_2=80 and I_3=60% ET_c of the total amount of water applied 3698.77, 2958.02 and 2219.75 m^3 ha^{-1}, respectively). The second factor as a foliar application with either potassium selenate (K_2SeO_4) at 0.0, 0.3 and 0.6 mM and potassium silicate (K2SiO3) at 0.0, 5 and 10 mM. Faba bean plants were sprayed after 30, 45 and 60 days of sowing. Every experimental unit got two liters of each foliar application solution using super film ata rate of 1 cm L^{-1} as the spreading agent to get better the spray adherence to the foliage of the plant for increasing the plant's absorption (Mortvedt et al., 1991). The control treatmentwas sprayed with distilled water and a spreading agent. All treatments of the foliar application were carried out early in the morning (7.00 - 7.30 am).

Agricultural practices

The source of seeds (cv. Sakha 3) was obtained from Legumes Crops Research Department, Agriculture Research Center, Giza, Egypt. The seeds of faba bean were sown on the 15th November in both seasons at the rate of 74 kg ha^{-1}, after inoculation with root nodules bacteria (*Rhizobium leguminosarum*). Two seeds were sown in each pit on one side of the ridge. Fifteen days after sowing, the plants of each pit were thinned to one plant. Between every two experimental units, one row was left as a safeguard row to avoid overlapping with the spray solution for both the potassium silicate and the potassium selenate. Faba bean plants were irrigated in all treatments by a trickle irrigation system. The dripper discharge rate was 4 L h^{-1}, the distance between the drippers (plants) was 0.30 m; the distance between the lateral line (faba bean rows) was 0.60 m and the border between irrigation treatments was two m wide.

According to the recommendation of the Ministry of Agriculture, faba bean plants were fertilized with the fertilizers of nitrogen (N), phosphorus (P), and potassium (K). 15.5% P_2O_5 (Super-phosphate) was applied before planting at a rate of 493.83 kg ha^{-1}. 48% K_2O (Potassium sulphate) was applied at a rate of 123.46 kg ha^{-1} to the soil during seedbed preparation. After 15, 30 and 45 days of sowing, ammonium sulfate (20.6% N) was applied at a rate of 123.46 in three equal doses by injection into a drip irrigation system network. Organic manure was added at a rate of 50 m^3 ha^{-1} by the mixed with super-phosphate during the preparation of soil for cultivation.

The measurements of the reference evapotranspiration using Class-A pan. The potential evapotranspiration and irrigation requirements were calculated withthe following equations:

$$ET_o = E_{pan} \times K_{pan} \quad \ldots(1)$$

$$ET_c = ET_o \times K_c \quad \ldots(2)$$

$$IR = ET_c + LR \times 4.2 / E_i \quad \ldots(3)$$

Where:

ET_o Reference evapotranspiration (mm day^{-1}),

E_{pan}: Pan evaporation (mm day^{-1}),

K_{pan}: Pan coefficient,

ET_c: Evapotranspiration of crop (mm day^{-1}),

K_c: Crop coefficient of faba bean (dimensionless) according to Allen et al. (1998),

IR: Irrigation requirement for the crop (m^3 ha^{-1} day^{-1}),

LR: Leaching requirement (%), and

E_i: Efficiency of the irrigation system (%).

Data recorded

After 85 days of sowing, five plants were randomly selected from the center row of every plot to estimate the mean value of plant height (cm) and the number of branches per plant in the two growing seasons. At full seed maturity (after 120 days of sowing), a sample of ten randomly protected plants from each plot was used to record the yield and the compound characteristics of the crop such as dry seeds weight (g plant^{-1}), the weight of 100 dry seeds (g) and the whole plot were harvested to calculate the yield of seed (kg ha^{-1}).

Seeds were dried in the open air after the harvest process avoiding sunlight to determine their N, P and K. The sample of grains were grounded in a stainless-steel mill and taken for chemical analysis. 0.5 g of grains dry matter was wet digested using a mixture of percloricand sulphuricacids (H_2SO_4+ $HClO_4$) according to a Jones (2001) procedure. By the Kjeldahl method, the total nitrogen was determined according to the procedure described by Page et al. (1982). The protein percent (%) in seeds was calculated by multiplying nitrogen (%) content by 6.25 (Boulos et al., 2020). The phosphorus percent (%) was determined by the colorimetric method (ascorbicacid) using a spectrophotometer according to Page et al. (1982). Using Flame photometer, potassium (%) was determined photo-metrically according to Chapman and Pratt (1982).

