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Effects of Foliar and Soil Applications of Silicic Acid (Silicon 0.8%) on the Growth and Yield of Tomato under Greenhouse Conditions

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Abstract. Tomato (*Solanum Lycopersicum* L.) is an important vegetable crop in Iraq. Experiments have been conducted to compare the effects of foliar and soil surface (drench) applications of silicic acid on tomato under greenhouse conditions. The experiment consisted of treatments with or without silicic acid (AB Yellow) treatments with different concentrations to evaluate the efficacy on growth, yield, and quality parameters of tomato. The results showed that foliar applied and soil drenching of silicic acid in different concentrations (0.5, 1 and 2 ml/L) significantly increased yield and quality attributes compared to control. Silicic acid, applied as foliar spray or as soil drench, as 2 ml/L increased growth and yield significantly.

Keywords. Foliar, Soil drench, Silicon, Growth, Yield.

1. Introduction

Tomato (*Solanum Lycopersicum* L) is an important crop in Iraq. Due to as well abiotic (soil conditions, drought, heat,.. etc.) as biotic stresses (like fungi and insects) there are serious economic losses, so new technologies are important to optimize growth and yield [1]. One such technology is SAAT, the Silicic Acid Agro Technology [2]. This technology is based on the application of (soluble and stabilized) silicic acid, the only plant available silicon compound. During these experiments, the growth and yield of the tomato plants was enhanced significantly as well [3].
Up till now, the importance of Silicon for agriculture is too much ignored despite the many publications during the last two decades showing the beneficial effects of different Silicon compounds

[4]. Siliconis a beneficial element for different crop species and may protect plants from biotic and abiotic stressors (.Silicon Two decades ago, silicic acid was introduced, and a new technology was introduced: SAAT silicic Acid Agro Technology). Foliar applied silicic acid increased the growth and yield of many corps [5]. Moreover, it was demonstrated that SAAT was able to reduce the amounts of phytosanitary products while the growth and yield parameters of rice were increased [6]. In a recent overview the valuable benefits of the use of different Silicon compounds in agriculture were presented [7,8].

Silicon is present in almost any soil type, as silicates, silicon dioxide (= silica) and biogenic silica, but these compounds are not plant available. Only mono silicic acid ($Si(OH)_4$) is plant available, but its concentration (as plant available silicon) in the soil is often too low resulting in a silicic acid deficiency [9]. Based on the Si concentration in the plant tissues, high, intermediate, and low-accumulator plant species can be distinguished [10]. In general, monocots accumulate more Si in their tissues (1-10%) compared to dicots (0.05-1%). These Si-concentrations equalize the quantities of many other macro- or micronutrients. The different tissue concentrations in monocots and dicots correlate with the differences in silicon uptake amongst these plant species [8,9,11]. The uptake is also dependent on the amount of plant available silicon (silicic acid) in the soil.

Because the low Silicon concentration in the tomato plant, it was believed that Silicon is not very important for this species. Nevertheless, it was demonstrated that tomato plants profit from extra Si supplementation, in particular silicic acid, showing a higher growth rate, more chlorophyll, decrease of abiotic and biotic stresses, which results in more yield with higher quality [12]. One such silicon formulation is AB Yellow (developed by ReXil-Agro, the Netherlands) and is classified as a biostimulant and recommended for agricultural and horticultural crops [7,12].

Compared to the more traditional silicon applications (silicates, etc.), silicic acid is not a fertilizer sense strict, because only small quantities are sufficient for growth stimulation: silicic acid is as well abiostimulant (plant growth promoter), based on its physiological effects on the plant. Silicon, as fertilizers/ biostimulant, is also effective in organic and sustainable crop production [13,14], because it is critical to plant defiance against pests and diseases as well as a biotic stresses. For these reasons it is important to include Si management to increase growth, yield, and quality in a more eco-friendly way.

The objective of this study was to determine and compare the effects of two types of Silicon applications, foliar sprays, and soil-drenching with stabilized silicic acid, on the growth and yield of tomato plants cultivated under greenhouse conditions in an organic farming regime.

