Potassium silicate for mitigation of irrigation water deficiency for Faba bean intercropped with sugar beet in a sandy soil

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Abstract

A field experiment was carried out at Ismailia Agricultural Research Station, Agricultural Research Center, Ismailia governorate (Lat. 30° 35' 30" N, Long. 32° 14' 50" E, 10 m a.s.l.), Egypt, during 2018/2019 and 2019/2020 growing seasons to determine the suitable rate of potassium silicate that could mitigate the effect of irrigation water deficiency on productivity of both faba bean and sugar beet under intercropping system. Three irrigation regimes (I1(120% ETo), I2 (100% ETo) and I3 (80% ETo)) and three rates of sprayed potassium silicate (Si0 (unsprayed-control), Si1(200 ppm) and Si2 (300 ppm)) were used. The results showed the highest intercropped faba bean and sugar beet yields and their components were attained under spraying with Si1 under the three irrigation regimes in both growing seasons. Furthermore, spraying intercropped faba bean and sugar beet with Si1 under I2 and I3 relieved water deficiency and increased yields, compared to no spraying. The 2-year average values of applied irrigation water to sugar beet intercropping system were 9252, 7730, 6184 m^3/ha, respectively under I1, I2 and I3. Using cereal units analysis showed that the highest values of WUE and WP were found under application of I3, namely 0.29 CU/mm and 0.36 CU/mm for WUE and 0.24 CU/mm and 0.25 CU/mm for WP in the first and second seasons, respectively. The highest values of WER were 1.41 and 1.42 obtained from the interaction between irrigation with I2 and spraying with Si1 in the first and second season, respectively. Thus, it could be concluded that to mitigate the effect of irrigation deficiency applied to faba bean intercropped with sugar beet, a spray with 200 ppm of potassium silicate should be applied.

Key words: Deficit irrigation, potassium silicate, Cereal Units analysis, water use efficiency, water productivity, water equivalent ratio

INTRODUCTION

Deficit irrigation is one of the most important management strategies to face water scarcity. Fereres and Soriano (2007) defined deficit irrigation as an irrigation strategy to maximize yield with a minimum rate of water application. Deficit irrigation increases water use efficiency through increasing application efficiency, consumption efficiency and yield efficiency (Hsiao *et al.*, 2007). Increases in application efficiency occur as a result of lower amount of water applied than full evapotranspiration, thus most or all the water applied remains in the root zone and water lost by run off and deep percolation decreases (Sepaskhah and Ghahraman, 2004).

To assess the effectiveness of the application of different amounts of irrigation water, two measurements can be used, namely water use efficiency and water productivity. Water use efficiency serves as a key variable in the assessment of plant responses to water stress induced by deficit irrigation (Chai *et al.*, 2016). It describes the intrinsic trade-off between carbon fixation and water loss, because water evaporates whenever stomata opens for CO_2 acquisition for photosynthesis (Bramley *et al.*, 2013). In plant research, water use efficiency is defined as crop yield per unit of water used (Chai *et al.*, 2014). Feleafel and Mirdad (2014) reported that water use efficiency is probably results from its role in advancing root development and penetration, which increases the ability of plants to absorb water from the soil. Whereas, water productivity is a quantitative term used to define the relationship between crop produced and the amount of water involved in crop production (Igbadun *et al.*, 2006). Valipour (2014) defined water productivity as the ratio of yield or marketable product to water used by the crop. Under limited water supplies, the farmer's goal should be to maximize net income per unit water used rather than per unit land (Fereres and Soriano, 2007). Water productivity increases under deficit irrigation, relative to its value under full irrigation (Fan *et al.*, 2005). It is necessary for irrigation management in the areas suffers from water scarcity to shift from emphasizing production per unit area towards maximizing the production per unit of water consumed, which is "water productivity" (Rekaby *et al.*, 2016).

Intercropping is one of the techniques that can be used to increase land utilization and improve production (Bhattanagar *et al.*, 2007), as well as increase water productivity (Mao *et al.*, 2012). Yield advantages is the most common motive to adopt intercropping systems, which lead to greater resource depletion by intercrops, compared to monocultures (Hauggaard-Nielsen *et al.*, 2006). When the co-crops in an intercropping system having different requirements of the available resources, namely quantity, quality, and time of demand, the advantages of intercropping system could be more apparent (Alfa and Musa, 2015). The efficiency of the intercropping directly depends on proper management of the factors of production (Porto *et al*., 2011), which bring ecological and economic benefits and consequently increase production, as compared to monoculture (Batista *et al*., 2016). Water utilization is increased under intercropping systems, where the applied amount of irrigation water to the main crop is used to irrigate both intercrops and that reduces water runoff and soil loss (Lithourgidis, 2011).

