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An Assessment of the Influence of Foliar Spray Gradient Concentrations of TiO_2 on Maize

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ABSTRACT

A lysimeter experiment was conducted in 2019 to investigate the impacts of foliar spraying of titanium oxide (TiO_2) on maize plant development, yield, and chemical characteristics. The effect of three concentrations of Ti (2, 4, and 8 ppm Ti) and nil as a control on the characteristics of maize in sandy soil was investigated using three replications in a complete randomized design. The growth of maize plants, yield and yield components, quality metrics, and nutrient uptakes like N, P, and K (%) have all been examined. As a result of foliar spraying 8 ppm Ti in the application (N-P-K + Ti 8 ppm) onto leaves of maize plants, a significant enhancement was seen in the final plant length (11.7 %), chlorophyll (9.4%), W.100 grain (17.4%), fresh and dry weight of kernels plant^{-1} (7.5 and 21.3 %) and kernels and grains yield pronouncedly increased (4714.0- and 3469.2-ton fed^{-1}) with an improvement (10.2 and 14 %) correspondingly, whenever compared its control (N-P-K) without Ti. Consistent with the findings, titanium is a helpful mineral for plants at low concentrations.

Keywords: Titanium, foliar spraying and maize plants

1. Introduction

Titanium (Ti) is a transition metal with an atomic number of 22 and an atomic weight of 47.88 that is a member of Group 4 (IVB) in the center of the Periodical Table. It is the tenth most plentiful element, accounting for 0.25 percent of moles and 0.57 percent of the weight of the earth's crust (Buettner and Valentine, 2012).

TiO_2 occurs in nature in three structural forms: two tetragonal forms (anatase and rutile), and one less uncommon orthorhombic form (broquite). The majority of TiO_2 is made from the mineral ilmenite ($FeTiO_3$), which is found in metamorphic and igneous rocks and is insoluble in the pH range of 4.0 to 8.0, making it unavailable to plants (Skocaj *et al.,* 2011).

A few of the variety of applications of TiO_2 are Pigments, photo catalysts, sunscreens, photovoltaic solar cells, optical filters, anti-reflection coatings, chemical sensors, catalysts, and sterilizing materials. Ti is a mineral that aids in the growth of plants. The mean of Ti contents in plants is 33.4 mg kg^{-1}. Ti has been shown to promote seed germination, enhance root uptake of other nutrient elements, stimulate the activity of some enzymes, increase chlorophyll biosynthesis and photosynthesis, strengthen stress tolerance, and improve crop quality and yield (Lyu *et al.,* 2017).

The percentage of titanium in the soil can range from a few tenths to a few percent. Because it is found in water-insoluble minerals, the great majority of it is unavailable to plants. Ti is only found in trace amounts in plants (0.1-10 ppm) Mohammad and Abdul Kareem, (2019).
(Cigler *et al.,* 2010) realized that a Ti compound is not poisonous to mammals.

Ti is also employed as a helpful element in crop productivity in China (Li *et al.,* 2011). In wandflower, Ti increased overall output by 20% and commercial yield by 7% (Marcinek and Hetman, 2008). In this context, Kleiber and Markiewicz, (2013) found that adding 960 g Ti ha^{-1} to the soil for a year enhanced fruit output. Raliya *et al.,* (2015) as a result of foliar spraying 10 ppm TiO_2 onto leaves of mung bean plants, a considerable improvement was seen in the shoot length (17.02%), root length

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(49.6%), root area (43%), and root nodule (67.5%), as well as the amount of chlorophyll (46.4%) and total soluble leaf protein (94%) in the plants.

Comer and Medford (2018) creating reactive nitrogen compounds under favorable condition is made possible by photo catalytic nitrogen fixation. Ti acts as an active photo catalyst for turning dinitrogen into ammonia.

El-Ghamry *et al.,* (2018) stated that adding TiO_2 to lettuce plants in concentrations ranging from 0.0 to 25 ppm improved the plant's levels of N, P, K, Fe, carotene, vitamin C, and chlorophyll.

Haghighi and Daneshmand, (2018) Ti increased photosynthesis and improved nitrogen absorption and nutrient utilization efficiency, chlorophyll, and photosynthesis causing increasing plant growth. (Doklega *et al.,* 2022) Ti improved plant uptake of elements and increased yield.

Maize *(Zea maize L.)* is an important grain crop that is grown primarily in the summer. Maize grain is consumed by humans, animals, and birds. The crop's local output is insufficient to meet demand's continual rise (Moaveni and Kheiri, 2011). Maize is one of Egypt's most important crops because it is the primary source of human nutrition. Egypt's maize production has skyrocketed in the last three decades. Its high nutritional value for humans and cattle, where it is considered an essential source of oil, protein, and carbohydrates, as well as being one of the world's most cost-effective crops (Kandil, 2013 and Abdrabbo *et al.,* 2016).