2. Material and Methods

2.1. Methodology

A greenhouse (9 x 50 m) experiment was conducted at winter season 2019-2020 at the agricultural research station, College of Agriculture, University of Basrah, South Iraq. Tomato seeds (hybrid variety of tomato (*Solanum esculentium* L.) RED FLORA were used to compare the effects of two types of applications and different concentrations of silicic acid on growth and yield of tomato. Seeds of tomato plants were grown under lath house conditions up to 45 days and next the seedlings were transferred to the greenhouse (1st October 2019). Planting distance was 50cm between each plant in a zig-zagging way on the sides of a drip system pipe [15].

The soil used for this study was classified as Entisol, a soil type with a high quartz content [16]. The soil of the greenhouse was ploughed three times and then settled. A randomized sample was collected from the surface (0-30cm) to determine several physical and chemical properties (Table 1). The analysis was conduct at central Lab. of the College of Agriculture - Basrah University.

The soil was mixed with organic (cattle) residuals (chemical composition shown in Table 2) and covered with black mulching plastic sheet.

Drip irrigation was used for all experimental plants. All agricultural practices were conducted as the common locally recommended protocol according to [15].

Table 1. Specification of chemical and physicals properties of the soil and irrigation water.

Soil properties		UUnit	VValue
pH		---	77.56
E.Ce		$ddS.m^{-1}$	66.45
Soluble captions	CCa^{+2}	$MMmoL^{-1}$	330.19
	MMg^{+2}	$MMmoL^{-1}$	225.98
	NNa^{+2}	$MMmoL^{-1}$	33.01
	K^{K+}	$MMmoL^{-1}$	11.14
O.M.		%%	00.63
Soluble anions	$HHCO^{3}$	$MMmoL^{-1}$	23.22
	CCO^{3}	$MMmoL^{-1}$	---
	SSO_4^{-2}	$MMmoL^{-1}$	226.32
	CCl^{-}	$MMmoL^{-1}$	99.66
Total N		$gg\ kg^{-1}$	222.2
Available P		$g\ gkg^{-1}$	00.015
C.E.C		$g\ gkg^{-1}$	117.33
Soil separated	SSand	%%	112.20
	SSilt	%%	442.7
	CClay	%%	445.1
Texture		---	SSilty clay
Weight soil humidity		%%	66.87
Soil humidity at field capacity		%%	331.02
Irrigation water			
E.C		$ddS.m^{-1}$	11.85
pH		-	77.40

Table 2. Chemical properties of organic fertilizers used in experiment.

Properties	Unit	Cattle residual
pH	-	6.8
E.C	dSm^{-1}	3.6
Organic C	$g\ kg^{-1}$	64.5
Total N	$g\ kg^{-1}$	2.95
Total P	$g\ kg^{-1}$	1.91
Total K	$g\ kg^{-1}$	1.2
O.M.	%	36.63

In November 2019, the greenhouse was covered with a plastic sheet to protect tomato plants against low temperatures. The max. and min. temperatures varied between + 40 C°(September 2019) and +4 C° (December 2019) to raise to 35 C°(April 2020). There relative humidity fluctuated between 20% (September 2019) and 80% (January 2020).

The treatments were laid out in a randomized complete block design (RCDB) with three replicates. The areas of the experimental units were 2.5 m x 0.7 m .

The treatments consisted of two types of Si applications (Soil drench treatment and Foliar spaying) with three Si concentrations at 0.5, 1 and 2 ml/L of silicic acid (AB Yellow). Untreated plots were used as control receiving no silicon amendment.

The silicic acid applications as foliar spray or as soil drench were carried out with 20 days intervals. The first applications were given at 30 days after the seedling transplantations.

2.2. Data Analysis

The outcome data were analyzed statically utilizing the Gen-stat software. The minor significant differences test (L.S.D.) at 0.05 has been used according to [17].

2.3. Parameters

2.3.1. Growth Parameters
Five tomato plants were selected randomly from each experimental unit to measure the following parameters:

- Leaf area: the leaf surface area (cm^2) of the 4th leaf was taken 2 weeks after each silicic acid application. Samples were taken 3 times during experiment period.
- Fresh weight of 4^{th} leave(gm):from each experiment unit plant was taken 2 weeks after each silicic acid application. Samples were taken 3 times during experiment period, cleaned (clean cloth) and measured by sensitive balance under laboratory conditions.
- Dry weight(gm):collected by drying the above wet weight in oven under 70 C° for 48 hours till weight stability and recorded.

