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ORIGINAL ARTICLES

Silicon and Water Regime Responses in Bean Production under Soil Saline Condition

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ABSTRACT

Two field experiments were carried out to compare between potassium silicate and magnesium silicate as a source of silicon in increasing bean production. As well as, investigate the role of irrigation levels (I_1=75, I_2=100 and I_3=125% of water requirements, last rate is the traditional irrigation water amount by farmers) and silicon rates (Si_1=300, Si_2=600ppm SiO_2 and control) in alleviating salt stress (Soil salinity = 7.5 dS/m) on bean growth. Plant growth parameters, yield calculations and water relations were recorded. Highest basic branch, bods number, biological yield, stover yield and plant height were obtained from potassium silicate application. But, no significant difference between potassium and magnesium silicate in their effect on bods number, seed yield and plant height. Plant height, biological, stover and seed yield follow the same order: $I_3>I_2>I_1$. Silicon addition promoted bean growth, increased yield and its measured parameters compared with control. Both of IWUE values (calculated by seed or stover yield) increased with increasing Si levels. Highest irrigation rate (I_3) has the lowest economic water productivity. Application of I_1 and I_2 rates increased EWP by 15.63 and 20.31% compared with I_3, respectively. Generally, the present results confirm the pathway which called to considering silicon one of the essential elements to plant growth.

Key words: Silicon – Water regime – Bean – Saline soil

Introduction

With the changes occurring in the global environment, the role of Si will become more important for better and sustainable production of crops. Although Si is not generally listed in the list of essential elements for higher plants (Marschner, 1995), it is considered as one of the important beneficial nutrient for plant growth (Liang *et al*., 2006). Most soils contain significant quantities of silica, but continuous cropping, particularly with crops that accumulate significant quantities of silica, can reduce plant-available levels of Si to the point that supplemental Si fertilization is required (Ma *et al*., 2001). Plants growing under natural conditions do not appear to suffer from Si deficiencies. However, Si-containing fertilizers are routinely applied to several crops including rice (Pereira *et al*., 2004) to increase crop yield and quality. Since 1955, Si fertilizers have been applied to paddy soils in Japan resulting in a significant increase in rice production (Takahashi *et al*., 1990). Various Si fertilizers are now widely applied in other countries such as Korea, China, and the USA. Silicate slag ($CaAl_2Si_2O_8$ or $CaSiO_3$) applied at a rate of 1.5-3.0 t/ha is common practice in degraded paddy fields in Japan (Takahashi and Miyake, 1977). Potassium silicate is a source of highly soluble potassium and silicon. It is used in agricultural production systems primarily as a silica amendment, and has the added benefit of supplying small amounts of potassium. Potassium silicate contains no volatile organic compounds, and applications will not result in the release of any hazardous or environmentally persistent byproducts (Blumberg, 2001).

Salinity is a major factor in limiting plant growth and productivity. It is estimated that about a third of the world's cultivated land is affected by salinity (Perez-Alfocea *et al*., 1996) and more land become non productive each ear because of salt accumulation. So, living with salinity is the only way of having sustaining agricultural production in the salt affected soil (Al-Rawahy *et al*., 2011). Oxidative damage induced by salt may be alleviated by Si addition (Liang *et al*., 2003).

Surface fresh water is scarce. If it is used adequately, the problem of water shortage would be alleviated. Egypt is characterized by high temperatures, high evapotranspiration and low rainfall. We wanted to find an effective way to use the brackish water in winter wheat production. The water deficiency promotes biochemical changes in plants as accumulation of organic compounds (Costa *et al.*, 2008) and promotes strong decrease in stomatal conductance (Lobato *et al.*, 2009).

In Egypt, dry and green bean seeds are used as human food, also it's a permanent component of most animal feeds. It has potential N_2-fixing and exhibit high levels of protein (28-36% of seed dry matter). Like all legume, it can play an important role in improving soil fertility, so it used as break crop between cereals (Mona *et al*.,

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2011). Bakry *et al*., (2011) reported that, production of faba bean in Egypt is limiting and affected by different factors such as soil fertility and water supply. Abundant yield and healthy plants are essential goals in this research.

This research was designed to compare between potassium and magnesium silicate in there effect on bean production under salt stress condition. In addition to, investigate the role of silicon and irrigation rates in alleviating salt stress effect on improving bean production.

