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Research article

Assessing effect of potassium silicate consecutive application on forage maize plants (*Zea mays* L.)

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Keywords: Potassium silicate, Foliar application, Nutrient content, Growth parameters, Forage Yield, Maize plants.

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Abstract

Silicon (Si) beneficial effects reported to improve growth, biomass and yield of wide range of plants including monocotyledonous crops that have the ability to accumulate high amounts of Si in their organs. This research study aimed to assess the effect of using consecutive rates of potassium silicate foliar sprays on forage maize plants. A field experiment performed to achieve this purpose by applying three foliar application treatments of Si as potassium silicate source. Results denoted that weekly foliar spraying of potassium silicate in a gradual increased series of concentrations (5, 6, 7, 8, 9, 10 cm^3/L)resulted in a significant effect on all growth parameters: plant height, stem diameter, leaf area, no. of leaves/plant, fresh and dry weight of leaves and stem of maize. Also, the same treatment helped improving some photosynthetic pigments, macro and micro nutrients by plants which translated finally to an increment in forage maize yield as compared with the using of weekly constant rates $5cm^3/L$ or $10cm^3/L$ and the control.

Introduction

In the world production, maize is the third major cereal crop after rice and wheat. The crop has numerous uses including: industrial processed food production of starch, used as forage to feed animals and human food. It has a wide range of tolerance to different environmental conditions with its different maturity periods and large number of cultivars [1]. Maize is grown as forage to solve problems of animal feed shortage. Its high energy content and considerable protein proved to be most suitable forage in contrast with other cereal fodder crops. The main reason behind cultivating maize for green forage production is to obtain succulent vegetative part in a comparatively short time [2].

Nowadays, Silicon hardly ever gets a mention. It is an essential element in high yielding plant species like rice, sugarcane, cereals, legumes, vegetables, tree crops and some leafy ornamentals and many plants species. However it may be observed in limiting levels under some growing conditions. Without Silicon these plants may suffer in a similar way to any plant suffer from a major or micro-nutrient deficiency but the signs are not as evident. Silicon deficiency reduced photosynthesis, low Brix, increased disease attack and insect, increased sunburn and wilting, enhanced postharvest fall are all signs of stress [3].

Silicon observed to be beneficial to plants where high levels of some nutrients content e.g. manganese and iron may be present in the soil. Silicon will alleviate the reinforcement of these elements in plant tissue preventing tissue damage [4]. Researchers have shown that Silicon have a positive effect on yield quality and quantity. This might be due to its role in ethylene inhibition, which reduces the speed of aging and death of harvested plant parts. Silicon also have a good effect on plants chlorophyll content and help plants to maintain over a longer period with better shelf life and appearance [5].

Potassium silicate foliar application has many benefits in improving leaf erectness, and improving photosynthesis efficiency also reducing capability to lodging in grasses [6]. In addition, it offers benefits in many agricultural applications e.g. increases growth and yield, improves strength, minimize climate stress and provides impedance to mineral stress.

The great attention in this study is to show the best method and rate of adding liquid potassium silicate using foliar application and observe its effect on some growth parameters, some macro and micro nutrients content and the fodder yield of maize plants.

Experimental

Material and methods

The experimental site and soil preparation

Field experiment conducted in a private farm Shalaqan village, Al Qalyubia Governorate, Egypt, during the summer (at mid-June) 2017. The soil site texture is clay composing of 28.8 % sand, 24.0 % silt and 47.2 % clay with an alkaline pH of 9.28, EC 0.24dS m^{-1}, OM 1.98%, $CaCO_3$ 2.51%. Average available N, P and K from surface soil layer down to 60 cm depth were 14.8, 2.76

and 38.2 mg kg^{-1} soil, respectively before the initiation of the experiment.

The experimental nursery land area well prepared. Compost added with a rate of12 m^3/feddan. Calcium superphosphate (15.5% P_2O_5) incorporated with soil during tillage operation at a rate of150 Kg/feddan, potassium sulphate (48% K_2O) at a rate of 50 Kg/feddan applied after 35 days of cultivation. Nitrogen in the form of ammonium nitrate (33.5% N) at a rate of 100unit N/feddan was added into two portions, half being applied after 19 days from plantation while the remaining portion was applied at the time of appearance of male flowers then irrigate immediately.