Water use efficiency

According to Doorenbos and Pruitt (1977), the water use efficiency (WUE) was calculated with equation (4).

$$WUE = \frac{Y}{IR} \quad \text{…(4)}$$

Where:

WUE: Water use efficiency (kg m^{-3}),

Y: Marketable yield (kg ha^{-1}), and

IR: Irrigation requirement for a crop (m^3 ha^{-1}).

Statistical analysis

The layout of the experiment was a randomized complete blocks design. Data were subjected to the analysis of variance (ANOVA) and after confirmation of errors homogeneity, the combined analysis over the two seasons was mentioned by Gomez and Gomez (1984) and the least signifi-cant differences test (LSD) between treatments were done at 0.05 level of probability as outlined by Waller and Duncan (1969). The combined analysis was calculated for all the studied characters in the two seasons.

Results and Discussion

Effect of different treatments on plant growth and yield parameters

Effect of irrigation water levels

Data presented in Fig. 1 showed that there was a significant influence of applied irrigation water levels on growth and yield parameters of faba bean plants as the average of the two seasons 2018/2019 and 2019/2020.

The growth and yield parameters of faba bean plants as affected by different irrigation water levels could be arranged in the following descending order: 100% > 80% > 60% of IR, respectively. Where, faba bean plants subjected to 100% of irrigation requirements gave the highest values of growth and yield parameters, while the lowest values were more pronounced when 60% of irrigation requirements were applied to faba bean plants as averages of the two seasons. The highest mean values of plant height (cm), No. of branches per plant, dry seeds weight (g plant^{-1}) and weight of 100 dry seeds (g) were 74.98cm, 5.58, 25.80g plant^{-1} and 62.79g. These results could be enhanced by those obtained by Al-Suhaibani (2009); El-Shiekh et al. (2016); Gupta et al. (2017); Hegab et al. (2014) and Sarkar et al. (2017). The improvement in growth and yield parametersat 100% of IR may be attributed to the increase in the availability of soil moisture, which in turn increases water absorption and nutrient uptake, resulting in an improvement in the photosynthetic rate resulting in growth (Gunes et al., 2008). With the decline of the irrigation regime in two growing seasons, the total chlorophyll was significantly reduced, mostly due to the production of reactive oxygen species that deteriorate chloroplasts (Gill and Tuteja, 2010).

Effect of potassium selenate

The results obtained in Fig.1 show that the foliar application of potassium selenate either at 0.3 or 0.6 mM promoted almost all growth faba bean plants compared to the corresponding untreated control plants. It should be noted that plants sprayed with potassium selenate at a rate of 0.6 mM were significantly higher than those sprayed with distilled water or 0.3 mM potassium selenate. The maximum mean values of plant height (cm), No. of branches per plant, dry seeds weight (g $plant^{-1}$) and weight of 100 dry seeds (g) were 71.63cm, 5.50, 24.96g $plant^{-1}$ and 58.79g. Conversely, the minimum average values of growth and yield parameters for the untreated plants (control treatment) were obtained. These increases in growth and yield of faba bean plants under application of potassium selenate could be mainly due to the presence of selenium element that caused an increase in the content of antioxidant substances and enzymes activity in the cellsof plants (Boghdady et al., 2017; Mroczek-Zdyrska et al., 2017; Pennanen et al., 2002). On the other hand, the potassium concentration added with potassium selenate has a good effect on improving crop quality and maintaining the status of water within plant tissues (Marschner, 2002). The cell can be protected by selenium from oxidative damage by antioxidant defenses (Seppänen et al., 2003). Moreover, Mirza et al. (2010) obtained that selenium spraying increased several enzyme activities. These increments in parameters of growth under the influence of selenium treatments are in harmony with those obtained by Hawrylak-Nowak (2009) on cucumber and Boldrin et al. (2013) on rice plants.