As a staple food, it also offers protein and calories to most African countries. Maize is high in minerals and phytochemicals, as well as calories. Maize is utilized to bridge the lengthy dry "hunger season" all over the world (Goredema *et al.,* 2021). Maize can be consumed uncooked or transformed into flour, cornmeal, grits, starch, snacks, tortillas, and breakfast cereals. It’s also suitable for use as animal feed (Sun *et al.,* 2022).

From the previous introduction, this study aims to assessment of the influence of foliar spray gradient concentrations of TiO_2 on maize.

2. Materials and Methods

2.1. The location of the experiment

The present investigation was carried out in Talkha, Egypt, at the Fertilizer Development Center of the Delta Company for Fertilizers and Chemical Industries (ASMEDA).

2.2. Sampling and analysis of soil

According to (Dane and Topp, 2020 and Sparks *et al.,* 2020) for soil physical and chemical tests, the characteristics of starting soil detected in lysimeters were determined before beginning the experiment (Table1).

Table 1: Different physical and chemical characteristics of the fundamental sandy soil were identified in the lysimeters before Maize sowing during the growing season.

Soil characteristics			Values
	C. Sand (%)		82.3
	F. Sand (%)		8.0
	Silt (%)		2.5
	Clay (%)		7.2
	Soil texture		Sand
F. C (%)			18.0
$CaCO_3$ (%)			0.00
OM (%)			0.35
pH (1:2.5 soil suspension)			7.4
EC (dSm^{-1}) (in soil paste extract)			1.12
Soluble ions	Soluble cations ($meq\ L^{-1}$) Anions	Ca^{++}	2.20
		Mg^{++}	1.60
		Na^{+}	3.10
		K^{+}	4.30
	Soluble anions ($meq\ L^{-1}$)	CO_3^{--}	0.00
		HCO_3^{-}	3.80
		Cl^{-}	4.8
		SO_4^{--}	2.6
Available N -P -K (mg/kg soil)			19 -1-166

2.3. Experimental Setting

During the summer of 2019, a lysimeters experiment was conducted to show the impact of gradient concentrations of titanium foliar spray (0, 2, 4 and 8 ppm) as titanium dioxide (TiO_2) on plant growth, yield, quality, and chemical composition of maize plants grown on sanded soil.

The trail was constructed using a complete randomized design (CRD) with three replications, and a total of 27 lysimeters were examined. Each lysimeter measured 1.0 m2 (1.0 m length x 1.0 m width and 1.0 m depth) (9 treatments x 3 replicates).

Maize seeds (*Zea mays* L. Cv single Hybride 2031) were planted at a rate of 12 kg fed^{-1} on May 5th and harvested on August 7th, they were obtained from the Administration of Seed Approval, Mansoura screening station. As advised by the Ministry of Agriculture and Land Resources (MALR). The fertilizer application was applied in three doses, consisting of compound fertilizer (N-P-K) (19-19-19%) with 19% nitrogen, 19% phosphorous, and 19% potassium, produced by Delta Fertilizer Company under the brand name High Fertile, and a fertilizer (0-30-40%) with 0% N, 30% P, and 40% K, under the brand name Pota Delta. The prescribed dose was divided into three equal doses. The first of which was administered on May 25th, twenty days after culture, and the second was on June 15th, forty days later. The third was on July 2nd, 62 days following cultivation, with dosages based on Ministry of Agriculture recommendations of 200 kg (19-19-19 %) and 100 kg (0-30-40%) per fed for sandy soil for Maize. Plants were sprayed twice with varying concentrations of titanium dioxide (2, 4, and 8 ppm as Ti), the first dose was after 30 days and the second was after 60 days. Every seven days, the irrigation operation was carried out beneath the surface.

2.4. Characteristics of Measurement

Three maize plants were chosen at random from each lysimeter 60 days after planting, and oven-dried maize stover was digested with a of the mixture of sulphuric (H_2SO_4) and perchloric ($HClO_4$) acids (1:3) to determine the chemical components of stover at the flowering stage, as follows: According to Kjeldahl technique, spectrophotometer, and flam photometer apparatus, respectively, (N, P, and K) were calculated (Piper, 2017) .The amount of total chlorophyll in the leaves was also measured using a total chlorophyll meter (model SPAD-502 from Minolta Camera Co. ltd, Japan). Additionally, various maize growth factors, such as plant height, were measured. Other random samples of three maize plants were taken from each Lysimeter after harvest after 120 days from sowing to estimate chemical composition (N, P, and K %) in grains and stover, as well as some maize growth criteria such as plant height, as well as some yield characteristics such as kernel fresh and dry weights, No. of grains kernel^{-1}, the weight of 100 grain, and total yield.