Sugar beet is becoming one of the important cultivated crops in Egypt as it is used to reduce sugar production-consumption gap in Egypt. Compared to sugarcane, it has lower growth season and consequently lower water requirements. In the past 10 years, the cultivated area of legume crops, specifically faba bean has been steadily decreasing as a result of expansion in the cultivation of sugar beet. One of the solutions that could be used to solve part of the problem of legumes deficiency is to intercrop it with sugar beet (El-Mehy *et al*., 2020). Several researchers studied the effect of intercropping faba bean with sugar beet in Egypt. Azad and Alam (2004), Marey (2004) and Salama *et al*., (2016) intercropped faba bean with sugar beet and they reported higher land productivity, compared to monoculture of either crops. Furthermore, higher water utilization, expressed by higher water equivalent ratio was also reported. Zohry and Ouda (2019) intercropped faba bean with sugar beet and they found that water equivalent ratio were 1.31, whereas, El-Mehy *et al*., (2020) indicated that water equivalent ratio reached 1.50 for the intercropping system of faba bean and sugar beet. Moreover, Abd-Allah *et al*., (2021) indicated that water equivalent ratio for faba bean intercropping system with sugar beet could reach 1.48.

In sandy soil, silicon (Si) is considered a limiting factor for plant growth and yield. Si is continuously lost via leaching, thus fertilization with it could increase yield, soil productivity and improve nutrients content (Meena *et al*., 2014). Si plays an important role in photosynthetic rate, plant growth and nutrients uptake (Wang *et al*., 2006). Long-term of intensive crop cultivation and sprayed with silicates compounds increased growth parameters, yield and yield components of several crops (Henk, 2018). Abd El-hady and Bondok (2017) reported that sugar beet plants sprayed with 16 cm^3/L of K-silicate,150 and 180 days after sowing produced the highest mean values of sugar beet root yield, biological yield and sugar yield, compared to unsprayed treatment. Furthermore, it was reported that using of silicate compounds increased plant growth, yield and its components, and yield quality of squash (Abd El-Mageed *et al*., 2016). Application of foliar spraying with K-silicate to pea plants at the rate of 228 ppm enhanced growth parameters, yield and yield components, as well as nutrients contents (Ismail *et al*., 2017). Furthermore, Abdul-Qadir *et al*., (2017) reported that, when okra plants were treated with Ca-silicate, improvement in shoot fresh weight, shoot length, leaf area and leaf length were observed under water stress.

In spite of all the research work done on the application of potassium silicate in Egypt, no work was done on its application on faba bean intercropped with sugar beet under irrigation water deficiency. Thus, the objectives of this study were to find the suitable rate of potassium silicate that could mitigate the effect of irrigation water deficiency on productivity of both faba bean and sugar beet under intercropping system and its effect on water utilization by the intercropping system.

MATERIAL AND METHODS

A field experiment was carried out at Ismailia Agricultural Research Station, Agricultural Research Center, Ismailia Governorate (Lat. 30° 35’ 30” N, Long. 32° 14’ 50” E, 10 m above sea level), Egypt during 2018/2019 and 2019/2020 seasons. Daily values of weather elements at the experimental site during the two growing seasons were obtained from https://power.larc.nasa.gov/data-access-viewer/site and used to calculate monthly averages of reference evapotranspiration (ETo) values using The Basic Irrigation Scheduling model (BISm, Snyder *et al*., 2004) (Table 1). The model used Penman-Monteith equation presented in the United Nations FAO Irrigation and Drainage Paper (Allen *et al*., 1998) to calculate ETo values.

Disturbed and undisturbed soil samples from the surface 60 cm at the experimental site were collected for the analysis of main physical, hydro-physical and chemical soil properties. The analyses of the soil samples collected before sowing from the experimental site were conducted by the standard method of Tan (1996) and Page *et al*. (1982). The obtained values are presented in Tables 2 and 3.