Materials And Methods

Two field experiments were carried out in Ismailia governorate (Latitude: 30 35 Longitude: 32 16 Elevation: 11.2), during two successive seasons (2008-2009 and 2009-2010). First one was in winter season (2008-2009) to compare between potassium silicate and magnesium silicate as a source of silicon in increasing bean production. Whereas, field affected with salinity (7.5 dS/m) was parted into three plots and sprayed with; 1) potassium silicate, 2) magnesium silicate and 3) water (control). The second field experiment was conducted in winter season (2009-2010) to investigate the role of irrigation levels and silicon rates in alleviating salt stress on bean plants. Whereas, field was parted into three main plots separated by 2m and contained three levels of irrigation water (I_1=75, I_2=100 and I_3=125% of water requirements, last rate is the traditional irrigation water amount by farmers). Each main plot divided into three sub-plots. The first and second sub-plot were sprayed with two different rates of silicate (Si_1=300 and Si_2=600ppm SiO_2), respectively. The third sub-plot was sprayed with water (control). Potassium silicate used as a silicon source in second trial. Foliar application treatments were applied at three successive times 30, 60 and 80 days after sowing faba bean plants (*Vicia faba* L.) var. Giza37. Some physical and chemical properties of the soil used are analyzed (Page *et al*., 1982 and Klute, 1986) and given in Table (1).

Nitrogen, phosphorus and potassium fertilization was carried out according to Ministry of Agriculture recommendations. Ammonium sulphate (20.6% N) was added at rate of 20kg N /fed. in three equal portions before cultivation, after two weeks from cultivation and after three weeks from second addition. Super-phosphate (15.5% P_2O_5) and potassium sulfate (48% K_2O) were added before planting at the rate of 200 and 50 kg/fed., respectively. The field was leveled to facilitate uniform distribution of applied irrigation water and fertilizer. Plants were irrigated every two days by drip irrigation system. Crop evapotranspiration (ETc) was calculated as illustrated in Table (2) and according to the following formula:

$ETc = Kc \times ET_0$ Equ. (1) FAO-56 (Allen *et al*., 1998), wherease;
ETc = crop evapotranspiration in mm.
ET_0 = potential evapotranspiration in mm/day.
Kc = crop coefficient.

The data of water requirement was calculated by average 8 years of meteorological parameters using CROPWAT computer model (FAO 1992), based on calculation using Penman Monteith equation and the Kc values illustrated in FAO-56 (Allen *et al*., 1998). Irrigation water use efficiency (IWUE kg/m^3) is expressed in gross weight of product (kg) per water supplied (m^3), and was calculated for each treatment using the following formula:

IWUE= Seed or stover yield (kg/fed.)/total water applied (m^3/fed.) Equ. (2) (Tanner and Sinclair, 1983; Howell *et al*., 1990; Sezen *et al*., 2006 and El-Hendawy and Schmidhalter 2010).

Economic water productivity (EWP) was expressed in gross income in Euro (€) per gross water supplied in m^3, and computed from the estimated irrigable area, obtainable yield and from the seasonal price (€) of the main product and bi-product as shown in following formula:

EWP = GI/ GIWR Equ. (3) (Araya *et al*., 2011)

Where, GI is gross income from the sale of seeds (€); GIWR is gross irrigation water requirement (m^3).

In first experiment, four randomly selected plants were taken at 75 days of sowing. The following measurements were recorded: shoot and root fresh weight (g/plant), shoot and root dry weight (g/plant), shoot and root water content ml/plant (Romero-Aranda *et al*., 2006) and plant height (cm). At harvest (120 days after sowing), the following measurements were estimated in first and second trials: basic branch, pods number/plant, plant height (cm), biological yield (kg/fed.), stover yield (kg/fed.), seed yield (kg/fed.), harvest index (seed yield/biological yield*100) and pods/stover ratio. Total N, P and K of seeds were determined according to Cottenie *et al*., (1982). Irrigation water use efficiency and economic water productivity were calculated at the end of second experiment.

Data were statistically analyzed through analysis of variance (ANOVA) and least significant difference (LSD) at 0.05 probability level was applied as described in Gomez and Gomez, (1984).