2.5. Statistical Analysis

After the data were statistically evaluated, the least significant difference (LSD) at the 5% level was calculated Gomez and Gomez (1984).

3. Results and Discussion

3.1. Vegetative growth.

Data illustrated in Table (2) show that the differences resulting from the effect of various rates of titanium applications on the values of vegetative growth parameters of maize were significant.

This show the effect of TiO_2 foliar spray gradient concentrations on maize plant height (cm) through the flowering and after harvest stages. According to the data, increasing titanium concentration to (8 ppm) and adding to the complete fertilization dose (N, P and K) as the treatment (N-P-K+ Ti 8 ppm) significantly improved the plant's length and it was the superior to the other treatments and obtained the highest values of all studied vegetative growth parameters, they were (293.3 cm and 329 cm) with increasing rates (4.3 and 11.7 9.1%) respectively, compared to the addition (N-P-K) (19-19-19%).

However, the lower level of Ti enhanced maize length in the presence of phosphor and potassium, despite of the absence of the nitrogen , It is clear that the treatment (0-30-40+ Ti 2 ppm) significantly increased maize height with values (291.7 and 326.0 cm) at the flowering stage and final stage with improvement rates (44.8 and 21.6) compared to its control (0-30-40) without any nitrogen ,this emphasizes the importance of titanium in plants even in the absence of one of the necessary elements like the nitrogen .These findings are in line with those of Dehkourdi and Mosavi, (2013). They discovered that adding TiO_2 to the plant resulted in a considerable rise in the proportion of plant length, as well as (Raliya *et al.,* 2015 and Khater, 2015), discovered that TiO_2 improved plant length.

Table. 2: Effect of spraying different rates of TiO_2 on leaves of maize height at the flowering and after harvest stages.

Treatment	Plant height (cm)	
	Flowering stage	After harvest
Control	127.0	255.0
N-P-K (19-19-19%) *	280.7	290.7
(0- 30- 40 %) **	161.0	255.7
N P K+ Ti 2 ppm	257.7	302.0
N P K+ Ti 4 ppm	258.7	306.3
N P K+ Ti 8 ppm	293.3	329.3
0-30-40+ Ti 2 ppm	291.7	326.0
0-30-40+ Ti 4 ppm	241.0	320.0
0-30-40+ Ti 8 ppm	213.7	291.3
F-Test	***	***
LSD at 5 %	34.6	16.1

* (N-P-K) (Fertilization recommended dose of elements nitrogen, phosphor and potassium fertilization).
** (0 -30- 40) (Fertilization recommended dose of nutrients P and K fertilization but in the absence of nitrogen).

3.2. Yield and yield component of maize.

3.2.1. The effect of titanium spraying on weights (fresh and dry weights) on kernels and grains, (g plant^{-1}) in maize.

Table 3 demonstrates the influence of titanium at various concentrations on weights (fresh and dry weight, g plant^{-1}) of kernels and grains after harvest; the result revealed that TiO_2 had a serious influence on these characteristics. The findings revealed that it's obvious TiO_2 had a substantial impact on kernel weights. P 0.05 for fresh and dry weight, as well as grains yield. In the presence of complete fertilization dose of the nutrients (N,P and K), it is noticeable that the higher level of Ti (N P K+ Ti 8 ppm) produced the highest fresh and dry weight values of kernels (382.7 and 168.7 g plant^{-1}) with an increased rate of (7.5 and 21.3 %), however the less direct level (N P K+ Ti 4 ppm) produced the maximum dry weight of grains per kernel with (133.0 g kernel^{-1}) and an increased rate of (26.6 %) correspondingly when compared to its control treatment (N-P-K).

Table 3: Effect of spraying different rates of titanium on kernels and grains weights (g plant^{-1}) in maize.