Experimental treatments

The experiment conducted using Randomize Complete Block Design (RCBD). Each treatment replicated three times. Each replicate represented by a plot. The cultivation method was at a rate of 12 lines / 2 reeds with a line width of 70 cm. Foliar spray with liquid potassium silicate (K_2SiO_3) (10% K_2O, 25% SiO_2) (kindly obtained from Abo Ghaneima Company for fertilizers and chemical industries) applied weekly after the appearance of the first three leaves. The experimental treatments were as following:

1) Control
2) T1: Potassium silicate weekly foliar spray with constant rate 5 cm^3/L for six weeks.
3) T2: Potassium silicate weekly foliar spray with constant rate 10 cm^3/L for six weeks.
4) T3: Potassium silicate weekly foliar spray with increased consecutive concentrations (gradual increased series) (5, 6, 7, 8, 9, 10 cm^3/L) in one cycle for six weeks.

Cultivation

Seeds of maize hybrid single cross (Giza 10) were kindly obtained from Agricultural Research Centre (ARC), Egypt and sowed in mid-June. The seeds sowed manually on two sides of the line where two Seeds drilled in each hole, intra hole spacing was 25 cm apart. The plots irrigated immediately after sowing then regularly irrigated every 10 - 15 days until the full male flowering stage.

Plant samples and analysis

At harvesting stage, random sample of three plants were chosen from each plot and prepared for chemical analysis. Samples dried at 70°C; ground using stainless steel equipment's. Then 0.5 g of each sample digested by mixture of sulfuric (H_2SO_4) and perchloric ($HClO_4$) acids (1:1) to analyze N, P, K, Ca, Mg, Fe, Zn, Mn and Cu content of leaves and stems as described by Cottenie *et al.* [7]. Also, the protein contents in harvested seeds calculated by multiplying nitrogen percentage by value of 6.25 as described by Association of Official Analytical Chemists [8]. While, Si content analyzed using spectrophotometer according to Snyder [9]. Fresh leaves of maize plants subjected to photosynthetic pigments analyses (chlorophyll a, band a+b) according to Soric *et al.* [10].

Parameters measured

Five plants selected randomly from each treatment to measure the following plant growth parameters: plant height (cm); stem diameter (cm); number of leaves per plant; leaf area (cm^2); fresh and dry weight per plant (gm).

Forage yield of maize plants was taken from the beds of each treatment then weighted and represented in Kg/m^2. Also, dry weight versus fresh weight of forage maize yield (%) calculated to determine forage feeding quality [8].

Infrared analysis

Samples prepared as pellets using KBr binding material and subjected to a bruker vector spectrophotometer (FT-IR-22 Germany), in region of 4000-250 cm^{-1}used according to [11]. The IR analysis conducted in Micro Analytical Center, Cairo University.

Scan analysis

Most analysis performed using low vacuum with magnification ranges from 100x to 1000x in the ESEM mode. The operating conditions were followed at a resolution equal to 3.5 nm at 30 KV, 25 nm at 1 KV BSE equal 10.0. This analysis was under taken in the Nuclear Materials Authority Laboratories.

Statistical analysis

Least significant difference test in one-way randomized complete block design of analysis of variance in SAS Program (SAS 7.1, 2014) used to analyze the data and separate the means.

Result and discussion

Growth parameters

The results represented in table 1 illustrated that the treatment of weekly foliar spray of potassium silicate with increased consecutive concentrations (T3) significantly increased plant height, stem diameter, leave area, number of leaves per plant, fresh and dry weight of leaves and stem followed by the treatment of using 5 cm^3/L of potassium silicate (T1) as compared with the treatment of using 10 cm^3/L (T2) and the control.