Table 1: Average monthly weather data and the calculated ETo values for 2018/2019 and 2019/2020 growing seasons

Month	2018/2019 growing season					Month	2019/2020 growing season				
	SR	Tx	Tn	WS	ETo		SR	Tx	Tn	WS	ETo
Oct-18	19.2	30.2	18.6	2.8	**3.6**	**Oct-19**	18.9	29.2	18.1	2.7	**4.8**
Nov-18	15.3	25.2	14.4	2.1	**2.5**	**Nov-19**	14.6	24.3	14.2	2.4	**3.3**
Dec-18	13.3	20.1	9.70	2.7	**1.9**	**Dec-19**	11.2	21.5	12.3	2.5	**2.7**
Jan-19	12.8	17.8	7.5	2.6	**2.4**	**Jan-20**	12.8	17.4	6.2	2.3	**2.3**
Feb-19	16.0	19.7	8.5	2.5	**2.9**	**Feb-20**	16.0	19.4	6.8	2.3	**2.9**
Mar-19	20.5	23.9	11.5	3.0	**4.5**	**Mar-20**	20.5	23.8	10.4	2.6	**4.4**
Apr-19	24.1	27.4	13.5	3.1	**5.8**	**Apr-20**	24.1	27.9	12.7	2.9	**6.0**

SR = solar radiation (MJ/m²/day), TX and TN = maximum and minimum temperatures, respectively (°C), WS = wind speed (m/s), ETo = reference evapotranspiration (mm/day).

The experiment was carried out in sandy soil and it was arranged in a split plot design with three replicates. Three applied irrigation water treatments (I_1, 120% ETo; I_2, 100% ETo; I_3, 80% ETo) were assigned to the main plots, while three rates of potassium silicate (Si_0, unsprayed (control); Si_1, spraying 200 ppm; and Si_2, spraying 300 ppm) were arranged in the sub plots. The area of the experimental plot was 14.4 m^2. The sub-plot consisted of 4 ridges (3 m long and 1.2 m width).

Peanut was the previous summer crop in both seasons. Sugar beet (cultivar Sauther) was sown on the 1st and 5th of November 2018 and 2019, respectively and harvested on the 5th and 6th of May 2019 and 2020, respectively in both solid and intercropped culture. Whereas, faba bean (cultivar 843) was sown on October 15th and 17th in 2018 and 2019, respectively and harvested on April 10th and 13th in 2019 and 2020, respectively. Faba bean seeds were inoculated with *Rhizobium leguminosarum* before sowing and Arabic gum was used as a sticking agent in both solid and intercropping culture.

In the intercropping culture, sugar beet seeds were sown on both sides of the ridge (1.20 m width) in hills spaced 30 cm apart (84000 plant/ha, 100% of solid crop). Faba bean seeds were sown in one row on top of the ridge (1.20 m width) in hills, 20 cm apart. Plants were thinned to two plants per hill, with 25% planting density of the recommended faba bean solid culture.

In the solid culture, sugar beet seeds were sown on both sides of the ridge (1.20 m width) in hills spaced 30 cm apart (84000 plant/ha, 100% of solid crop). Faba bean seeds were sown on ridges (1.20 m width), 20 cm apart between hills on the top of ridges at 4 rows, 2 plants per hill (336000 plant/ha, 100% of solid crop). The solid culture of both crops was used for comparison purposes.

Potassium silicate fertilizer (K_2SiO_3, 500 g K L^{-1} and 114 g Si L^{-1}) was used at 3 rates, 0, 200 and 300 ppm (foliar spray). Fertilizer of K-silicate solution at rate 200 ppm Si was prepared by mixing K-silicate equal 1.75 L with 998.2 L ha^{-1} irrigation water and 300 ppm equal 2.63 L with 997.37 L $ha^{-1}$of irrigation water. Four doses of foliar spray at 25, 40, 55 and 70 days after sowing were applied. The EC of spray solution was from 400 to 450 ppm.

Other fertilizers were applied during growing season as follows: two doses of ammonium sulfate (200 g N kg^{-1}) were added to the soil at rate 20.16 kg N ha^{-1} for faba bean 20 and 35 days after sowing. For sugar beet, mono calcium super phosphate (67.4 g P kg^{-1}) was added to the soil before sowing at rate 16.2 kg P ha^{-1}, 240 kg N ha^{-1} was added at four doses before the second, the third,the fourth, and the fifth irrigations, and potassium sulfate (400 g K kg^{-1}) was added at rate 95.8 kg K ha^{-1}.

Sprinkler system was used to irrigate the experiment. A solid-set sprinkler irrigation system with rotary RC 160 sprinklers of 0.40 to 1.12 an average 0.58 m^3/hour discharge rate at 2.80 bars nozzle pressure was used to irrigate the crops. The sprinkler system consists of main PVC pipe line (160 mm diameter), sub main PVC pipelines (110 mm diameter), and PVC lateral lines (50 mm diameter). The laterals were spaced at 10 x 10 meters apart. Application of the irrigation water treatments started after 30 and 15 days from sowing sugar beet and faba bean, respectively. The solid culture of both crops was irrigated using the I_1 (120% ETo) irrigation treatment only.