Effect of potassium silicate

The foliar application of potassium silicate at different levels of 5 and 10 mM had a significant effect on the growth parameters and yield of faba bean plants compared to the control treatment in the two seasons. Data in Fig.1 showed that, the highest significant values of growth and yield parameters of faba bean plants were recorded using 10 mM foliar spray of potassium silicate compared to control treatment or/and 5 mM potassium silicate as a foliar application. These findings were true in two seasons of study. In the same respect, foliar spray of 10 mM potassium silicate exhibited a significant superiority on the studied parameters of faba bean plants over than treatment of 5 mM. The highest mean values of plant height (cm), No. of branches per plant, dry seeds weight (g $plant^{-1}$) and weight of 100 dry seeds (g) were 75.78cm, 6.64, 25.84g $plant^{-1}$ and 62.67g recorded with 10 mM potassium silicate. On the contrary, the lowest mean values of growth and yield parameters were obtained from the control treatment. These results could be supported by those obtained by Abou-Baker et al. (2012), who found that applied rates of potassium silicate led to significantly increased plant height, number of leaves and branches per plant and dry seed yield of faba bean. The highest values of plant growth yield and its components as a result of foliar spray potassium silicate for faba bean plants could be due to beneficial effects of silicon, where many beneficial effects of silicon have been observed on plant growth, either under normal or stress conditions. Some of the positive effects could be attributedto the deposition of Si in the cell wall of plant tissues especially in levees, this gives the plant strength and stiffness against pest attacks and increase the light-receiving position, and finally increase the rate of photosynthesis and growth of promoting (Epstein, 1999). Many scientists have pointed out that the effective role of silicon in reducing multiple stresses (both biotic and abiotic stress) through maintaining water content in leaves, decrease rate transpiration from the cuticle thus preventing the destruction of photosynthetic process and chlorophyll in leaves consequently increasing the resistance to stress conditions (Ali et al., 2019; Das et al., 2017; Shaaban and Abou El-Nour, 2014; Shen et al., 2010). On the other hand, the potassium concentration added with potassium silicate has the main role for basic physiological processes, i.e. photosynthesis, the formation of sugars, starch, cell division, proteins and this reflected positively on plant growth and yield quality of faba bean plants (Abbas and Fares, 2009 and Marschner, 2002).

Effect of interaction

The results presented in Fig.1 showed that there was a significant increase in the growth and yield parameters of faba bean plants as a result of foliar spray by potassium selenate and potassium silicate under water stress compared with the control treatment. In general, potassium silicate was more effective than potassium selenite for improving all studied parameters. This may be due to the presence of potassium and silicon at appropriate levels that allow the mitigation of drought stress compared to the level of potassium and selenium especially at a lower concentration of 0.3 mM potassium selenate.