2.3.2. Chemical Parameters

- Chlorophyll content in leaves: total chlorophyll was measured in the fourth leaf (mg/ 100 gm fresh weight), 2 weeks after each application according to [18].
- Vitamin C (mg/ 100 gm fresh fruit)was measured in the fourth leaf, 2 weeks after each application.

2.3.3. Yield Parameters

- Early yield (kg):first four harvests of tomato fruits in each experiment units (plot) was collected and weighted by kilogram.
- Total yield (Kg): total harvest of all treatments in each experiment units (plot) was collected and weighted by kilogram.

3. Results

3.1. Leaf Size
The results of the applications of foliar spays with different concentrations of silicic acid (0,0.5, 1 and 2 ml/L) on the size of the leaf surface (cm^2) of tomato plants during the 3 sampling stages, are shown in Table (3) The data show a direct (and significant) increase in the surface area of all silicon treatments at the end of the last sampling stage, with increases of 13,3%, 25,8% and34.2%, for the 0,5, 1 and 2ml/L concentrations, respectively.

Table 3. The effects of foliar applications with different silicon concentrations on the mean ± SE leaf area (cm^2) of tomato. Means followed by the same lower-case letter within each column and upper-case letter in each row are not significantly different using Tukey-Kramer (HSD) test at P = 0.05.

Concentration of	Time intervals (20 days)		
Silicic acid: ml/L	T1	T2	T3
0	85.9±15.7	116.9±18.7	265.2±34.8
0.5	87.8±10.1	157.7±30.1	300.4±11.1
1	100.9±29.1	162.1±60.7	333.6±66.6
2	148.3±55.6	173.2±68.1	355.8±66.9
$F_{3,8}$ P	0.79, 0.53	0.25, 0.88	0.61, 0.63

The results of the soil (drench) applications with different concentrations of silicic acid (0, 0.5, 1 and 2 ml/L) on the size of the leaf surface (cm^2) of tomato plants during the 3 sampling stages, are shown in Table (4) The data showed an increase in the surface area of all the silicic acid treatments after the third application. The results show increases of the leaf area of all silicon drench applications with largest increase for of 2 ml/L drench application of silicic acid compared to the control. The increases result in + 59% (2 ml/L), + 22,3% (1 ml/L) and + 26% for the 0,5 ml/L drench application, respectively.

Table 4. The effects of soil drench applications with different silicon concentrations on the mean ± SE leaf area (cm^2) of tomato. Means followed by the same lower-case letter within each column and upper-case letter in each row are not significantly different using Tukey-Kramer (HSD) test at *P* = 0.05.

Concentration of Silicic acid: ml/L	Time intervals (20 days)		
	T1	T2	T3
0	116.2±27.6	136.4±35.3	273.7±28.8
0.5	85.9±15.7	116.9±18.7	355.8±66.9
1	89.6±15.4	124.2±23.6	345.4±42.1
2	113.6±9.8	136.7±23.8	435.3±107.8
$F_{3,8}$ P	0.79, 0.53	0.25, 0.88	0.61, 0.63

3.2. Chlorophyll Content

The results of the applications of foliar spays with different concentrations of silicic acid (0, 0.5, 1 and 2 ml/L) on the total chlorophyll content (mg/100 gm)of tomato plants during the 3 sampling stages, are shown in Table (5). It shows a limited effect of adding different concentrations of Silicon fertilizer by spraying method of tomato during the sampling stages. The data showed only a positive increase in total chlorophyll for the treatment of foliar sprays 1 ml/L concentrations, but no differences between control and the 0.5 and 2 ml/L concentrations at the end of the sample-taking stages.

The results of the soil (drench) applications with different concentrations of silicic acid (0, 0.5, 1 and 2 ml/L)on the total chlorophyll content (mg/100 gm)of tomato plants during the 3 sampling stages, is shown in Table (6). The data show a significant and direct increase in the total chlorophyll content for all experimental silicon treatments, during the stages of plant growth. The results of the soil (drench) application with 2 ml/L of silicic acid were significantly higher compared to the control treatment (+ 21,4%), as well as the silicic acid treatments of 1 and 0,5 ml/L at the end of the sample-taking stages with increases of 11,2% (1 ml/L) and 9.2% (0.5 ml/L), respectively.