Other regular agronomic practices were done according to the technical recommendations of both crops. At harvest, ten individual plants of faba bean and sugar beet were taken from each experimental plot. The collected data for faba been were number of branches/plant, number of pods/plant and seed yield (ton/ha). For sugar beet, roots of ten plants were taken from the plot to measure root length (cm), and the plants of whole plot were separated into tops and roots and weighted, then converted to estimate roots and tops yield per hectare.

To determine the quality traits of sugar beet, samples of 26 g fresh root weight were taken from each treatment to determine total soluble solids percentage (TSS %) measured by refractometer according to AOAC (1990). Sucrose (%) was estimated according to methods described by Le-Docte (1927). Sugar yield per hectare was calculated according to the following equation:

$$Sugar\ yield\ (ton/ha) = (root\ yield * sucrose\ \%)$$

Table 2: Physical and hydro-physical soil properties at the experimental site before sowing

Soil depth (cm)	Particle size distribution			Texture Class	Bulk density (mg m^{-3})	Field capacity (%)	Permanent wilting point (%)	Available water (%)
	Sand (%)	Silt (%)	Clay (%)					
0-20	94.30	3.70	2.00	Sandy	1.65	12.75	3.60	9.15
20-40	95.80	3.00	1.20		1.73	11.20	2.90	8.30
40-60	96.20	2.95	0.85		1.70	7.40	2.10	5.30

Table 3: Chemical properties of the soil at the experimental site before sowing.

Soil depth (cm)	pH (1:2.5)	ECe (dS m^{-1})	Soluble cations (meq L^{-1})				Soluble anions (meq L^{-1})			
			Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}
0-20	7.66	0.55	1.22	0.53	1.54	0.18	-	1.10	1.72	0.65
20-40	7.59	0.47	1.20	0.50	1.58	0.15	-	1.06	1.74	0.63
40-60	7.40	0.39	1.25	0.48	1.62	0.16	-	1.08	1.75	0.68

Available nutrients (mg kg^{-1})			
N	P	K	Si
12.15	4.50	57.2	40.2

pH at 1: 2.5 (soil: water suspension), ECe: soil saturation extract

Water relations

Applied irrigate ion water

The amounts of applied irrigation water were calculated according to the equation given by Vermeiren and Jopling (1984) as follows:

$$AIW = \frac{ETo \times I}{Ea\,(1 - LR)}$$

Where:

AIW = depth of applied irrigation water (mm).
ETo = reference evapotranspiration (mm d^{-1}).
I = irrigation intervals (days).
Ea = application efficiency of the irrigation system.
LR = leaching requirements. The LR was not considered because the ECe of the soil profile is very low.

The values of water consumptive use (WCU) were calculated using BISm model (Snyder *et al.*, 2004).

Water use efficiency (WUE) and water productivity (WP)

To calculate water use efficiency and water productivity for the studied intercropping system, calculation of Cereal Units (CU) (Brockhaus, 1962) was done, then it was added together to obtain one value to represent the total yield from the two crops in the intercropping system. The CU has been used as a common denominator in German agricultural statistics for decades and it were mainly based on the nutritional value. Brankatschk and Finkbeiner, (2014) stated that CU is an appropriate unit for the description of agricultural products. Furthermore, Macak *et al.*, (2015) used CU to evaluate productivity of different crop rotations. This methodology is widely used in Egypt to evaluate the production of different intercropping systems. Abou Keriasha *et al.*, (2013) reported that according to Brockhaus (1962), 100 kg of faba been is equal to 1.20 CU. Furthermore, 100 kg of sugar beet is equal to 0.25 CU. Thus, water use efficiency and water productivity (CU mm^{-1}) was calculated using the accumulated values of cereal units as numerator and the applied water in millimeters as dominator.