Silicon (Si) reported to increase the biomass and the different growth parameters of a wide range of crops including monocotyledonous crops such as wheat, rice, maize, barley, sugarcane and sorghum. Maize is one of these crops that actively take up and accumulate Si into its organs[12]. Liu *et al.* [13] illustrated that maize growth and yield are highly responsive to Si fertilization. In addition, Si helps the plant to develop healthy. The analysis of plant tissue revealed that silicon optimum amount is necessary for cell development and differentiation [14]. Pilon *et al.* [15] found that leaf area of potato plants increased because of silicon application. Similarly, silicon application reflected an increase in the leaf area and haulm dry weight readings [6-16-17-18]. This may be due to that silicon is responsible to control stomatal activity, photosynthesis and water use efficiency which ultimately results in better vegetative growth. Also they found that all the vegetative parameters that were improved can be attributed to the way Si deposition occurs in passive Si accumulators. Similar results also observed in rice and wheat plants where Si applications increased the resistance of plants to lodging stem and strength due to Si deposition as a double layer underneath the cuticle [19]. Kamenidou [20] illustrated that potassium silicate weekly foliar spray improved plants and increased the thickness of stems, diameter and early flowering of cut flower plants in Si optimum treatments compared to untreated controls. In addition, the same researcher recommended that several horticultural plants were improved due to Si supplementation depending on source, rate, content of Si and its deposition in plant tissue that varied among the species.

Table 1. Different applications of silicon foliar spray effect on some plant growth parameters of maize plants.

Treatments	Plant height (cm)	Stem diameter (cm)	Leaf area (cm^2)	Number of leaves per plant	Fresh weight (FW/Plant) Leaves (gm)	Fresh weight (FW/Plant) Stem (gm)	Dry weight (DW/Plant) Leaves (gm)	Dry weight (DW/Plant) Stem (gm)
Control	1.19	1.34	210.0	9	88.7	290.4	30.9	73.5
T1	2.56	2.04	667.9	13	143.3	426.9	45.0	106.7
T2	1.95	1.80	537.6	11	98.2	413.5	35.1	97.9
T3	2.78	2.50	728.1	16	159.5	491.9	55.4	125.8
LSD (5%)	0.713	0.484	231.4	2.99	34.3	84.1	10.9	21.7

Photosynthetic pigments

Table 2 shows the effect of method and rate of foliar application of silicon on some photosynthetic pigments content in fresh leaves of maize plants. Chlorophyll a, b and total content follow the same trend of results of vegetative growth parameters in which the highest significant values (1.613, 1.029 and 2.642 mg/g fw) of chl a, b and a+b, respectively, were obtained using potassium silicate weekly foliar spray with increased consecutive rates (T3) that followed by the treatment of using 5 cm^3/L of potassium silicate (T1) as compared with the treatment of using 10 cm^3/L (T2) and the control.

Table 2. Different applications of silicon foliar spray effect on some photosynthetic pigments content in fresh leaves of maize plants.

Treatments	Leaves (mg/g FW) *Chl a	**Chl b	Chla+b
Control	1.43	0.51	1.94
T1	1.58	0.85	2.44
T2	1.46	0.52	1.99
T3	1.61	1.03	2.64
LSD (5%)	0.08	0.25	0.34

*** Chlorophyll a, ** Chlorophyll b (determined according to Soric M *et al.* [10]).**

Photosynthesis is an important and determinant factor for crops growth and development as maximum photosynthesis contributes toward more yield and production. It is the most basic and critical physiological process that related directly to maize yield, especially at late developmental stages [21]. The role of silicon in plant growth concluded that a reduction amount of silicon in plant affect leaves content of both chlorophyll a and b which finally affecting the photosynthetic efficiency [22-23]. The total chlorophyll contents were significantly increased by increasing Si application in studying of all the growth stages [24]. In addition, there was another effect of Silicon addition where it can increase the photosynthesis and relevant carboxylase activities as it plays a role of a mechanical and a physiological barrier as found in wheat [25]. Si benefits in maize plants were related to its effect on improving of the effectiveness of leaf area and photosynthetic efficiency as well as the delay of leaf senescence [26-27].