Table 5. The mean ± SE of total Chlorophyll content (mg/100gm) in the 4th leave of tomato plant treated with foliar sprays with different silicic acid concentrations. Means followed by the same lower-case letter within each column and upper-case letter in each row are not significantly different using Tukey-Kramer (HSD) test at *P* = 0.05.

Concentration of Silicic acid: ml/L	Time intervals (20 days)		
	T1	T2	T3
0	5.8±0.4	9.9±1.6	10.8±0.6
0.5	6.8±0.4	9.1±0.5	10.8±0.3
1	8.2±0.4	10.5±1.3	11.9±0.7
2	6.4±0.3	8.5±0.5	10.7±0.5
$F_{3,8}$ P	1.4, 0.3	6.8, 0.01	1.1, 0.4

Table 6. The mean ± SE of total Chlorophyll content (mg/100gm) for tomato treated with different concentrations of silicic acid as surface drench. Means followed by the same lower-case letter within each column and upper-case letter in each row are not significantly different using Tukey-Kramer (HSD) test at *P* = 0.05.

Concentration of Silicic acid: ml/L	Time intervals (20 days)		
	T1	T2	T3
0	5.8±0.6	8.4±0.4	9.8±1.6
0.5	7.7±0.5	9.5±0.6	10.7±1.2
1	8.7±1.1	9.3±0.4	10.9±0.3
2	8.6±0.3	10.8±0.2	11.9±1.3
$F_{3,8}$ P	4.3, 0.04	13.8, 0.002	1.6, 0.3

3.3. Fresh and Dry Weight

The results of the applications of foliar spays with different concentrations of silicic acid (0, 0.5, 1 and 2 ml/L) on the fresh weight of leaves of tomato plants during the 3 sampling stages, is shown in Table (7). The data show a significant effect of all foliar silicic acid applications on an increase in the fresh weight of the leaves compared to control during all growth stages. The foliar applicationswith2 ml/L silicic acid induced a value of 12.8 gm fresh weight (4 leaves per plant)being a significant increase compared to the control treatment (5.6 gm) and the other silicic acid treatments (1 and 0.5 ml/L) achieved values of 10,1 and 8.6 gm (4 leaves per plant)at the end of the growing stages being increases of 128.6 % (2 ml), 80.4% (1 ml) and 53.6% (0.5 ml), respectively.

The results on the dry weight of leaves show similar trends. The 2 ml/L silicic acid foliar applications induced a value of 1.7 gm dry weight (4 leaves per plant) being a significant increase compared to the control treatment (1.1 gm) and the other silicic acid treatments (1 and 0.5 ml/L) achieved values of 1.4 and 1.3gm (4 leaves per plant)at the end of the growing stages being increases of 54.5 % (2 ml), 27.2% (1 ml) and 18.2% (0.5 ml), respectively.

Table 7. The mean ± SE of fresh and dry weight of the 4th leaf (gm) for tomato treated with foliar sprays with different concentrations of silicic acid. Means followed by the same lower-case letter within each column and upper-case letter in each row are not significantly different using Tukey-Kramer (HSD) test at *P* = 0.05.

F_1P	**Conc.SA ml L^{-1}**	**Time interval (20 days)**		
		T1	**T2**	**T3**
Fresh Weight	0	2.9±0.6	3.3±0.3	5.6±3.2
	0.5	3.6±1.2	5.4±2.2	8.6±1.5
	1	3.1±0.2	5.0±2.9	10.1±2.8
	2	5.3±2.1	6.8±1.3	12.8±0.3
	$F_{3,8}$ P	0.8, 0.5	0.4, 0.8	0.4, 0.7
		T1	T2	T3
Dry Weight		0.5±0.1	0.7±0.1	1.1±0.3
	0.5	0.7±0.2	1.3±0.4	1.3±0.1
	1	0.6±0.1	1.2±0.5	1.4±0.4
	2	0.9±0.3	1.4±0.3	1.7±0.4
	$F_{3,8}$ P	0.6, 0.6	0.5, 0.7	0.7, 0.6

The results of the soil (drench) applications with different concentrations of silicic acid (0, 0.5, 1 and 2 ml/L) on the fresh weight of leaves of tomato plants during the 3 sampling stages, is shown in Table9. The data show a significant effect of all soil (drench) applications on the fresh weight of tomato plants compared to control during all growth stages. The soil drench applications 2 ml/L silicic acid induced a value of 16.6 gm fresh weight (4 leaves per plant) being a significant increase compared to the control treatments (11,6 gm) and the other silicic acid treatments (1 and 0,5 ml/L) achieved values of 15,8 and 14,1gm (4 leaves per plant)at the end of the growing stages being an increase of 43% (2 ml), 36% (1 ml) and 21,6% (0.5 ml), respectively compared to controls.