Results and Discussion

3.1. First experiment:

3.1.1. Growth parameters:

Shoot and root fresh weight, shoot and root dry weigh, and plant height were significantly influenced by silicon addition compared to control. In Nubaria research station the plant height and dry weight of faba bean shoot at 75 days reached to 96.11 cm and 33.11 g/plant, respectively, whereas, soil salinity (EC) is 1.39dS/m (Ragab *et al*., 2010). The results in Table (1) showed that plant height and dry weight of shoot were 32cm and 11.52g/plant, respectively. Generally, the reduction in values may be referring to salinity stress effect. Hashemi *et al*., (2010) reported that salinity decreased plant growth parameters such as tissue fresh and dry weights. Although, application of magnesium silicate and potassium silicate raised plant height to 44 and 50cm and raised shoot dry weight to 20.27 and 24.39g/plant, respectively. Silicon is reported to enhance growth of many higher plants (Zhu *et al*., 2004) particularly under biotic stress (Epstein, 1999), led to the prevention of lignin and Na+ accumulation in the shoots, reduced levels of lipid peroxidation in the roots and higher levels of chlorophyll (Hashemi *et al*., 2010). Potassium silicate addition increased the mentioned measurements more than magnesium silicate. The increase percentages were 29.3, 11.7, 20.3, 1.5 and 13.6% when adding potassium silicate compared with magnesium silicate and were 37.1, 30.8, 76.0, 63.9 and 37.5% when adding magnesium silicate compared with control for shoot fresh weight, root fresh weight, shoot dry weight, root dry weight and plant height. The superiority of potassium silicate may be due to the role of K in mitigating the toxic effect of Na under salt stress (Tahir *et al*., 2006).

3.1.2. Shoot and root water content (ml/plant):

The shoot and root water uptake, calculated as the difference between fresh and dry weight, was increased with silicon addition by 50.2% and s9.1 for shoot and root respectively compared with control and irrespective of silicon source (Fig. 1). In another study, when salinized tomato plants were treated with Si their plant water content increased by 40% (Romero-Aranda *et al*., 2006). This may be due to 1) silicon impregnates along epidermal cell walls, these layers become effective barriers against water loss through the cuticles (Takeoka *et al*., (1984) and Trenholm *et al*., (2004)). However, shoot and root of bean plants treated with potassium silicate showed values of water content 31.6 and 16.6% higher than those of plants that were treated with magnesium silicate, respectively. The beneficial effect of potassium silicate has been related to significant role of potassium in improving plant water status (Tahir *et al*., 2006). The higher plant water content could explain the higher plant growth, and could be related with a salt dilution into the plant and the consequent mitigation of salt toxicity effects (Romero-Aranda *et al*., 2006).

3.1.3. Bean yield and its component:

Data of yield and its component of bean plants are presented in Table (4). Generally, the effect of silicon addition is significantly important in order to obtain higher yield of bean plants grown under salt stress condition. Moreover, Highest basic branch, bods number, biological yield, stover yield and plant height were obtained from potassium silicate application. The lowest values of these parameters recorded in control treatment. But, no significant difference between potassium and magnesium silicate in their effect on bods number, seed yield and plant height. Potassium silicate addition increased basic branch significantly (by 72.3%) compared to magnesium silicate, this reflect on biological and stover yield. The increase in basic branch is the most important factor in yield increase. The maintenance of erect leaves as a result of silicate application can easy account for 10% increase in the photosynthesis of the canopy and consequently increase in growth and yield (Ma and Takahashi, 1993). Plant height (cm) increased by 35.8% and 18.5% with potassium and magnesium silicate application, respectively compared to control. Silicon not only contributes to cell wall rigidity and strengthening but might also increase cell wall elasticity during extension growth (Marschner, 1995).

3.2. Second experiment

3.2.1. Yield and its measurements:

Potassium silicate used as a silicon source in this trial, because it is the best as mentioned in results of first experiment. Data on Basic branch, pods number/plant, plant height, biological yield, stover yield, and seed yield as affected by water rate, silicon rate and the interaction between them are presented in Table (5).

As for effect of water rates without appropriate silicon doses, basic branch increased by 40.6 and 50% with adding I_2 and I_3 compared with I_1. The increase percentage of basic branch by application of I_3 compared with I_2 is 6.71% only. This small percent may be refer to the plant response to first irrigation dose is higher than its response to second dose (Abou-Baker, 2008). Both of I_2 and I_3 treatments increased pods number /plant by 12.2 compared to I_1, whereas no differences between them. Plant height, biological, stover and seed yield follow the same order: $I_3 > I_2 > I_1$. The increase percentages were 16,9, 29.2, 15.4 and 40.2% by addition of I_2 compared with I_1 and reached to 9.3, 8.04, 14.3 and 4.1% with applying I_3 compared to I_2 for plant height, biological stover and seed yield, respectively.