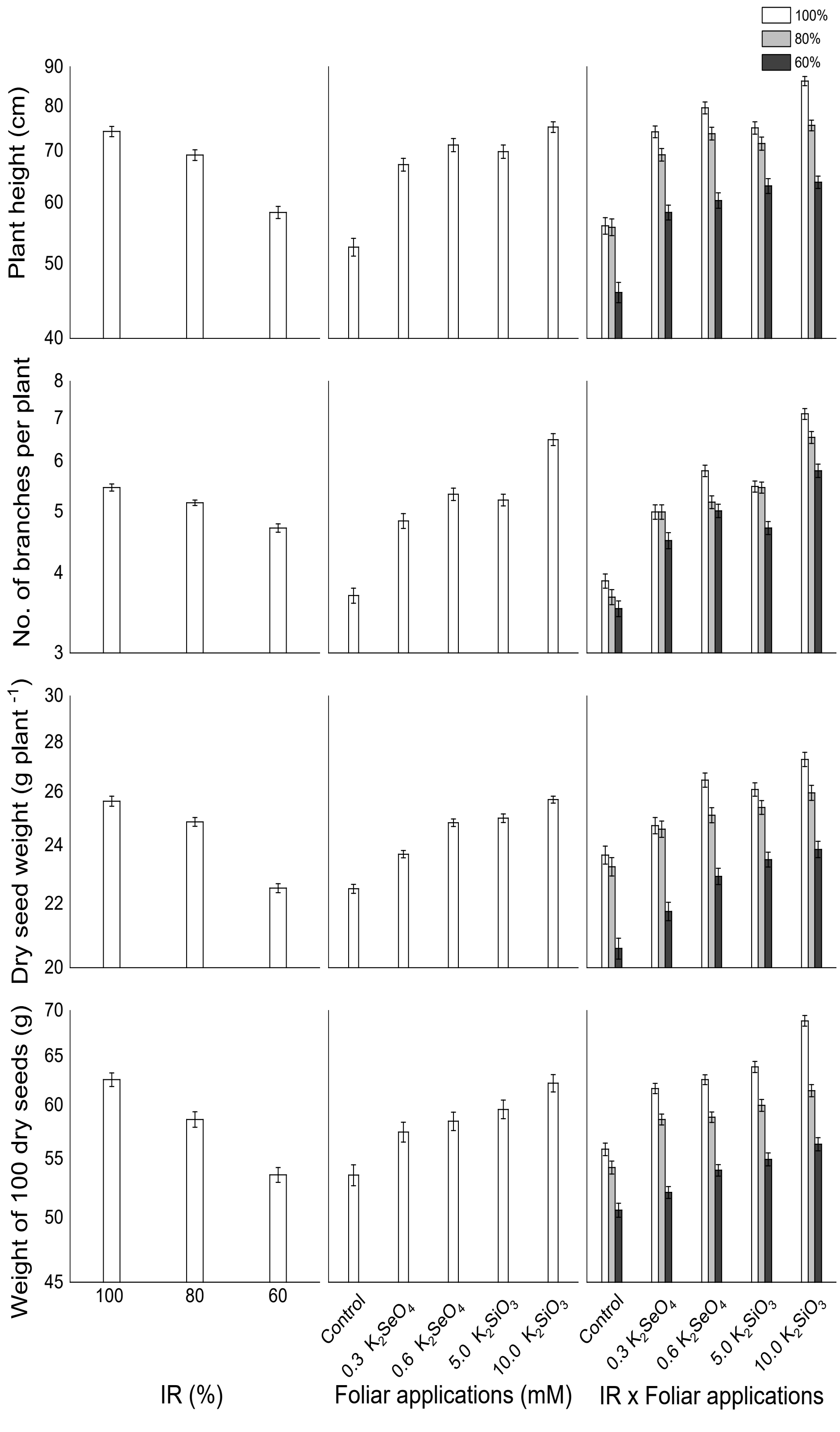

Fig. 1. Plant height, No. of branches, dry seed weight and weight of 100 dry seeds of faba bean plants as affected by different treatments (Average two seasons). Data are the mean value ± SE

Regarding the interaction effect of both factors data in Fig.1 indicated that the interaction effect between the applied irrigation water levels at 100% of IR and potassium selenate had a significant effect on vegetative growth characteristics of faba bean plants. The highest mean values growth parameters of faba bean plants were recorded using 100% of IR with the foliar application of 0.6 mM potassium selenate, with mean values of 79.96cm, 5.89, 26.66 (g plant^{-1}) and 62.79g for plant height, No. of branches per plant, dry seeds weight and the weight of 100 dry seeds, respectively.

Concerning the interaction between the effect of applied irrigation levels 100% of IR and potassium silicate, the results presented in Fig.1 showed that the highest mean values of plant height (cm), No. of branches per plant, dry seed weight g plant^{-1} and weight of 100 dry seeds g were 87.26cm, 7.27, 27.53g plant^{-1} and 68.97g, respectively. These results were obtained when using 100 % of IR and foliar spraying of potassium silicate at a rate of 10 mM. Conversely, the lowest averages of these characters produced from the applied irrigation levels 60% of IR and untreated (control) plant treatment. Whereas foliar spraying with potassium silicate at a rate of 10 mM was appropriate for achieving the best values of all the studied parameters followed by potassium selenate at 0.6 mM compared to the control treatment.These results could be supported by those of Hattori et al. (2005), who mentioned that the application of potassium silicate at 1.66 mM as a foliar spry ameliorated the decrease in dry weight of sorghum plants under drought stress conditions. Also, these findings are following those stated by Ahmed et al. (2011), who found that the soil application of 200 ml^{-1} of K_2SiO_3 kg soil^{-1}, could be useful for improving the drought tolerance of the sorghum plant by enhancing its ability to absorb water. Such results were confirmed with the faba bean crop by the findings of Abou-Baker et al. (2012).

Effect of different treatments on dry seed yield, water use efficiency, protein, N, P and K contents in seeds of faba bean plants during the two seasons

Effect of irrigation water levels

Concerning the effect of applied irrigation levels and some foliar application substances on dry seed yield, water use efficiency, protein and the content of N, P and K in seeds of faba bean plants were presented in Fig. 2 and 3. The results showed that dry seed yield, P and K contents in seeds of faba bean significantly increased with increasing irrigation water levels up to 100% IR. Irrigation level at 100% of IR, recorded the maximum mean values, where the values of dry seed yield (kg ha^{-1}), P (%) and K (%) were 2474.82kg ha^{-1}, 0.53% and 2.79% in faba bean seeds, respectively. The effect of irrigation water levels on dry seed yield was in the following order: 100% followed by 80% and finally 60% of IR which recorded the minimum mean values. This can be attributed to the fact that during the period of vegetative growth and reproduction of faba bean, an increase in the amount of irrigation water added leads to improved photosynthesis led to more nutrient synthesis and accumulation, which leads to increased yield and components. These findings are by those obtained by Erdem et al. (2006) who showed that the increase in available soil moisture contributed to an increase in various physiological processes, better nutrient absorption, and higher rates of photosynthesis, which may be reflected in higher production values and its components.On the other hand, under drought stress conditions, the plants suffer from a disorder of many physiological processes i.e.inhibition of cell division, photosynthesis, water and nutrient uptake as well as damage of cell membrane and cell wall (Taiz and Zeiger, 2006). In this concern, Al-Suhaibani (2009) stated that plants of faba bean under drought stress conditions had fewer leaves number per plant. Consequently, reduced leaf expansion for plants under water deficit was associated with produced less leaf area per plant and resulted in decreased rate of transpiration. The deleterious impact of water stress on the growth and yield parameters of faba bean were recorded by many authors, i.e. (Alderfasi and Alghamdi, 2010; El-Shiekh et al., 2016; Gupta et al., 2017; Hegab et al., 2014 and Sarkar et al., 2017).