The results on the dry weight of leaves show similar trends (Table 8). The 2 ml/L silicic acid foliar applications induced a value of 2.4gm dry weight (4 leaves per plant) being a significant increase compared to the control treatment (1.5 gm) and the other silicic acid treatments (1 and 0.5 ml/L) achieved values of 2.1 and 1.7gm (4 leaves per plant)at the end of the growing stages being increases of 60 % (2 ml), 40% (1 ml) and 13.3 (0.5 ml), respectively.

Table 8. The mean ± SE of fresh and dry weight of the 4th leaf (gm)for tomato treated with soil amendments with different concentrations of silicic acid. Means followed by the same lower-case letter within each column and upper-case letter in each row are not significantly different using Tukey-Kramer (HSD) test at *P* = 0.05.

F_1P	**Concentrations SA ml L^{-1}**	**Time interval (week)**		
		T1	**T2**	**T3**
Fresh Weight	0	2.9±0.6	3.3±0.3	11.6±3.2
	0.5	3.4±0.7	4.1±0.9	14.1±2.3
	1	4.2±0.4	4.8±1.1	15.8±3.9
	2	4.5±1.3	4.8±1.5	16.6±1.1
	$F_{3,8}$ P	0.8, 0.5	0.4, 0.7	0.9, 0.5
		T1	T2	T3
Dry Weight		0.5±0.1	0.7±0.1	1.5±0.3
	0.5	0.6±0.2	0.8±0.1	1.7±0.2
	1	0.7±0.1	1.1±0.2	2.1±0.4
	2	0.9±0.3	1.1±0.3	2.4±0.1
	$F_{3,8}$ P	0.8, 0.5	0.8, 0.5	1.1, 0.4

3.4. Vitamin C

The results in Figure 1 indicate that the foliar and drench applications 0,5 and 1 ml/L silicic acid as well as foliar spray as drench application, increase the Vitamin C content of tomato plants (mg/100gm fruit) during the ripening period of the fruits compared to the control. The foliar application with 2 ml/L silicic acid was superior with a value of 15.8 (mg/100 gm fruit) being significantly increased compared to control 9.2 mg/100gm (+ 71,7%)and compared to the 0.5- and 1-ml silicic acid foliar treatments with 11.8 and 12.2 mg/100 gm fruit) with increases of 29.50 and 33.9%, respectively. Moreover, the 2 ml/L foliar spray was also superior compared to the 2 ml/L drench application.