According to Stan hill (1986), water use efficiency can be calculated as follows:

WUE (kg/m³) = crop yield (kg/ha)/ consumed irrigation water (m³/ha)

Thus, to calculate WUE of the intercropping system, it was changed to CU and the following equation was used:

WUE (CU/mm) = CU (sugar beet + faba bean)/ consumed irrigation water(mm)

Similarly, according to the equation presented by Zhang (2003), crop water productivity can be calculated as followed:

WP (kg/m³) = crop yield (kg/ha)/ applied irrigation water (m³/ha)

Thus, to calculate WP of the intercropping system, it was changed to CU and the following equation was used:

WP (CU/mm) = CU (sugar beet + faba bean)/ applied irrigation water (mm)

Water equivalent ratio (WER)

Water equivalent ratio is used to quantify the efficiency of water use by an intercropping system (Mao *et al.*, 2012). The WER is defined as the total water needed in sole crops to produce the equivalent amount of the species yields on a unit area of intercrop as follows:

$$WER = \frac{\left(\frac{Y_{int,f}}{WU_{int}}\right)}{\left(\frac{Y_{mono,f}}{WU_{mono,f}}\right)} + \frac{\left(\frac{Y_{int,s}}{WU_{int}}\right)}{\left(\frac{Y_{mono,s}}{WU_{mono,s}}\right)}$$

Where: $Y_{int,f}$ and $Y_{int,s}$ are the yield of intercropped faba bean and sugar beet. WU_{int} is water consumptive use by the intercropped faba bean and sugar beet. $Y_{mono,f}$ and $Y_{mono,s}$ are the yield of mono faba bean and sugar beet. $WU_{mono,f}$ and $WU_{mono,s}$ are water consumptive use by mono faba bean and sugar beet, respectively.

If the WER > 1, it suggests that the water utilization of intercrops is higher than that of monoculture and that imply advantage in implemented inter-planting system. If WER < 1, it shows that water utilization of intercrops is lower than that of monoculture and that imply disadvantage.

Statistical Analysis

Data were statistically analyzed using the MSTAT-C Statistical Software Package (Freed,1991). The treatment means were compared using the Least Significant Differences (LSD) test with a significance level of 5% according to Gomez and Gomez (1984). The values of solid faba been and sugar beet yield were not included in the analysis.

RESULTS AND DISCUSSION

Effect of irrigation amounts and potassium silicate rates on faba bean yield and its components

The results in Table 4 indicated that all faba bean yield and its attributes were significantly affected by irrigation amounts and potassium silicate rates in both growing seasons. Different trends were observed for the interaction between irrigation and potassium silicate treatments, where seed yield only was found significantly affected in the first season. In the second season, only number of branches/plant was found significantly affected. The results also showed that the highest faba bean yield was obtained under I_1 and spraying with 200 ppm potassium silicate, which increased faba yield components, more than the unsprayed plants and plants sprayed with 300 ppm. Results in Table (4) also showed that the highest values of yield and its components were obtained when I_1 was applied. Furthermore, application of Si_2 resulted in the highest values of yield and its components. Whereas, the interaction effect between I_1 and Si_2 attained the highest yield and its components of faba bean.

Mona *et al.*, (2011) and Divito and Sadras (2014) observed the same effect of potassium silicate on faba bean, where they stated that potassium silicate, as a source of potassium, is an activator for many enzymes involved in N-fixation and in protein synthesis, in addition to its role in maintaining water balance in the plants. Furthermore, application of I_2 and spraying with 200 ppm potassium silicate reduced intercropped faba been yield by only 2% in the first season and by 6% in the second season, compared to the application of I_1 and unsprayed treatment. This result implied that application of potassium silicate could lower faba bean yield losses under irrigation water deficiency. Similar trends were obtained by Abou-Baker *et al*. (2012) and Ismail *et al* (2017).

Effect of irrigation and potassium silicate rates on sugar beet yield and its components

The results in Table 5 indicated that there were significant effects of irrigation and potassium silicate rates and their interaction on all sugar beet traits in both growing seasons, except root length in the second growing season. Furthermore, the highest sugar beet yield was obtained under application of I_1 and spraying with 200 ppm potassium silicate. This result could be explained by the suggestions of some studies that silicon could be used as a growth regulator (Eneji *et al*., 2008).The table also showed that application of I_2 increased sugar beet yield losses under spraying with potassium silicate.

Furthermore, application of I_2 and spraying with 200 ppm potassium silicate increased intercropped sugar beet yield by 3%, compared to the application of full and unsprayed treatment averaged over the two growing seasons. Artyszak *et al*., (2016) reported that foliar application with silicon resulted inan increase in sugar beet fresh root weight, and root yield. Ali *et al*., (2019) indicated that spraying sugar beet with potassium silicate mitigated water stress resulted from delayed irrigation and increased sugar beet yield, compared to unsprayed plants.