Regarding the data presented in Fig. 2 and 3, it is seen that increasing the irrigation water levels significantly decreased the water use efficiency, protein and N content in seeds of faba bean. The highest mean values of water use efficiency (kg m^{-3}), protein (%) and N (%) were 0.90kg m^{-3}, 22.45% and 3.59%, respectively, recorded at an irrigation level of 60%. The effect of different irrigation water levels on the water use efficiency, protein and N content can be arranged in the descending order as follows: 60% >80% >100% of IR, where the lowest values were obtained using 100% of IR. The same trend was recorded with the protein percentage of seeds, where the seeds of faba bean plants that received the lowest water supply (60 and 80% of IR) had more protein % compared with the highest water supply (100% of IR).

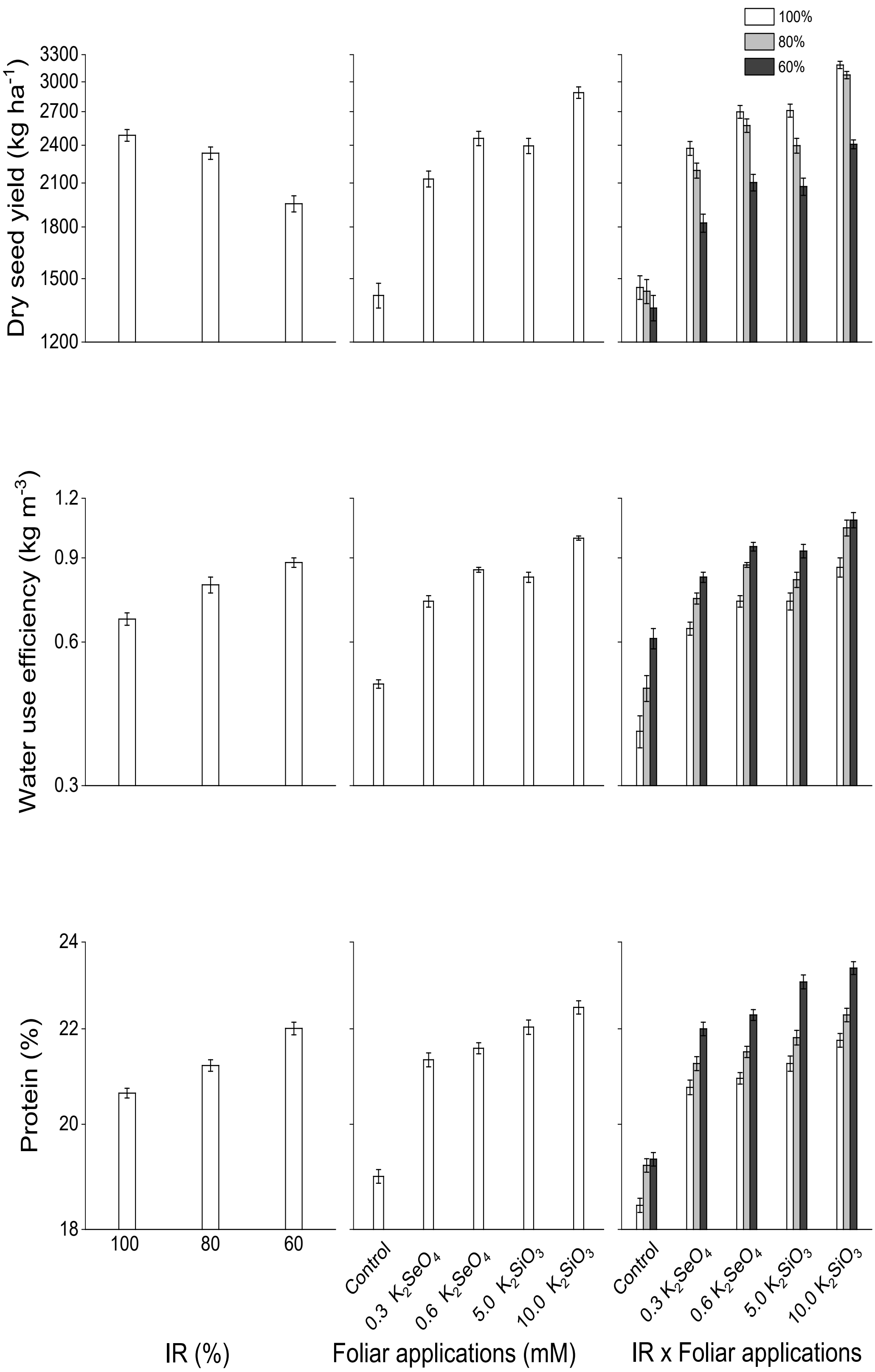

Fig. 2. Dry seed yield, water use efficiency and protein content of faba bean plants as affected by different treatments (Average two seasons). Data are the mean value ± SE