	Weight of kernel		Grains weight
Treatment	Fresh w. (g kernel^{-1})	Dry w. (g kernel^{-1})	Dry w. (g kernel^{-1})
Control	99.7	26.7	17.7
N-P-K (19-19-19%)	354.0	132.7	97.7
0 -30- 40	184.7	58.0	36.0
N P K+ Ti 2 ppm	330.0	111.3	90.3
N P K+ Ti 4 ppm	344.0	166.3	133.0
N P K+ Ti 8 ppm	382.7	168.7	126.3
0-30-40+ Ti 2 ppm	327.3	140.3	102.7
0-30-40+ Ti 4 ppm	252.3	115.7	78.7
0-30-40+ Ti 8 ppm	256.3	101.3	76.3
F-Test	***	***	***
LSD at 5 %	60.4	37.3	24.8

On the other hand, in absence of nitrogen the less concentration of Ti (0-30-40+Ti 2 ppm) get the greatest rates increase of fresh, dry weight of kernels and dry grains per kernel (43.6, 58.7 and 64.9 %)

with values (327.3, 140.3 g plant^{-1} and 102.7 g kernel^{-1}). This result is in harmony with (Radkowski *et al.,* 2015 and Doklega *et al.,* 2022) who stated that titanium fertilization via leaf spray enhanced seed output, dry weight, thousand-grain weight, and germination considerably.

3.2.2. Effect of spraying different concentrations of TiO_2 on kernels and grains yields in maize.

Table 4 shows that TiO_2 had a statistically significant (p 0.05) influence on maize grains yield. The effect of TiO_2 dry weight of kernels, and grains yield per ton fed^{-1} was highly significant in P 0.05; nonetheless, there was no significant increase in the number of a kernel per plant. When the Ti concentration was raised in the presence of nitrogen it was observed that (N P K+ Ti 8 ppm) treatment generated an increase in maize yield pronouncedly (4714.0 and 3469.2 ton fed $^{-1}$) with an improvement (10.2 and 14 %) when compared to its control.

In contrast as usual in the presence of nitrogen, the lest concentration of titanium (0- 30 -40+ Ti 2 ppm) was superior of kernels and grains yield achieved increased rates (74.3 and 75.0 %) compared to its control (0-30-40) investigators of values (3536.3 and 2587.2 ton fed $^{-1}$). Furthermore, the current findings are consistent with those of Moaveni and Kheiri, (2011) their results showed that the effect of TiO_2 was significant on the number of corns in a plant, maize dry weight, and corn yield maize dry weight. Several writers claim that Ti can has been shown to encourage plant growth and enhance yields by up to 30-50% in a wide range of crops (Cigler *et al.,* 2010 and Shah *et al.,* 2021).

Table 4: Effect of TiO_2 spraying on kernels and grains yield in maize per ton fed $^{-1}$.

Treatment	Number of kernels per plant	Dry W. of kernel per ton fed^{-1}	Dry w of grains per ton fed^{-1}
Control	0.7	500.6	324.24
N-P-K (19-19-19%)	1.2	4231.3	2978.6
0- 30- 40	0.7	907.3	646.8
N P K+ Ti 2 ppm	1.0	3141.6	2276.4
N P K+ Ti 4 ppm	1.0	4578.0	3351.6
N P K+ Ti 8 ppm	1.1	4714.0	3469.2
0-30-40+ Ti 2 ppm	1.0	3536.3	2587.2
0-30-40+ Ti 4 ppm	1.0	2914.7	1982.4
0-30-40+ Ti 8 ppm	1.0	2612.3	1898.4
F-Test	n. s	***	***
LSD at 5 %	0.4	1426.3	824.8

3.3. Quality of yield.

Table 5 shows how titanium fertilizers given via leaves affect the mean values of chlorophyll in leaves at the flowering stage, the number of grains per kernel, and the weight of 100 grain. Overall mean values of chlorophyll percentage show a considerable increase if compared with the control treatment. As usual, in the presence of ideal dose of fertilization as (N P K+ Ti 8 ppm) was applied, the maximum values in chlorophyll, number of grains per kernel, and W.100 grain (28.3 SPAD, 555, and 25 g.) were obtained, with improving rates (9.4, 0.8, and 17.4%) whenever compared its control (N-P-K).

However, application without nitrogen, as always, the highest values of number of grains per kernel and Weight of 100 grains (491.0 and 20.7 g) were obtained from the least concentration of Ti (0-30-40+ Ti 2 ppm) with improvements values (21.4 and 48.4 %) compared to (0-30-40). Unusually rustles revealed that the medium level of titanium (0-30-40+ Ti 4ppm) encourage leaves chlorophyll with value 16.7 SPAD achieving an increase rate of (36.0 %). In this context, these findings are consistent with those (Radkowski *et al.,* 2015; Lyu *et al.,* 2017 and Haghighi and Daneshmand 2018) who showed that the effect of TiO_2 was significant on chlorophyll and grains yield.

Table 5: Effect of TiO_2 spraying on chlorophyll, the number of grains kernel^{-1}, and the weight of 100 grain in maize (g).