Kaufman *et al.* [28] explained silicon-enhancement of photosynthesis and hypothesized that the action of silica bodies as 'windows' that helped the light transmission to mesophyll area. The improvement of maize photosynthesis might be as a result of increased total chlorophyll contents in leaves by optimum Si application [29-30]. These results are consistent with the finding of Kaya *et al.* [31] who found that chlorophyll a and b content in sugarcane leaves may be due to the formation of proteolytic enzymes such chlorophyllase, which is responsible for chlorophyll degradation.

Macronutrients

The results in table 3 showed that using the increased consecutive rates application of Si gave the highest significant values for N, P, K, Ca, Mg and the percentage of protein contents in leaves and stems of maize plants as compared with the control. On the other hand there was no significant effect between the treatments of 5cm³/L and 10 cm³/L of potassium silicate foliar spray and the control for the same studied parameters.

The results are in accordance with Lalithya *et al.* [32] who observed that silicon application gave the highest nitrogen, phosphorous and potassium content in the leaf of plants as it avoided leaching loss of N and helped in more accumulation of nitrogen in leaf. Silicon delivered more P available to the plants but its fixation as silicon competed for P fixation.

Table 3. Some macro-nutrients and protein contents (%) in leaves and stems of maize plants as affected by different applications of silicon foliar spray.

Treatments	Leave (%)						Stem (%)					
	N	P	K	Ca	Mg	Protein	N	P	K	Ca	Mg	Protein
Control	9.78	1.21	39.2	0.73	0.37	61.1	4.20	1.25	53.4	0.56	0.31	26.3
T1	10.3	1.47	45.8	0.76	0.44	64.4	5.32	1.26	61.1	0.59	0.39	33.2
T2	10.6	1.51	50.5	0.82	0.47	66.3	5.67	1.30	69.5	0.65	0.43	35.4
T3	11.9	1.62	53.5	0.94	0.54	74.4	6.81	1.55	74.5	0.72	0.46	42.6
LSD (5%)	0.91	0.17	6.23	0.09	0.07	5.66	1.08	0.14	9.30	0.07	0.06	6.72

Generally, data indicated that the foliar application of different rates of potassium silicate gave higher values for Leaf macronutrients compared with control as similarly observed by Abd El-Gawad *et al.* [18]. Potassium silicate treatments recorded more potassium percent compared to the control as it contained potassium along with silicon. The previous mentioned results are in conformity with the findings of Kamenidou *et al.* [33-34]. Silicon also helped in calcium uptake and thus resulted in more accumulation of calcium in leaf. Similar observations were found by Stamatakis *et al.* [35] and Prado *et al.* [36]. Silicon also helped in uptake of magnesium [32]. This may be due to the important role of Si in keeping the mineral balance in plants as in maize so it can increase the levels of some nutrients [31]. Potassium silicate foliar application had a positive significant effect on total soluble protein content. This result may be attributed to the potassium role in increasing the activities of enzyme which could be explained by that potassium neutralizes various organic anions and other compounds within the plant which helping in stabilizing the pH value between 7 and 8, the optimum pH for most enzyme reactions [37]. In this observation, Talebi *et al.* [38] found that potassium silicate application of exogenous had a positive significant effect by increasing soluble protein and carbohydrate contents in the leaves of potato plants.

Micronutrients and silicon

The foliar application of using increased consecutive rates from potassium silicate (T3) significantly improved Si, Fe, Zn and Mn contents (Table 4).

The results obtained from mean comparisons for silicon contents were affected by all different rates of potassium silicate which showed that silicon application caused a significant increase in silicon concentrations. Similar results were observed by Morsy *et al.* [39] and Jafarei *et al.* [40] who reported similar results in wheat and bean plants and stated that with the usage of silicon, amount of silicon absorption increases in plant. Silicon content in leaves of the plants was found to be high due to foliar spray of potassium silicate. The finding results are in conformity with Matchinkov *et al.* [41] in citrus, Ma JF *et al.* [42] in rice, Eraslan *et al.* [43] in spinach and Milne *et al.* [44] in lettuce.

The optimization of silicon nutrition has positive effects and plays an important role in the balancing of micronutrients in plants. Si presence in nutrient solutions affects the absorption and translocation of several macro and micro-nutrients in different plants [45].