Table 4: Effect of irrigation water amounts, potassium silicate and their interactions on faba bean yield and its components in both seasons

Irrigation (I)	Si	No. of branches/ plant	No. of pods/ plant	Seed yield ton/ha	No. of branches/ plant	No. of pods/ plant	Seed yield ton/ha
		2018/2019			2019/2020		
I_1	Si_0	4.36	13.6	1.37	4.33	13.1	1.42
	Si_1	4.76	14.7	1.61	4.46	14.2	1.55
	Si_2	4.53	14.4	1.50	4.03	13.7	1.49
Mean		4.55	14.2	1.49	4.27	13.7	1.49
I_2	Si_0	4.07	13.2	1.22	3.77	12.9	1.40
	Si_1	4.53	14.2	1.34	4.23	13.8	1.50
	Si_2	4.27	14.0	1.25	3.97	13.0	1.41
Mean		4.29	13.8	1.27	3.99	13.2	1.44
I_3	Si_0	3.53	12.0	1.22	3.33	11.4	1.24
	Si_1	3.86	12.6	1.25	3.70	12.4	1.35
	Si_2	3.73	12.4	1.22	3.50	12.0	1.31
Mean		3.71	12.3	1.23	3.51	11.9	1.30
Average Si treatments	Si_0	3.99	12.9	1.27	3.81	12.5	1.35
	Si_1	4.38	13.8	1.40	4.13	13.5	1.47
	Si_2	4.18	13.6	1.32	3.83	12.9	1.40
LSD 0.05 (I)		0.17	0.14	0.13	0.13	0.50	0.34
LSD 0.05 (Si)		0.14	0.21	0.11	0.11	0.31	0.22
LSD 0.05 (IxSi)		NS	NS	0.20	0.20	NS	NS
Solid		2.70	11.0	2.53	2.53	11.0	3.59

I_1= 120% ETo; I_2=100% ETo; I_3= 80% ETo; Si_0 = unsprayed with potassium silicate; Si_1= 200 ppm potassium silicate; Si_2= 300 ppm potassium silicate.

Table 5: Effect of irrigation water amounts, potassium silicate and their interactions on sugar beet yield and its components of in both seasons

Irrigations (I)	Si	Root length (cm)	Top fresh weight (g)	Root yield (ton/ha)	Root length (cm)	Top fresh weight (g)	Root yield (ton/ha)
		2018/2019			2019/2020		
I1	Si_0	17.8	464.3	58.9	16.8	455.6	57.7
	Si_1	18.2	480.0	62.0	17.9	475.6	60.7
	Si_2	17.7	468.3	60.4	17.3	466.6	58.6
Mean		17.9	470.8	60.4	17.3	466.0	59.0
I_2	Si_0	16.1	390.0	53.6	15.9	387.3	53.3
	Si_1	18.0	457.3	59.9	18.0	463.3	59.7
	Si_2	17.3	448.6	57.7	17.6	453.3	57.7
Mean		17.1	432.0	57.1	17.2	434.6	56.9
I_3	Si_0	14.8	324.3	51.1	15.4	313.3	48.9
	Si_1	17.6	419.3	58.0	18.1	409.6	57.0
	Si_2	17.1	405.6	54.5	17.2	394.0	53.5
Mean		16.5	383.1	54.5	16.9	372.3	53.1
Average Si treatments	Si_0	16.2	392.9	54.6	16.0	385.4	53.3
	Si_1	17.9	452.2	60.0	18.0	449.5	59.1
	Si_2	17.4	440.8	57.5	17.4	438.0	56.6
LSD 0.05 (I)		0.15	2.65	0.79	NS	8.98	0.84
LSD 0.05 (Si)		0.20	7.30	0.79	0.23	6.60	0.62
LSD 0.05 (I x Si)		0.35	12.6	1.39	0.41	11.4	1.08
Solid		19.0	525.0	65.8	8.5	495.0	64.2

I_1= 120% ETo; I_2=100% ETo; I_3= 80% ETo; Si_0 = unsprayed with potassium silicate; Si_1= 200 ppm potassium silicate; Si_2= 300 ppm potassium silicate.

Effect of irrigation and potassium silicate rates on sugar beet chemical traits

Results in Table 6 indicated that the effect of irrigation treatments and potassium silicate were found significant on sucrose percentage and T.S.S in both seasons. However, the interaction between irrigation treatments and potassium silicate was found insignificant in both seasons. The table also showed that there was clear reduction in sucrose percentage and T.S.S as a result of the reduction in the applied irrigation amounts from I_1 to I_2. It was also noticed from the table that, in general, spraying with 200 ppm of potassium silicate attained the highest value of sucrose percentage in both growing seasons under the three irrigation amounts. On the contrary, T.S.S values were the highest under no spraying with potassium silicate under the three irrigation amounts. Artyszak *et al.*, (2016) reported that foliar application of silicon had no effect on sugar beet roots quality parameters. Similar results were obtained by Ali *et al.*, (2019).