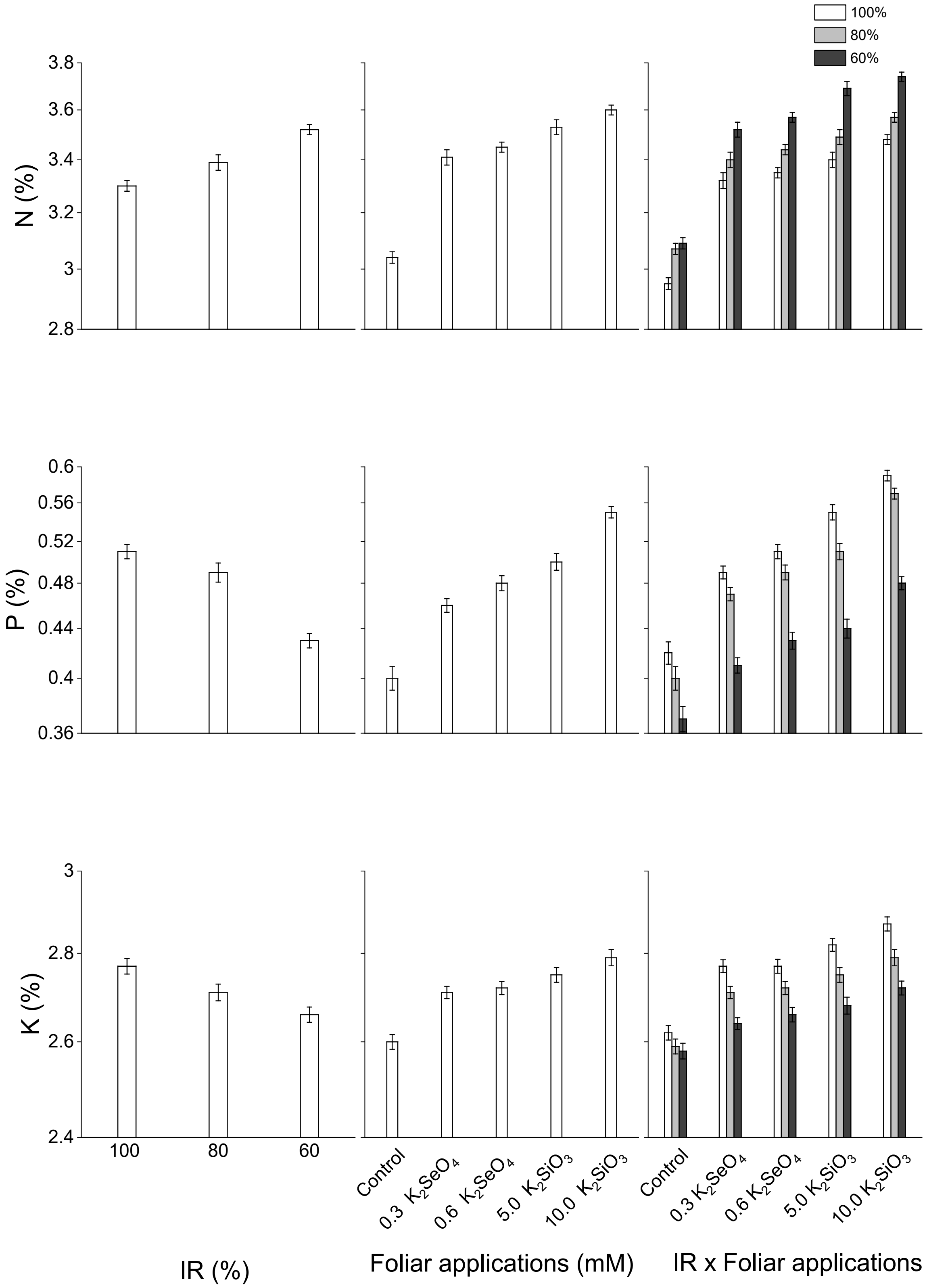

Fig. 3. Nitrogen, phosphorous and potassium (%) in seeds of faba bean plants as affected by different treatments (Average two seasons). Data are the mean value ± SE