Irrespective of water rates effect, silicon addition increased yield and its measured parameters compared with control. The high rate of silicon increased basic branch, pods number, plant height, biological, stover and seed yield by 38.1, 12.6, 6.5, 12.4, 20.7 and 6.8% compared with low silicon rate, respectively. Silicon promotes the growth of various higher plant species (Zhu *et al*., 2004). Similarly, Hwang *et al*., (2008) observed that Si application enhanced plant height and quality of rose plant (Pinocchio) but high doses of Si above a critical level may be less effective in maintaining higher growth rates. In contrast Hanafy Ahmed *et al*., (2002 and 2008) reported that the highest rate of silicon application (1000ppm SiO_2) resulted in pronounced increase on all of the studied growth characters and all yield components of wheat, especially at the highest level of soil salinity (6000ppm). However, addition of Si (50 and 130ug Si/g soil) improved wheat grain yield from 50% to 225%. So, it is intended to confirm the results of these studies by other field trials to know what the silicon critical level of most plant species is.

There was a significant interaction between water rates and silicon application. Both silicon concentrations improved all measured parameters under different water rates. The lowest values were found by using I_1 without Si application (I_1 x control) followed by (I_2 x control) the next is (I_3 x control). This increment may be contributed to that high irrigation maintains a low salinity zone around the roots and allowed plant establishment. While the highest values were obtained by using I_3 x Si_2 with one exception, whereas, the maximum seed yield was recorded by I_2 x Si_2. Although, biological yield increased with increasing irrigation rate with silicon addition, there was no significant reduction in seed yield with increasing irrigation water under two Si rates. The improvement in biological yield refers to the increment in stover yield. The data of basic branch, plant height and stover yield confirm this claim. This may be due silicon supply improved the structural integrity of crops (Epstein, 1999 and Ma, 2004) and promoted the increase of water retention in leaf tissue (Lobato *et al*., 2009). In addition to Si improves the water storage within plant tissues, which allows a higher growth rate that, in turn, contributes salt dilution into the plant (Romero-Aranda *et al*., 2006). So that, no more water is needed.

3.2.2. Macro nutrients concentration and uptake:

Nitrogen, phosphorus and potassium concentrations and uptake not affected significantly by both irrigation and Si rates (Fig. 2 and Table 6). Statistically, this means that there are high differences between replicates and it have to increase number of replicates in following studies and refuse the non-harmonious replicate to reduce the experimental error. Snyder *et al*., (1985) added calcium silicate to rice plants, it can be extracted that, NPK concentrations in young leaf decreased with applied 10 $Mgha^{-1}$ of calcium silicate without significant difference ($P < 0.05$). In contrast, Hanafy Ahmed *et al*., (2008) reported that NPK concentrations in rice shoots increased by silicon addition.

3.2.3. Yield calculations and water relations:

Table (7) and Fig.(3) present that harvest index (HI), bods/stover ratio, irrigation water use efficiency (IWUE) and economic water productivity (EWP), in addition to some relations between water rate and IWUE values.

3.2.3.1. Harvest index (HI):

Harvest index is defined as percentage of grains in the total plant biomass (Donaldson *et al*., 2001). Both of water and Si rates affected harvest index (Table 7). The second and third rates of water were better than the first rate. This may be due to the decrease in seed yield with I_1 application as a result of water shortage. The control and Si treatments gave highest harvest index compared with Si_2 treatment, under all irrigation rates. This may be due to big values of biological yield didn’t concomitant to high seed yield, and the increase in total biomass refer to high amount of stover yield. Tahir *et al*., (2006) reported that harvest index of wheat genotypes increased under saline conditions and not affected when Si was added.

3.2.3.2. Bods/stover ratio:

The ratio of pods to stover yield was enhanced by the addition of I_2 rate, followed by I_3 and minimum ratio was obtained from I_1 rate (Table 7). In three water rates, lowest ratio values were obtained in Si_2 treatment plots, followed by Si_1 and control with few differenced between them. This trend is close agreement with those recorded by harvest index data and may be attributed to increasing the stover yield by addition of Si_2 rate. The ratio of pod to stover yield ranged between 1.23 and 1.64.

3.2.3.3. Irrigation water use efficiency (IWUE):

The average obtainable bean seeds yield (main product) and stover yield (bi- product) in this study are 866 and 1507 kg/fed., respectively. Firstly, IWUE calculated as the ratio of seed yield to the seasonal amount of irrigation water applied per fed., were follow the order $I_2 > I_1 > I_3$ (Table 7). This would tend to indicate that I_2 rate improved seed yield of water unit (m^3). Secondary, IWUE calculated as stover yield to irrigation water decreased gradually in the order $I_1 > I_2 > I_3$ with increasing water rate. The results hypothesized that low yields due to water stress didn't concomitant to low IWUE values, and the increase in IWUE didn't refer to high amount of water. This may be due to 1) mathematically, hence increasing water rate tend to raise the denominator of equation (Equ.2) subsequently decrease the net result. 2) As for viewpoint of plant nutrition, the plant response to first application unit (water or fertilizer) is higher than that after adding second unit.3)Plants generally have the capability to optimize their water use in short term and maximize their chance of survival during drought in the long term (Zhang and Yang, 2005). 4) The high amount of water that may be move below the effective rooting zone and the plants can't use it effectively.