Applied irrigation water

The results in Table 7 indicated that the amounts of applied irrigation for faba bean intercropped with sugar beet were 9604, 8006, and 6403 m^3/ha in the first season and were 8900, 7456, and 5965 m^3/ha in the second season under I_1, I_2, and I_3 irrigation treatments, respectively. The values of WCU for faba bean intercropped with sugar beet were 7340, 6120 and 5200 m^3/ha in the first season and were 6300, 4980 and 4090 m^3/ha in the second season under I_1, I_2, and I_3 irrigation treatments, respectively. The results also showed that, in the first season, water saving was 17% under I_2, which resulted in 15 and 6% reduction in faba bean and sugar beet yield, respectively. Application of I_3 treatment saved 33% of the applied irrigation water, compared to I_1 and reduced the yield of faba been and sugar beet by 18 and 10%, respectively.

Similarly, in the second growing season, the saved percentage of irrigation water was 16 and 33% when I_2 and

Table 6: Effect of irrigation water amounts, potassium silicate and their interactions on sugar beet chemical traits in both seasons

Irrigation (I)	Si	Sucrose%		T.S.S	
		2018/2019	2019/2020	2018/2019	2019/2020
I_1	Si_0	18.2	18.1	20.6	20.6
	Si_1	18.6	18.6	20.3	20.1
	Si_2	18.6	18.4	20.4	20.4
Mean		18.5	18.4	20.4	20.4
I_2	Si_0	17.7	17.8	20.0	19.8
	Si_1	18.2	18.4	19.5	19.4
	Si_2	18.0	18.2	19.7	19.5
Mean		17.9	18.1	19.7	19.6
I_3	Si_0	17.2	17.3	19.4	19.2
	Si_1	17.7	17.8	19.0	18.5
	Si_2	17.7	17.7	19.2	18.8
Mean		17.6	17.6	19.2	18.8
Average Si treatments	Si_0	17.7	17.7	20.0	19.9
	Si_1	18.2	18.3	19.6	19.3
	Si_2	18.1	18.1	19.8	19.6
LSD 0.05 (I)		0.22	0.26	0.13	0.14
LSD 0.05 (Si)		0.16	0.08	0.11	0.15
LSD 0.05 (I x Si)		NS	NS	NS	NS
Solid		18.1	18.4	20.7	20.5

I_1= 120% ETo; I_2=100% ETo; I_3= 80% ETo; Si_0 = unsprayed with potassium silicate; Si_1= 200 ppm potassium silicate; Si_2= 300 ppm potassium silicate.

Table 7: Effect of irrigation treatments on the amounts of applied irrigation water (AIW, m^3/ha), percentage of saved water (IWS, %), water consumptive use (WCU, m^3/ha) of faba bean and sugar beet under the intercropping system, faba bean and sugar beet yield (ton/ha) and percentage of reduction in the yield (YR, %) in the two seasons

Irrigation treatments	AIW	IWS	WCU	Faba bean yield	YR	Sugar beet yield	YR
2018/2019							
I_1	9604	-	7340	1.49	-	60.4	-
I_2	8004	17	6120	1.27	15	57.1	6
I_3	6403	33	5200	1.23	18	54.5	10
2019/2020							
I_1	8900	-	6300	1.49	-	59.0	-
I_2	7456	16	4980	1.44	3	56.9	4
I_3	5965	33	4090	1.30	13	53.1	10

I_1= 120% ETo; I_2=100% ETo; I_3= 80% ETo

I_3 were applied, respectively. The results also showed that faba bean and sugar beet yield losses were lower in the second season, compared to the same values in the first season which can be attributed to climate variability between the two seasons. Application of I_2 reduced faba bean and sugar beet yield by 3 and 4%, respectively and application of I_3 reduced faba bean and sugar beet yield by 13 and 10% respectively, compared to application of I_1 treatment. These results implied that sugar beet is more tolerant to water stress than faba bean. The obtained results were similar to those reported by Hegab *et al.* (2014), where they indicated that saving 20% of the applied irrigation water to faba bean resulted in 19% reduction in its yield. Whereas, El-Darder *et al.* (2017) indicated that saving 23% of the applied water to sugar beet resulted in 8% yield losses.