In this concern, high photosynthetic is expected when the plants received adequate water supply (100% of IR) compared to the plants irrigated with a low amount of irrigation water (60 and 80% of IR). The seeds of these plants are also expected to have the lowest protein values, as adequate water supply causes hydrolysis, catabolism of proteins, and release of free amino acids and ammonia as well as proline (Fayed, 1972), these results showed that protein content is a good predictor of plant tolerance of water deficit. Moreover, El-Maghraby and Abd El-Hay (1994) showed that the protein content of faba bean differed according to irrigation treatments, where high available water decreased the crude protein content of broad bean. These results could be enhanced by those obtained by Hanna-Fardoas and Abdel-Nour (2000); El-Ghobashy and Youssef (2002). Also, Saleh et al. (2018) revealed that the water use efficiency values of green bean might be arranged in the ascending order of 4.33 < 5.68 < 6.33 kg m^{-3} for 100, 80 and 60% of IR treatments, respectively. However, the trend of obtained results is in good accordance with that of the previous investigators such as Alghamdi (2009); Megawer et al. (2017); Siam et al. (2017).

Effect of potassium selenate

Foliar application of potassium selenate at 0.6 mM had a significant effect on dry seed yield, water use efficiency, protein and concentrations of N, P and K in seeds of faba bean plants as compared with plants sprayed with distilled water (control) and 0.6 mM of K_2SeO_4 was more effective of 0.3 mM of K_2SeO_4 as presented in Fig. 2 and 3. Data revealed that the treatment of 0.6 mM potassium selenate gave high mean values of dry seed yield (kg ha^{-1}), WUE (kg m^{-3}), protein (%), N (%), P (%) and K (%), where the values were 2472.02kg ha^{-1}, 0.86kg m^{-3}, 21.89%, 3.50%, 0.49% and 2.73%, respectively. The obtained results under foliar application of potassium selenate could be attributed to the beneficial effects of selenium and potassium on promoting plant growth through the level of antioxidants, where selenium is a necessary component of various proteins, e.g. the antioxidant enzyme glutathione peroxidase, which can effectively remove oxygen free radicals especially with plants that subjected to stress condition (Hartikainen et al., 2000 and Ríos et al., 2009). In this concern, selenium can alter antioxidant levels in plants and detoxify superoxide radicals, consequently preventing oxidative damage and protecting the membranes and enzymes (Habibi, 2013). All the beneficial effects of added selenium were positively reflected on nutrient uptake, plant growth and yield of faba bean plants. Similar results were also reported by Hawrylak-Nowak (2009) on cucumber, Hu et al. (2002) on rice, Poggi et al. (2000) on potato, Yang et al. (2003) on soybean. On the other hand, potassium available from potassium selenate has a positive impact on many biological processes within the plant, such as photosynthesis, movement of water and other vital substances which led to increased plant growth and yield of faba bean.

Effect of potassium silicate

Regarding the applied effect of potassium silicate as a foliar spray on dry seed yield, water use efficiency, protein and concentrations of N, P and K in seeds of faba bean, a significant increase occurred compared to those obtained from the untreated plants (control treatment) as illustrated in Fig. 2 and 3. The application of potassium silicate had a favorable effect on all the parameters of faba bean yield and its components. On the other hand, increasing the potassium silicate concentration up to 10 mM led to increasing yield and its components as well as water use efficiency for all irrigation treatments as the averageof the two seasons. The potassium silicate treatment (10 mM) gave maximum mean values of 2862.14kg ha^{-1}, 0.99kgm^{-3}, 22.77%, 3.65%, 0.56% and 2.81% for dry seed yield, water use efficiency, protein, N, P and K, respectively. The increases in parameters of the growth and yield of faba bean may be due to the role of potassium silicate in impregnates along epidermal cell walls. Thus, these layers become effective barriers against water loss during the cuticles (Trenholm et al., 2004). Furthermore, Tahir et al. (2006) concluded that the beneficial impact of potassium silicate has been correlated with the important role that potassium plays in enhancing water status of a plant. The use of silicon can also reduce drought stress by increasing plant uptake of mineral nutrients and altering plant gas exchange attributes (Rizwan et al., 2015). Moreover,the silicon improvement effect was attributed to its effect in the stimulation of photosynthetic apparatus protection and chlorophyll formation. Thus, reduced the damage caused by deficit irrigation water (Ávila et al., 2010).

In this respect, other researchers reported that broad bean growth characteristics increased as a result of foliar potassium silicate spraying, as reported by Ahmed et al. (2007).