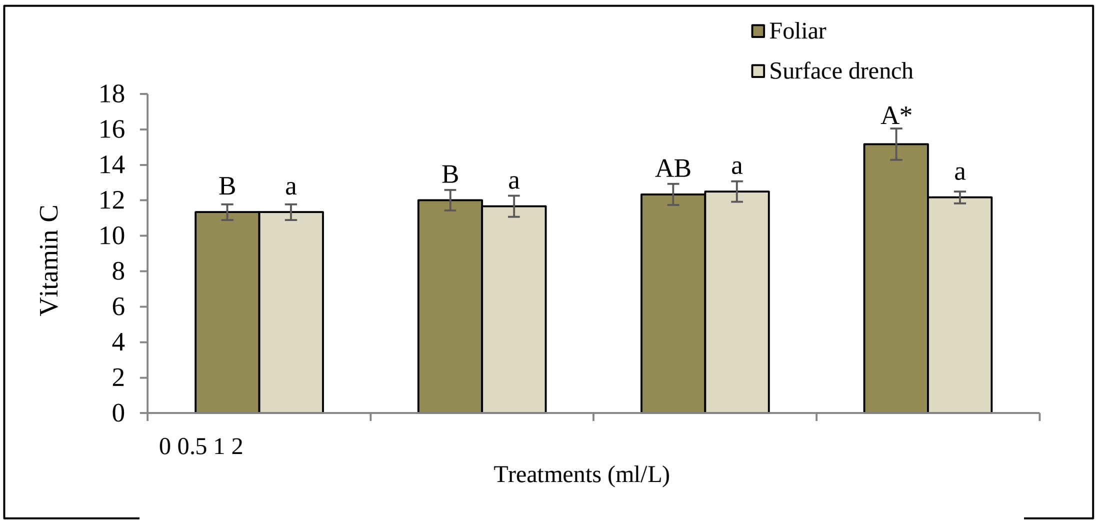

Figure 1. The mean ± SE of vitamin C content for tomato treated with different concentrations of silicon as foliar and drench applications. Means followed by the same uppercase letters for foliar and lower-case letter for drench application are not significantly different by using Tukey-Kramer (HSD) test at P = 0.05; asterisk indicates significant difference between foliar and soil (drench) applications.

3.5. Early Yield

The effects of the foliar and drench applications on the early yield are shown in Fig.2. Both application types increased the early yield of tomato plants (kg) during the fruit ripening period. The data show a significant increase in early production for all silicic acid applications compared to the control. The 2ml/L silicic acid sprays induced the best results being significantly superior with a value of 2.38 (kg) compared to the control (1,45 kg). The 0,5 ml foliar spray did not increase the yield (1,45 kg), while the 1 ml/L sprays yielded 1.78 kg.

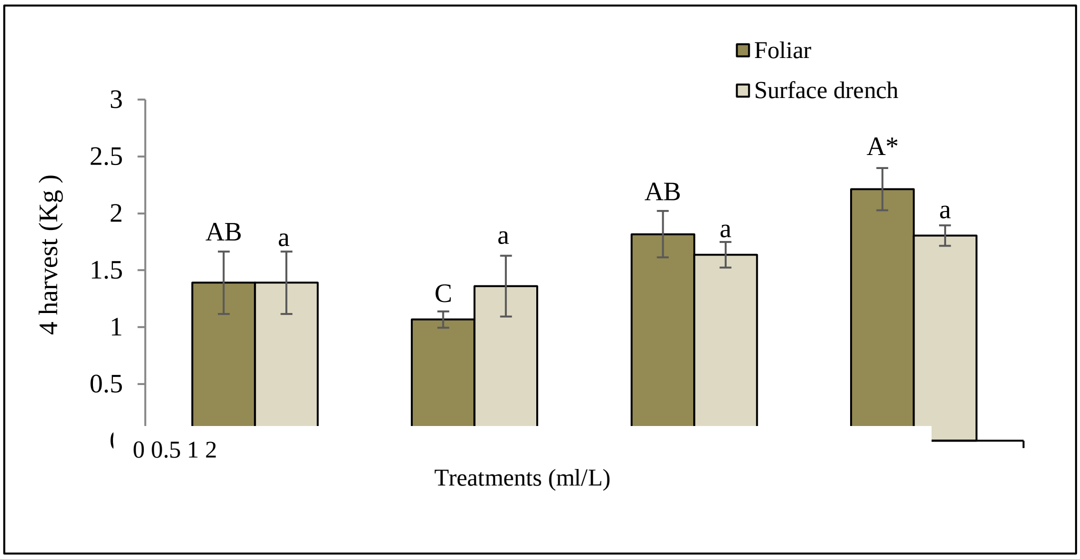

Figure 2. The mean ± SE of early yield for tomato fruits treated with different concentrations of silicon as foliar and drench application. Means followed by the same uppercase letters for foliar and lower-case letter for surface watering application are not significantly different by using Tukey-Kramer (HSD) test at P = 0.05; asterisk indicates significant difference between foliar and surface watering applications.

3.6. Total Yield

The effects of the foliar and drench applications on the total yield are depicted in Fig. 3.The 1 ml/L and 2 ml/L silicic acid foliar and drench applications induced significant increases in the total yield of tomato plants (kg/plot) compared to control and the 0.5 ml/L concentration. The 2 ml/L silicic acid sprays were superior with a tomato fruit yield of 14.35kg/plot followed by the 1 ml/L spray application with a yield of 11.8 kg. Overall, the foliar applications induce higher yields compared with the drench applications.