Treatment	Total Chlorophyll (SPAD)	Number of grains per kernel	W.100 grains (g)
Control	7.0	250.0	6.7
N-P-K (19-19-19%)	25.7	550.3	21.3
0- 30- 40	10.7	386.0	10.7
N P K+ Ti 2 ppm	27.3	438.3	23.3
N P K+ Ti 4 ppm	27.7	554.0	24.3
N P K+ Ti 8 ppm	28.3	555.0	25.0
0-30-40+ Ti 2 ppm	14.3	491.0	20.7
0-30-40+ Ti 4 ppm	16.7	449.7	17.7
0-30-40+ Ti 8 ppm	14.3	464.0	17.7
F-Test	***	**	***
LSD at 5 %	4.7	142.5	24.8

3.4. Chemical composition (N, P, and K %) in the stover and grains in maize after harvest stage.

Data illustrated in Table (6)**:** show the effect of different rates of titanium on macronutrients (N, P and K) percentages in the straw and grains at final stage (%). In the straw, absorption of N and K content was greatly enhanced due to spraying titanium om maize plant. Furthermore, in the presence of nitrogen the lowest level of Ti (N P K+ Ti 2 ppm) was superior to the other treatments and supplied the highest value of (N) (4.5 %) at an increased rate (14.1 %) once compared to its control treatment ((N P K), this result with harmony with **Comer and Medford, (2018**) who stated that Ti can participate in nitrogen fixation and plays some of its role in plants.

Table 6: Indicate the effect of TiO_2 spraying on straw and grains after harvest in maize on macronutrient percentages (N, P, and K).

Treatment	Harvest stage					
	Straw			Grains		
	N%	P %	K %	N%	P %	K %
Control	2.3	0.26	1.8	2.0	0.17	1.9
N-P-K (19-19-19%)	3.9	0.44	1.9	3.1	0.38	3.3
0- 30- 40	2.8	0.45	1.9	2.2	0.34	3.9
N P K+ Ti 2 ppm	4.5	0.37	2.2	2.6	0.41	3.3
N P K+ Ti 4 ppm	3.7	0.31	2.5	3.2	0.53	4.2
N P K+ Ti 8 ppm	3.9	0.30	2.0	2.8	0.47	3.3
0-30-40+ Ti 2 ppm	4.0	0.32	2.4	3.3	0.58	2.7
0-30-40+ Ti 4 ppm	3.1	0.33	2.3	3.0	0.35	2.8
0-30-40+ Ti 8 ppm	2.8	0.42	2.1	3.2	0.39	3.1
F-Test	***	n. s	***	*	***	***
LSD at 5 %	0.5	0.14	0.3	0.8	0.11	0.7

On contrast, the (P) content did not increase significantly. The same data also revealed that the average values of (K) content had increased considerably when compared to the (N P K). The treatment (N P K+ Ti 4 ppm) enhanced nutrient (K) absorption (2.5%) at an increased rate (21.6%). As for the absence nitrogen (0-30-40+ Ti 2 ppm) the lowest level of Ti was the best application on absorption of (N and K) (4 and 2.4 %) with improvement rates (30.0 and 23.3 %) compared to application (0-30-40). When it comes to grains, rustles show positive effects of Ti applications on the absorption of essential elements. The mean values of (N, P, and K) in the grains were determined to be significant at P 0.05. Also, (N) contents had increased considerably, according to data in the same table, in the absence of nitrogen, the treatment (0-30-40 +Ti 2 ppm) promotes nutrients (N and P) uptake (3.3-0.58%) at a higher pace than untreated soil, with increasing rates (31.6-41.4%). However, using Ti without nitrogen with treatment (0-30-40) decrease the uptake of (K).

It was revealed in the presence of nitrogen that (N P K+ Ti 4 ppm) produced higher (N, P and K) percentages than (N-P-K) only while utilizing titanium fertilizers with values (3.2, 0.53 and 4.2 %) with increasing rates (3.1, 27.2 and 20.8 %). Furthermore, the current findings are consistent with those (Burke *et al.,* 2015 and Haghighi and Daneshmand 2018) who released that TiO_2 supplementation has been demonstrated to improve nutritional absorption.

4. Conclusion

From the above-mentioned and exhibited data, it can be stated that: Even Ti isn't essential element, Ti is a beneficial element in crop productivity. At low concentrations, Ti has been found to improve plant performance by increasing component absorption. As a result of TiO_2 fertilization via leaf spray, the growth parameters, chemical composition, chlorophyll, the number of grains kernel^{-1}, the weight of 100-grain in maize, and the yield and yield component of the maize plant were greatly improved in the presence of ideal fertilization dose or even in the absence of nitrogen element.

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