Similar results were noticed by Salim *et al.* [46] who observed that potassium silicate increased mineral nutrients (N, P, K, Ca, Mg, Zn, Mn and Fe) in wheat leaves. This might be attributed to the promotion effect of Si in translocation of those nutrients including Cu, Mo and B to the growing parts of the plant and which could enhance the growth of sugarcane as found by Huang *et al.* [47].

Adding Si increased Fe in leaves of maize, this may be due to the indirect effect of Si in maintaining membrane integrity [48]. In addition, Increasing Si fertilization increases Zinc (Zn) uptake because Si has role in the transport of Zn into the vacuole [49]. The present study showed that Si application had no effect on Mn content in maize leaves and stems, this agree with findings of Iwasaki *et al.* [50-51] who concluded that released Si might cause Mn oxidation in the deposited form *via* relation with apoplast phenolic substances, which leads to improve the tolerance of leaves to Mn.

Table 4. Effect of the different silicon application on some micro-nutrients(ppm) and silicon contents (%) in leaves and stems of maize plants.

Treatments	Leaves					Stem				
	(%)	(ppm)				(%)	(ppm)			
	Si	Fe	Zn	Mn	Cu	Si	Fe	Zn	Mn	Cu
Control	0.35	140.0	79.4	28.8	22.8	0.15	188.8	52.6	24.6	20.4
T1	0.73	214.6	79.4	30.6	22.9	0.33	198.8	60.2	25.1	20.7
T2	1.04	239.8	86.0	36.0	24.2	0.39	212.0	72.1	26.8	21.9
T3	1.89	316.0	98.2	37.4	23.6	0.46	244.6	84.4	27.5	21.4
LSD (5%)	0.66	72.6	8.86	4.15	1.66	0.13	24.3	13.9	1.37	1.71