Concerning the effect of Si application, data revealed that, both of IWUE values (calculated by seed or stover) increased with increasing Si levels. The increase percentage of IWUE (seeds) in plots treated with Si_1 and Si_2 were 34.8 and 50.7% for I_1 and 32 and 42.7 for I_2 and 4.0 and 6.7% for I_3 compared with plants that were not treated with Si, respectively. Although the highest IWUE (seeds) obtained by I_2 x Si_2 followed by I_1 x Si_2, the maximum percentage of increase was 50.7% produced by I_1 x Si_2 compared with control. Generally, irrigation water use efficiency values calculated by seed yield were relatively lower than those calculated by stover yield. The first (seeds) ranged between 0.69 and 1.07 and the second (stover) ranged between 1.24 to 2.06. It is interesting to note that, silicon addition perhaps increase the ability of plants maximize there water use efficiency especially under water stress condition. In addition to, silicon is playing important role viz. increased water use efficiency, improved P nutrition, improved structural strength and improved photosynthesis through better use of sunlight (Berthelsen *et al*., 1999). Applied Si significantly increased the water use efficiency of both maize cultivars under salt treatments (Parveen and Ashraf 2010). Agarie *et al*., (1992) working on rice, reported that silicon reduced transpiration and increased water use efficiency in leaves, which in turn reduced the decline in photosynthesis and chlorophyll destruction in older leaves. It can be predicted that application of Si with second rate with addition of 80 or 85% only of irrigation water requirement may be resulted in the same yield that gained from I_2 treatment, and it can be saved about 15-20% of irrigation water if farmers followed this application.

3.2.3.4. Economic water productivity (EWP):

The average current season of local market price of bean seeds was estimated to be 0.875 €, but there have been seasonal price fluctuations, So, there need to be assessment on the EWP parameters based on the anticipated price before planting. Increase in crop production per unit of water dose not necessary result into an increase in the farmer's income because of the non-linearity of crop yield with the price of products (Araya *et al*., 2011). Highest irrigation rate (I_3) has the lowest economic water productivity (Table 7). Application of I_1 and I_2 rates increased EWP by 15.63 and 20.31% compared with I_3, respectively. The income and productivity of seed yield per unit of water supplied are higher in I_2 x Si_2 treatment (0.88) followed by I_1 x Si_2 treatment (0.86) and the next is I_2 x Si_1 treatment (0.82), with few differences between them than that of other treatments. This parameter could be used in evaluation of the crops and selection of the suitable to cultivation, especially in arid and semi arid region where water scarcity is critical problem.

Water use efficiency and water rate relationship

Fig. (3) presented the relationship between IWUE values (were calculated two times by using pod yield and seed yield) and irrigation water. It could be used to determination of the optimal irrigation management in arid and semi arid regions. We can divide the Fig to two pikes and line. The tope of pikes expressed on Si_2 treatment under I_1 and I_2 treatments and the bottom expressed on control treatment. While, line shape expressed on that, there stability in IWUE with increasing water rate. Few differences were observed between irrigation rate and Si rate for bean under salt stress condition.

3.2.4. Reference Evapotranspiration (ET0) and Crop Evapotranspiration (ETc) relationship:

Data illustrated in Fig. (4) showed that the relationship between reference evapotranspiration (ET_0) and bean crop evapotranspiration (ETc). ET_0 of Ismailia governorate was calculated by average 8 years of meterological data using Penman Monteith equation based on Central Laboratory for Agricultural Climate (CLAC). ETc calculated as illustrated in Equ. (1) according to Allen *et al*., (1998) and it varied across the growing days. ETc at the initial stage (from 1 to 40 days after sowing) was lower than ET0. Both of ET_0 and ETc increased in mid stage than initial and late stage (from 80 to 120 days). This may be due to 1) mid stage contain many changes in plant characteristics as a result to high vegetative growth and flowering where plants need high amount of water. 2) Kc values increased from initial stage to mid season and decreased during the late season stage. ETc was lower than ET_0 during the late stage of the crop. ET_0 values varied between 2.13-2.64, 2.2-2.9 and 2.9-4.4 mm/day at initial, mid and late stage, respectively. The reduction in ETc at late stage may be refer to increasing plant height, number of leaves subsequently increasing plant cover and minimizing evapotranspiration, in addition to, relatively deeper roots to extract water from deeper soil layer.