Cereal units (CU), water use efficiency (WUE) and water productivity (WP)

The results in Table 8 indicated that under I_1, the values of CU for faba bean and sugar beet were the highest in both growing seasons, namely 17.9 and 17.9 CU for faba bean and it were 151.1 and 147.4 CU for sugar beet in the first and second season, respectively. Similarly, the highest values of the total CU for both faba bean and sugar beet followed the same pattern, namely 169.0 and 165.3 CU in the first and second season, respectively. Whereas, the lowest values for CU was found under I_3 in both growing seasons, namely 14.8 and 15.6 CU for faba bean and it were 136.3 and 132.8 CU for sugar beet in the first and second season, respectively. Whereas, the lowest values of total CU for both faba bean and sugar beet followed the same pattern, 151.1 and 148.4 CU in the first and second season, respectively.

The table also showed that the highest values WUE and WP were found under application of I_3, namely 0.29 CU/mm and 0.36 CU/mm for WUE and 0.24 CU/mm and 0.25 CU/mm for WP in the first and second seasons, respectively. The obtained results were in line with the findings of Zohry *et al* (2017) and El-Mehy *et al* (2018).

Water equivalent ratio (WER)

Results in Table 9 indicated that highest values of WER for faba bean, sugar beet and total WER were obtained under spraying with 200 ppm potassium silicate for the three irrigation treatments, compared to the other potassium silicate treatments in both growing seasons. However, the highest total WER of 1.41 and 1.42 were obtained from the interaction between irrigation with I_2 and spraying with Si_1 in the first and second season, respectively. This result showed that the water utilization of this intercropping system, represented by total WER was increased by 41 and 42%.The lowest value of total WER was obtained under I_3 in both growing season. Similar results were obtained by El-Mehy *et al.* (2020) and Abdallah *et al.* (2021).

Table 8: Cereal units (CU), water use efficiency (CU/mm) and water productivity (CU/mm) for faba been intercropped with sugar beet in both growing seasons

Irrigation treatments	$CU_{faba\ bean}$	$CU_{sugar\ beet}$	Total $CU_{faba\ bean + sugar\ beet}$	WUE	WP
2018/2019					
I_1	17.9	151.1	169.0	0.23	0.18
I_2	15.2	142.7	157.9	0.26	0.20
I_3	14.8	136.3	151.1	0.29	0.24
2019/2020					
I_1	17.9	147.4	165.3	0.26	0.19
I_2	17.3	142.2	159.5	0.32	0.21
I_3	15.6	132.8	148.4	0.36	0.25

I_1= 120% ETo; I_2=100% ETo; I_3= 80% ETo

Table 9: Effect of irrigation treatments and spraying with potassium silicate rates on water equivalent ratio for faba bean intercropped with sugar beet in the two seasons

Irrigation (I)	Si	2018/2019			2019/2020		
		$WER_{faba\ bean}$	$WER_{sugar\ beet}$	WER_{total}	$WER_{faba\ bean}$	$WER_{sugar\ beet}$	WER_{total}
I_1	Si_0	0.34	0.90	1.24	0.40	0.90	1.29
	Si_1	0.40	0.94	1.35	0.43	0.94	1.38
	Si_2	0.38	0.92	1.29	0.42	0.92	1.33
I_2	Si_0	0.38	0.92	1.30	0.49	0.80	1.29
	Si_1	0.42	0.99	1.41	0.52	0.89	1.42
	Si_2	0.39	0.95	1.35	0.49	0.86	1.35
`I_3	Si_0	0.31	0.87	1.18	0.35	0.77	1.12
	Si_1	0.32	0.99	1.30	0.38	0.90	1.28
	Si_2	0.30	0.93	1.24	0.36	0.85	1.21

I_1= 120% ETo;I_2=100% ETo; I_3= 80% ETo; Si_0 = unsprayed with potassium silicate; Si_1= 200 ppm potassium silicate; Si_2= 300 ppm potassium silicate.

CONCLUSION

In this research, we demonstrated that the effect of application of deficit irrigation, namely application of I_2 (100% ETo), on faba bean intercropped with sugar beet could be mitigated by spraying 200 ppm potassium silicate, which resulted in lower yield losses in both crops, compared to application of 120% ETo irrigation and without spraying. Water utilization of both intercrops expressed by water equivalent ratio was also increased under application of 100% ETo irrigation treatment and spraying with 200 ppm potassium silicate. Furthermore, in case of severe water shortage, namely application of 80% ETo, spraying with 200 ppm potassium silicate also could be used to avoid high yield losses in both crops.

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