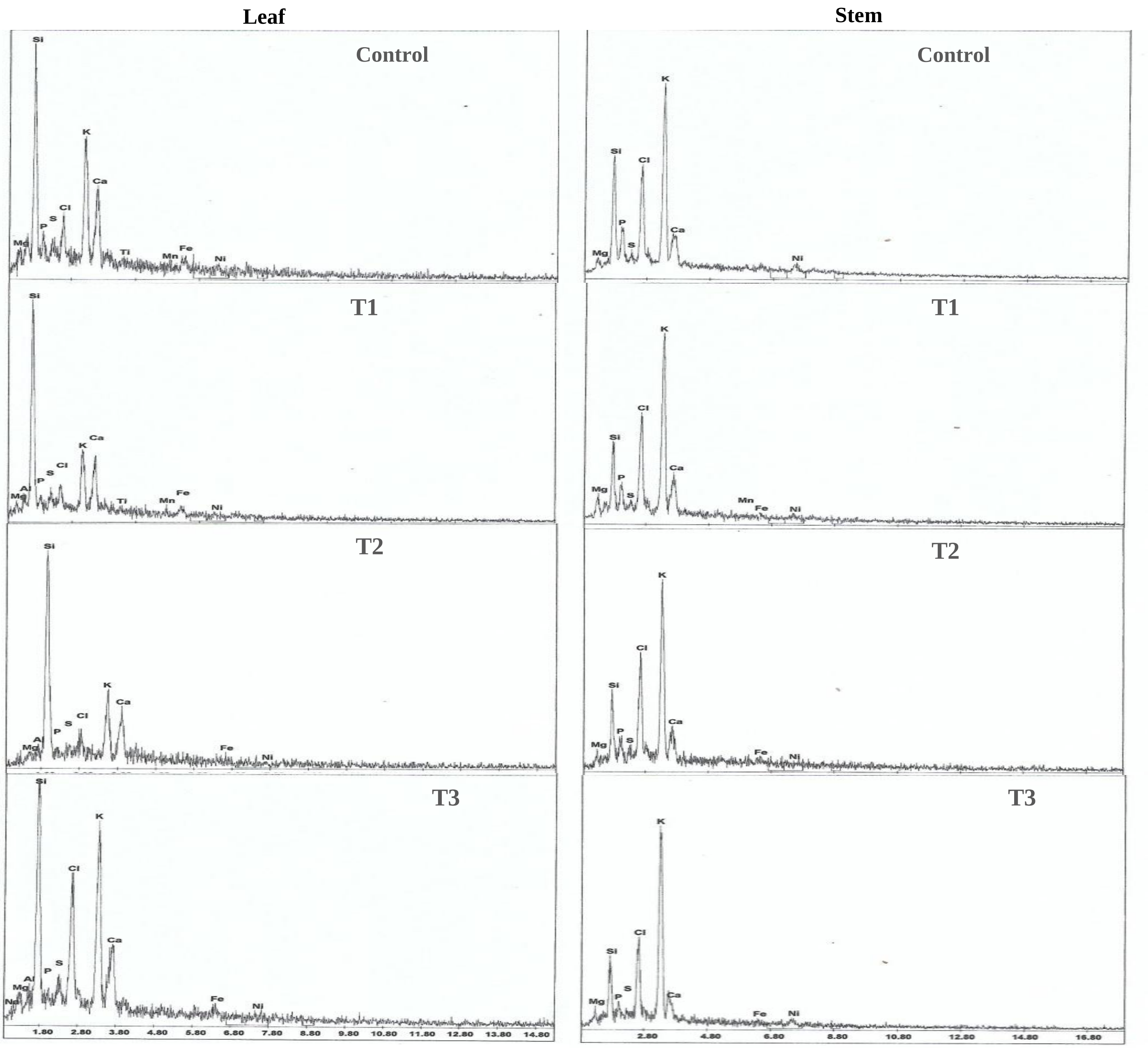

Figure 1. Semi-quantitative ESEM analysis pattern of Si in leaf and stem of maize plants.
Control
T1= constant rate of potassium silicate 5 cm³/L
T2= constant rate of potassium silicate 10 cm³/L
T3= gradual series of potassium silicate (5, 6, 7, 8, 9, 10) cm³/L.

On the contrary, the present study showed that the different treatments of potassium silicate had no effect on Cu content in leaves and stems of maize plants which agree with the observation of Keller *et al.* [52] who found that Si-mediated decrease in Cu uptake and translocation in wheat and in leaves of cucumber plants [53]. In addition, Iwasaki *et al.* [51] explained the reduction in metal uptake as Si reduces the apoplasmic transport of metals by decreasing free metal concentration in the apoplasm.

Semi-quantitative ESEM analysis pattern of Si in leaf and stem sample (scanning electron microscopy)

The concentration of Si examine in eight represented plant samples (stem and leaf) by ESEM. The EDX showed that concentration of Si in leaves have large differences between the treatments (Figure 1); the highest concentration of Si recorded by the treatment of increased consecutive concentration of potassium foliar spray as compared with the control. The concentration of Si can be arranged in descending order: increased consecutive rates > 10 cm³/L > 5 cm³/L > control by (45.2, 41.0, 37.0, and 26.6)%, respectively (Figure 1). On the contrary, the EDX showed a simple variation in the stem samples. These results of scan analysis were in the same trend of the chemical analysis.