Effect of interaction

The interaction effects of applied irrigation water and foliar spray with either potassium selenate and/or potassium silicate treatments were illustrated in Fig. 2 and 3. For the interaction between applied irrigation water levels and potassium selenate, the highest mean values of dry seed yield (kg ha^{-1}), P (%) and K (%) were 2702.47kg ha^{-1}, 0.53% and 2.79%, respectively, recorded using 100% of IR with the foliar application of 0.6 mM K_2SeO_4. On the contrary, the highest mean values of WUE (kg m^{-3}), protein (%) and N (%) were 0.96kg m^{-3}, 22.85% and 3.66%, respectively, under using 60% of IR with the foliar application of 0.6 mM K_2SeO_4.

Concerning the combined treatments which show the interaction effect between applied irrigation water and foliar spray of potassium silicate treatments are illustrated in Fig. 2 and 3. Data revealed that the maximum mean values were 3132.10kg ha^{-1},0.62% and 2.88% for dry seed yield, P and K, respectively. These values were recorded using 100% of IR with the foliar application of 10 mM potassium silicate. On the contrary, the maximum mean values of water use efficiency, protein and N were 1.10kg m^{-3}, 23.85% and 3.82% respectively, which were recorded when using 60% of IR with the foliar application of 10 mM potassium silicate.

Conclusions

These findings suggest that in general the highest mean values of growth and yield of faba bean plants were obtained using the full amount of applied irrigation water, whereas the highest mean values of N (%), protein (%), water use efficiency kg m^{-3} were recorded with the applied irrigation water amount 60% of IR. On the other hand, underwater stress conditions, the foliar application of 0.6 mM potassium selenate or 10 mM potassium silicate as a supplementary fertilizer increased the plant growth, the yield of dry seed and water use efficiency of faba bean plants. However, the application of 10 mM potassium silicate was more effective on other foliar applications. Thus, there was no significant difference between 100% of applied irrigation water requirements and 80% of irrigation requirements with foliar application of 10 mM potassium silicate for dry seed yield of faba bean plants. Therefore, using 80% of IR and 10 mM potassium silicate are recommended to save 20% of the applied irrigation water amount for another use in agriculture.

Declaration of Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors contribution

All authors contributed to the design and implementation of the research, to the analysis of the results and the writing of the manuscript.

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تحسين نمو وإنتاجية محصول الفول تحت ظروف الري الناقص بواسطة الرش بسيلينات البوتاسيوم وسيليكات البوتاسيوم

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أجريت تجربة حقلية بمزرعة قسم الأراضي والمياه بكلية الزراعة، جامعة الأزهر، مدينة نصر، القاهرة، مصر خلال موسمي ٢٠١٨/٢٠١٩ و ٢٠١٩/٢٠٢٠ م لدراسة تأثير ثلاثة مستويات من مياه الري المضافة وهى I_2 ، I_1 وI_3 و تمثل الري عند ١٠٠ و ٨٠ و ٦٠٪ من الاحتياجات المائية على الترتيب) والرش الورقي بسيلينات البوتاسيوم (كنترول، ٣، و ٦ مليمول) وأيضا الرش الورقي بسيليكات البوتاسيوم (كنترول ، ٥ و١٠ مليمول) على النمو ،إنتاجية وجودة نبات الفول صنف سخا ٣ وكذلك كفاءة استخدام المياه. وقد أشارت النتائج إلى أن زيادة كمية مياه الري المضافة من ٢٢١٩.٧٥(I_3) إلى ٣٦٩٨.٧٧ (I_1) م٣/هكتار أعطت أعلى متوسط قيم لطول النبات، عدد الفروع، وزن البذور الجافة، وزن ١٠٠ بذرة جافة ومحصول البذور الجافة ومحتوى الفوسفور والبوتاسيوم في البذور. على العكس من ذلك، سجلت أعلى قيم لمتوسط كفاءة استخدام المياه ومحتوى البروتين والنيتروجين في البذور عندالري بنسبة ٦٠٪ من الاحتياجات المائية لكلا الموسمين. علاوة على ذلك، أدت جميع معاملات الرش الورقي إلى تحسن في جميع خصائص النمو وإنتاجية البذور الجافة ومحتوى البروتين وكذلك كفاءة استخدام المياه مقارنة بالكنترول. من ناحية أخرى، أدى الرش الورقي بسيليكات البوتاسيوم عند ١٠ مليمول إلى زيادة معنوية في جميع الصفات المدروسة يليه الرش الورقي بسيلينات البوتاسيوم عند ٠.٦ مليمول مقارنة بالكنترول. لذلك توصى الدراسة بزراعة نباتات الفول (صنف سخا ٣) بإضافة ٨٠٪ من الاحتياجات المائية (٢٩٥٨.٠٢م٣/هكتار) والرش الورقي عند ١٠ مليمول من سيليكات البوتاسيوم لتوفير ٢٠٪ من كمية مياه الري المضافة للإستخدامات الأخرى للزراعة في مصر.