The present results need to other studies to improve and modify the magnesium silicate because it is the cheaper and the most available silicon source in Egyptian agriculture markets, as well as, to determine the best Si application rate.

Table 1: Some physical and chemical properties of the studied soils.

Characteristics	Value
pH (1 : 2.5 soil : water ratio)	8.1
EC (Soil paste extraction) dSm^{-1}	7.5
Soluble cations (m.e./100g soil):	
Calcium	13.6
Magnesium	7.5
Potassium	0.9
Sodium	45.5
Soluble anions (m.e./100g soil):	
Carbonate	-
Bicarbonate	3.2
Chloride	65.5
Sulphate	6.3
Physical properties (%):	
Coarse sand	33.6
Fine sand	39.9
Silt	18.7
Clay	8.5
Textural class	Sandy loam

Table 2: Water requirements for drip irrigated bean grown at Ismailia governorate.

Month	Nov.	Dec.	Jan.		Feb.		March
Period	23-30	1-31	1-31		1-28		1-22
ET_0 mm/day	2.64	2.13	2.2		2.9		4.4
Kc	0.5			1.15		0.3	
ETc mm/day	1.32	1.07	1.1	2.53	3.34	0.87	1.32
Eu	90%						
Lr	10%						
IRg mm/day (I_2)	1.60	1.30	1.33	3.06	4.05	1.05	1.60

ET_0= reference evapotranspiration, Kc= crop coefficient, Eu= application uniformity, Lr = leaching requirements, IRg= gross irrigation requirements, I_1= 75% of water requirements ($758m^3$/fed.), I_2= 100% of water requirements ($1010m^3$/fed.), I_3= 125% of water requirements ($1263m^3$/fed.).

Table 3: Shoot and root fresh weight (g/plant), shoot and root dry weight (g/plant), and plant height (cm) of faba bean plants at 75 days of sowing.

Silicon source	Fresh weight (g/plant)		Dry weight (g/plant)		Plant height (cm)
	Shoot	Root	Shoot	Root	
Potassium silicate	127.15	23.23	24.39	6.9	50
Magnesium silicate	98.35	20.8	20.27	6.8	44
Control	71.71	15.9	11.52	4.15	32
$LSD_{0.05}$	10.25	1.6	2.9	0.08	4.9

Table 4: Basic branch, pods number/plant, biological yield (kg/fed.), stover yield (kg/fed.), seed yield (kg/fed.) and plant height (cm) of bean plants at harvest as affected by potassium and magnesium silicate.

Silicon source	Basic branch	Bods number/ plant	Biological yield kg/fed.	Stover yield kg/fed.	Seed yield kg/fed.	Plant height (cm)
Potassium silicate	5.17	22.34	4817	2277	1016	110
Magnesium silicate	3.00	20.835	3916	1560	942	96
Control	2.5	14.00	2589	920	668	81
$LSD_{0.05}$	1.01	5.19	384	273	82	14.7

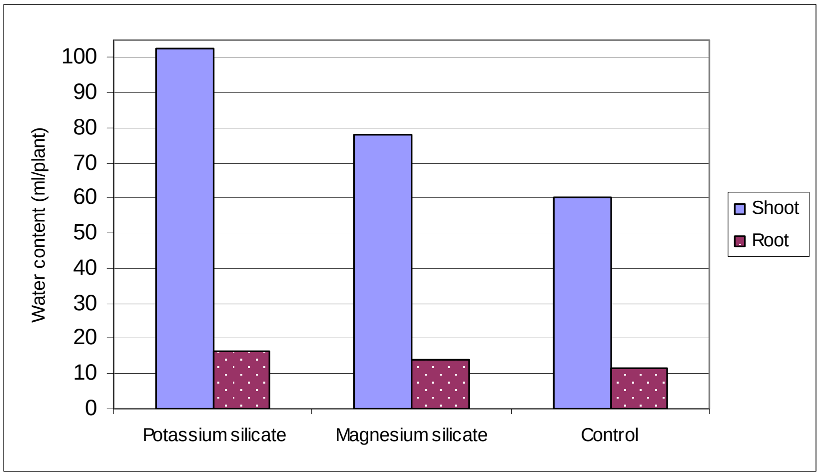

Fig. 1: Shoot and root water content (ml/plant) of faba bean plants at 75 days of sowing.