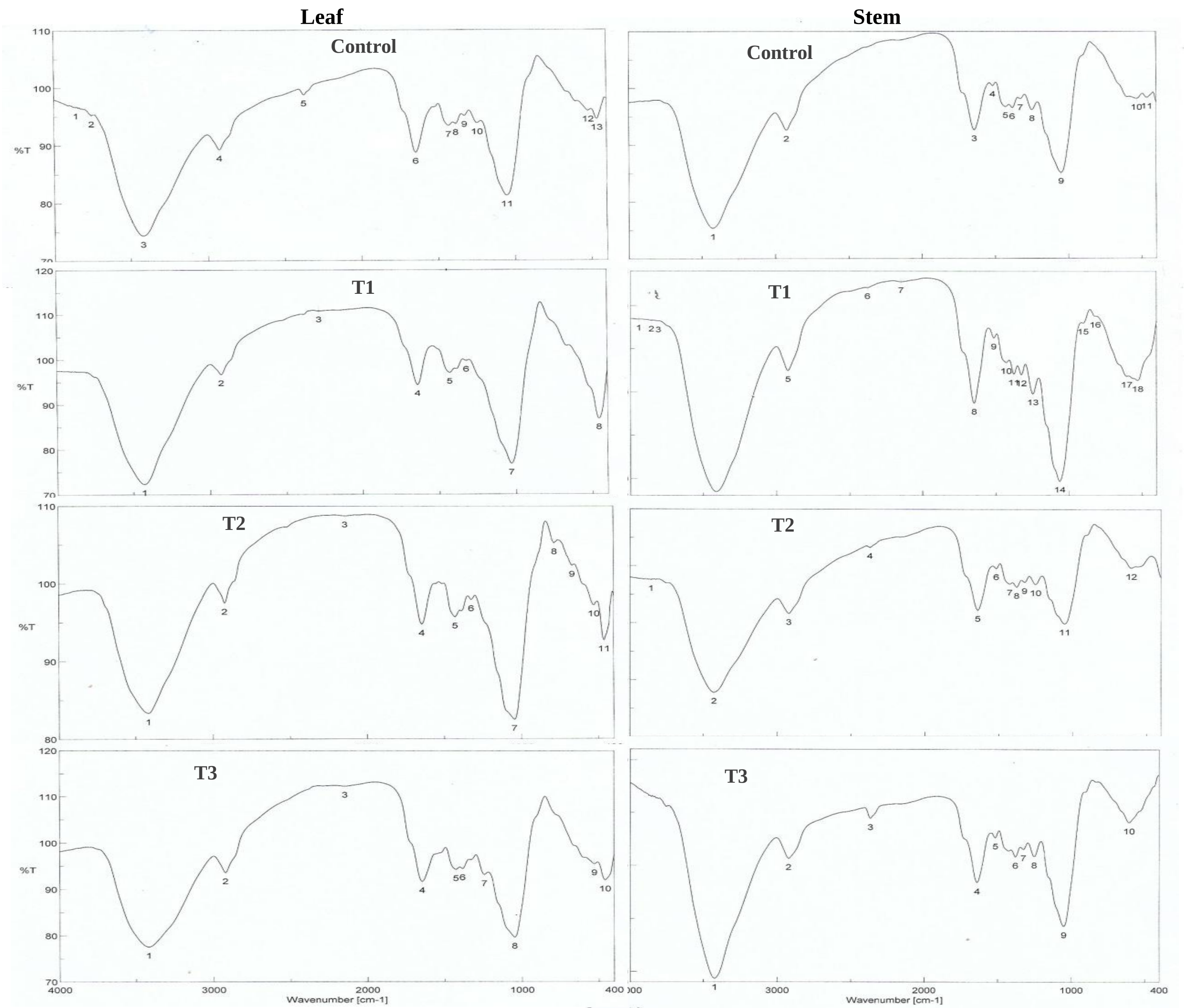

Figure 2. Infrared spectra of Si in different leaf and stem sample of maize plants.
Control
T1= constant rate of potassium silicate 5 cm³/L
T2= constant rate of potassium silicate 10 cm³/L
T3= gradual series of potassium silicate (5, 6, 7, 8, 9, 10) cm³/L.

Infrared (IR) Spectroscopy analysis of plant Samples (Maize plants)

The main IR adsorption bands of the studied leaf and stem samples represented in figure 2. The infrared spectrum band vibrational frequencies of leaf samples appeared at 462.8 cm^{-1} band that appear in the control treatment with intensity 94%. On the other hand two bands appeared at 465 cm^{-1} and1031 cm^{-1} which observed in a constant rate of 5 cm^3/L, (686, 783, 461) cm^{-1} in the constant rate 10 cm^3/L and (458, 1048) cm^{-1} which attributed to Si-O [54].

In stem sample only one band 462 cm^{-1} appear in control treatment as found by Zemnukhova *et al.* [54].

But, Si appeared at (902, 818, 602) cm^{-1} for the treatment at constant rate of 5 cm^3/L, (600, 1054) cm^{-1} bands appeared for the treatment of constant rate 10 cm^3/L and (604, 1051) cm^{-1} bands appeared for the treatment of increased consecutive rates representing Si-O as comparing with the international bands that between 600 – 900 cm^{-1}, 900-1100 cm^{-1}[55].