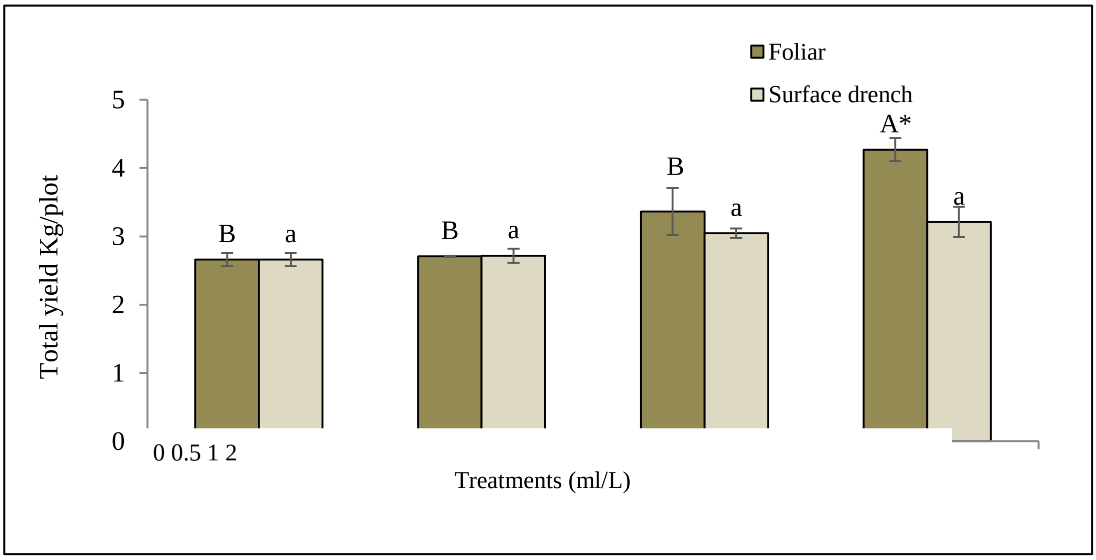

Figure 3. The mean ± SE of total yield for tomato fruits treated with different concentrations of silicon as foliar and soil drench application. Means followed by the same uppercase letters for foliar and lower-case letter for surface watering application are not significantly different by using Tukey-Kramer (HSD) test at P = 0.05; asterisk indicates significant difference between foliar and drench applications.

4. Discussion

The applications of (stabilized) silicic acid, as foliar spray or as soil (drench) application (1 and 2 ml/L) resulted in proportional and significant increases in growth, yield and chemical parameters in tomato plants grown in silty clay pretreated with organic fertilizers [19]. The soil (drench) application of silicic acid 2 ml/L was more effective on the increase of the growth parameters during the vegetative stage, like the leaf surface [7,20] , the fresh and dry weight, and the chlorophyll content, as compared to the foliar spray amendments 2 ml/L. At the other hand, the foliar silicic acid sprays 2 ml/L resulted in significant higher fruit yields (early and total yield) compared to the soil amendments 2ml/L. These differences could be due to a prolonged stimulating effect of foliar applied silicic acid resulting in a larger fruit yield [21]. [7] revealed that three applications of soil drenching with silicic acid 4 ml/L- 2 weeks intervals -significantly increased the yield attributes, viz. number of fruits per plant over control [11]. The results of this trial in India confirms the results of the current study in Iraq and show the efficacy of the foliar silicic acid applications [8].

Overall, the main conclusion is that the applications of silicic, as well as foliar spray and as soil (drench) amendment are significant effective on growth stimulation and yield increases [22]. Because the higher efficacy on yield attributes and pest reduction, the foliar applications of silicic acid 2 ml/L should be 'the first choice', also because the safety of silicic acid and its ecofriendly profile [23].

Author Contributions

All authors contributed to the study conception. Data collection and analysis were performed by Mohsin A. Desher , Husam H. Abdulali and Aqeel Adnan Alousuf. The first draft of the manuscript was written by Mohsin A. Desher . Amin Nikpay was analyze data and draw figures , Henk-M. Laane was reviewed the paper and added some references . All authors read and approved the final manuscript.

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