Table 5: Basic branch, pods number/plant, biological yield (kg/fed.), stover yield (kg/fed.), seed yield (kg/fed.) and plant height (cm) of bean plants at harvest as affected by water and silicate rates.

Water rate	Silicon rate	Basic branch	Pods number/plant	Plant height cm	Biological yield kg/fed.	Stover yield kg/fed.	Seed yield kg/fed.
I$_1$	Si$_1$	3.0	15.5	90.0	3068.2	1344.4	706.8
	Si$_2$	4.5	19.5	95.0	3476.2	1560.0	785.6
	Control	2.0	9.0	82.0	2286.8	1003.6	526.1
Water mean		3.2	14.7	89.0	2943.7	1302.7	672.8
I$_2$	Si$_1$	4.5	19.0	104.0	3916.2	1484.4	997.0
	Si$_2$	6.5	20.0	115.0	4508.8	1883.0	1076.6
	Control	2.5	10.5	93.0	2986.4	1141.6	756.4
Water mean		4.5	16.5	104.0	3803.8	1503.0	943.3
I$_3$	Si$_1$	5.0	18.0	116.0	4038.8	1632.4	986.6
	Si$_2$	6.5	19.5	120.0	4409.4	1943.6	1011.0
	Control	3.0	12.0	105.0	3880.2	1565.6	949.0
Water mean		4.8	16.5	113.7	4109.5	1713.9	982.2
Silicon mean	Si$_1$	4.2	17.5	103.3	3674.4	1487.1	896.8
	Si$_2$	5.8	19.7	110.0	4131.5	1795.5	957.7
	Control	2.5	10.5	93.3	3051.1	1236.9	743.8
LSD$_{0.05}$		W=1.3 Si=1.3 W*Si=3.8	W= 0.7 Si= 0.7 W*Si=2.0	W=1.8 Si= 1.8 W*Si=5.3	W=268 Si=268 W*Si=804	W=88 Si=88 W*Si=264	W=145Si= 145 W*Si=435

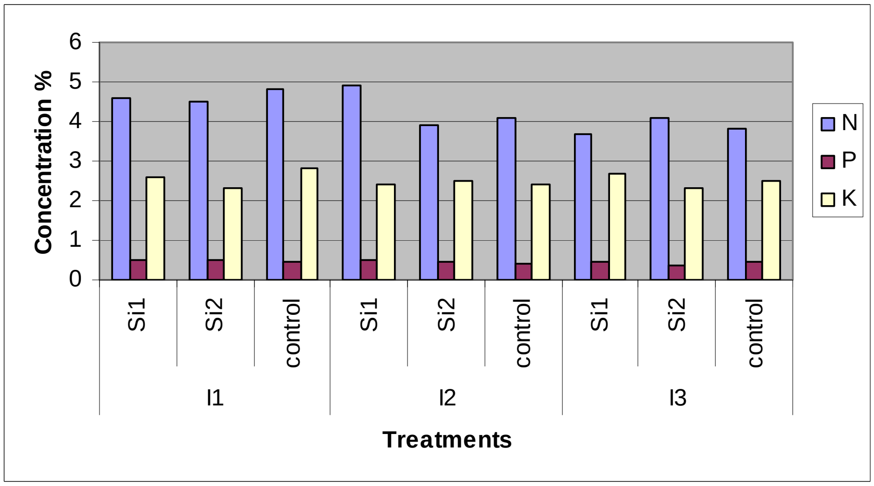

Fig. 2: Nitrogen, phosphorus and potassium concentration (%) as affected by water and silicon rates.

Table 6: Nitrogen, phosphorus and potassium uptake (kg/fed.) as affected by water and silicon rates.

Water rate	Silicon rate	Nutrients uptake (kg/fed.)		
		N	P	K
I_1	Si_1	32.51	0.16	0.85
	Si_2	35.35	0.18	0.81
	Control	25.25	0.11	0.71
Water mean		31.04	0.15	0.79
I_2	Si_1	48.85	0.24	1.17
	Si_2	41.99	0.19	1.05
	Control	31.01	0.12	0.74
Water mean		40.62	0.19	0.99
I_3	Si_1	36.51	0.16	0.99
	Si_2	41.45	0.15	0.95
	Control	36.06	0.16	0.90
Water mean		38.01	0.16	0.95

Table 7: Irrigation water use efficiency (IWUE), economic water productivity (EWP), harvest index (HI) and bods/stover ratio of faba bean plants as affected by water and silicon rates.