The infrared spectrum analysis of leaf and stem samples appeared at 3421 cm^{-1} for control, 3428 cm^{-1} for constant rate 5 cm^3/L, 3416 cm^{-1} for constant rate 10 cm^3/L and 3419 cm^{-1} for the treatment of increased consecutive rates with intensity (74, 72, 83 and 77)%, respectively, may be OH groups or carbohydrates or proteins compounds comparing with international bands at 3200 cm^{-1} to 3500 cm^{-1}.

And, the bands 2923 cm^{-1} for control, 2924 cm^{-1} for constant rate 5 cm^3/L, 2923 $cm^{-1}$for constant rate 10 cm^3/L, 2923 cm^{-1} for the treatment of increased consecutive rates with intensity (89, 96, 97 and 93)%, respectively, were interpreted to CH_2 stretching mainly lipids with little contribution from protein and carbohydrates comparing with international bands at 2920 to 2930 cm^{-1}. While in leaf samples, the bands (1383 and 1384) cm^{-1} appear in control and the treatment of increased consecutive rates, respectively, may be interpreted C-H or CH_2 groups or polysaccharides, lipids and protein and they disappear in the other two treatments. But in stem samples, all bands were appear at (1381, 1380, 1380, 1379) cm^{-1} with intensity (96, 92, 96 and 90)% for control, constant rate 5 cm^3/L, constant rate 10 cm^3/L and the treatment of increased consecutive rates, respectively, comparing with international bands at 1370 cm^{-1} to 1380 cm^{-1}[56].

Fodder maize yield

The results presented in table 5 clearly showed that, all treatments of potassium silicate foliar spray had a significant positive effect on forage fresh and dry weight (Kg/m^2) of maize plants that also affected the percentage of dry weight versus fresh weight. These obtained results confirmed that Si applications helped maize plants to retain water in its cell as compared with the control treatment. The highest mean value of fresh, dry weight and the percentage of dry weight versus fresh weight (5.59, 1.57 Kg/m^2 and 28.1%), respectively obtained from the treatment of weekly foliar spray of potassium silicate with increased consecutive concentrations (T3) as compared with the other treatments (T1 and T2) and the control.

Table 5. Means of fodder yield (fresh, dry weight (Kg/m²)) and (DW vs FW (%)) of maize plant as influenced by different applications of silicon foliar spray.

Treatments	Fresh weight (FW) (Kg/m²)	Dry weight (DW) (Kg/m²)	DW VS FW (%)
T1	3.68	0.88	23.9
T2	4.88	1.27	26.0
T3	5.14	1.36	26.5
T4	5.59	1.57	28.1
LSD (5%)	0.816	0.289	1.733

These results agree with Ren *et al.* [57] findings who found that Si application increased yield of maize due to increased utilization rate and absorbing ability of nutrients. The yield increment attributed to the direct beneficial effects of Si such as vegetative growth, increase of chlorophyll content, photosynthetic activity of plant, more formation of carbohydrates, membrane lipid peroxidation, protective enzymes and water metabolism [32], and to some indirect effects such as acquisition of macro- and micronutrients. Similar results obtained by Wang *et al.* [58] and Yuan *et al.* [59] who showed that summer yield of maize receiving Si fertilization increased compared with control treatment.

Conclusion

From the above presented results, it could be summarized and concluded that: All the studied silicate foliar application rates had a significant positive effect on growth parameters, chlorophyll content, macro& micro nutrients status and forage yield of maize plants as compared with the control. Foliar silicate application achieved Si content in the leaves and stems of forage maize plants. Results indicated that the treatment of adding potassium silicate weekly foliar spray by an increased consecutive concentrations improve and increase all the studied parameters of forage maize plants as compared with using weekly foliar spray with a constant rate. The author recommended that the best method and rate to use silicon as potassium silicate foliar spray is to be weekly in a gradual increased series of concentrations starting with 5 cm^3/L and ending by 10 cm^3/L.

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