Water rate	Silicon rate	IWUE (seeds)	IWUE (stover)	EWP (€)	HI	Bods/stover
I_1	Si_1	0.93	1.77	0.77	23.03	1.28
	Si_2	1.04	2.06	0.86	22.60	1.23
	Control	0.69	1.32	0.58	23.01	1.28
Water mean		0.89	1.72	0.74	22.86	1.26
I_2	Si_1	0.99	1.47	0.82	25.46	1.64
	Si_2	1.07	1.86	0.88	23.88	1.39
	Control	0.75	1.13	0.62	25.33	1.62
Water mean		0.93	1.49	0.77	24.80	1.53
I_3	Si_1	0.78	1.29	0.65	24.43	1.47
	Si_2	0.80	1.54	0.66	22.93	1.27
	Control	0.75	1.24	0.62	24.46	1.48
Water mean		0.78	1.36	0.64	23.90	1.40

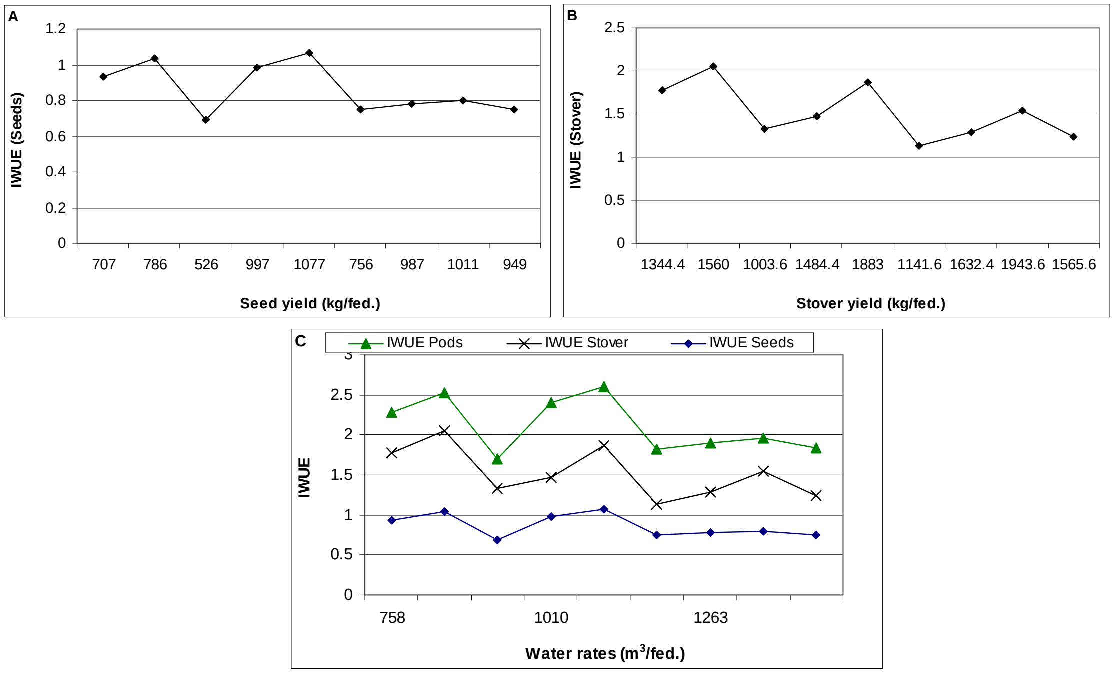

Fig. 3: The relation between irrigation water use efficiency and A) seed yield (kg/fed.), B) stover yield (kg/fed.) C) water rate (m^3/fed.)

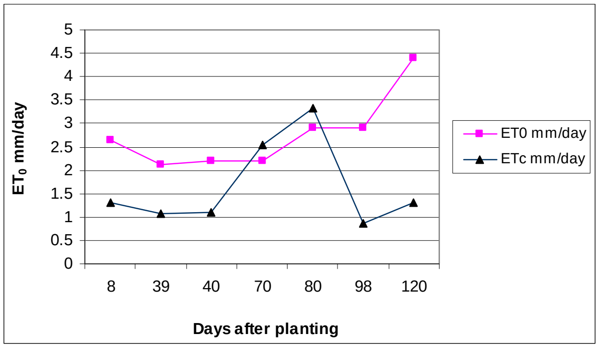

Fig. 4: The ET_0 and ETc for bean plants grown at Ismailia governorate.

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