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Ameliorative Effects of Organic Fertilizer, *Trichoderma* and Silicon on Productivity and Quality of Tomato Grown under Contaminated Soil Conditions

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THE PRESENT study was carried out during the summer seasons of 2017 and 2018 in Talkha city, Dakahlia Governorate, Egypt near El-Mansoura-Damietta highway and El Delta Company for Fertilizers and Chemical Industries, where lead (Pb) and copper (Cu) levels in the soil exceed the permissible levels. Therefore, the aim of this study was to alleviate the adverse effects of heavy metals (HMs) on tomato plant (*Solanumlycopersicum* L.) Super Strain B F_1. Twelve treatments were conducted which were the interactions between two silicon (Si) foliar spraying (without or 300 ppm Si) and six soil amendments : 100% chemical fertilizers (CF), 50% farmyard manure (FYM), 100% FYM, 100% CF+ *Trichoderma spp.* (*T.*), 50% FYM + *T.* and 100% FYM + *T.* Data indicate that Pb and Cu were accumulated in tomato organs to hazardous levels in the following descending order : roots > shoots > fruits and shoots > roots > fruits, respectively which consequently severely reduced tomato plant growth and fruit yield and fruit quality. Results also, showed that the application of Si treatment sole or in combination with soil amendments markedly enhanced plant height, dry weight, total chlorophyll, number of fruits/plant, total yield/fed, Vitamin C, acidity %, TSS and taste index, where as, reduced Pb and Cu concentrations in different plant organs, bio-concentration factor (BCF) and translocation factor (TF). However, Si + FYM + *T.* treatment was superior in these respects, therefore increased the net return. Also, negative correlations were obtained between fruit yield and BCF of Pb or Cu and between taste index and TF of Pb or Cu.

Keywords: *Solanumlycopersicum* L., Bio-concentration factor, Lead, Copper, Farmyard manure, *Trichodermaspp.*, Silicon.

Introduction

Contamination by HMs has emerged with the industrial revolution and then sharply increased in urban due to due to increased population activity and in rural areas due tointensive agriculture production to meet food demand of a growing population. Intensive agricultural pollution arises from both natural (geological) and anthropogenic activities i.e., various stationary and mobile sources (Bilos et al*.,* 2001). Agricultural amendments e.g., sewagesludge, mineral synthetic fertilizers and pesticidesrelease large quantities of HMs (Anagawa et al., 2019), exceeding critical limits i.e., 60mg/kg Pb and 70mg/kg Cu in the soil according to FAO/WHO (2001).This is acutely evident inEgypt, especially in areas adjacent to the highways, domestic wastewater and industrial zonewhich pose a critical concern to plants,environment and human at the end of the food chain. In northeastern of the Delta, particularly in Talkha, an industrial and agricultural city, the soil is heavy in texture with relatively high pH, low organic matter and contaminated by copper and lead, besides low quality irrigation water which was a mixture of industrial waste from El Delta Fertilizers Co. and sewage and agricultural wastewaters.

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Thus, high amounts of potential toxic HMs were transported for more than five decades before necessary safety precautions were taken recently. Plants differ in their tolerance to HMs and most of the economic plants are fortunately not hyperaccumulators. Therefore, they evolved a range of mechanisms in the detoxification such as avoidance i.e., preventing HMs uptake, exclusion into the vacuole away from metabolic processes, chelation of HMs by organic components (organic acids, amino acids or peptides) and/or enhancing oxidative defense system. In Egypt, tomato crop occupies about one third of vegetables area (182444 hectares) in 2017 according to FAO Stat. Although tomato is considered as an intermediate accumulator to HMs, but it is the most consumed vegetable as fresh and cooked fruits (7297108 ton/year) in 2017 according to FAOSt at (2017). It is also an important export crop (more than 20 tons/year). The presence of HMs such as Pband Cu reduces the nutritional value of tomato fruit (Anagawa et al., 2019) as they are considered systemic toxicants to human, since Pbrecommended permissible limits in tomato fruit are 0.1- 10mg/kgdw, while the normal limits of Cu in plant tissues are 2-20mg/kgd waccording to FAO/WHO (2001). Although copper is a micronutrient, but at high levels can be a major health hazard to human that causing GI mucosal ulcerations, bleeding, acute hemolysis, hepatic necrosis, nephropathy, hypotension, tachyeardia tachypnea, dizziness, headache, convulsions, lethargy and coma. However, lead (Pb) even in low level is toxic and could cause neurological damage, lowers IQ and attention, encephalopathy, bone deterioration, hypertension and kidney disease (as reported by Agency for Toxic Substances and Disease Registry).

HMs are bioaccumulated and non-biodegradable and their availability and uptake from soil to plants depend on plant variety and soil characteristics e.g., clay and organic matter contents, pH and cation exchange capacity (CEC). With increasing soil pH, the mobility of Pb increases, whereas of Cu decreaseswhich affectstheirabsorption by the plants (Podlesakova et al., 2002). Toxicity of HMs may result from the inhibition of plant cellular activities (Hall, 2002) by binding HMs with sulphydryl groups of proteins, the replacement of an essential element resulting in deficiency symptoms (Van Assche and Clijsters, 1990) or bythe stimulation of reactive oxygen species (ROS), (Dietz et al.,1999). Finally, plant growth inhibition, crop yield depression and quality deterioration are a result.

Removal or fixation of HMs by remediation can be the most appropriate techniques. Removal by phytoremediation is environmental safe, but it needs long time. However, removal by soil leaching is extremely expensive and polluted the ground water. On the other hand, fixation technique i.e., HMs immobilization by adsorption, absorption or chelation could be safer, cheaper and faster technique. vbThe organic fertilizersnot only improve physical, chemical and biological characteristics of soils, but also have a potential alleviation of metal toxicity (Gul et al., 2015 and Rady et al., 2016). Moreover, *Trichodermaspp.* fungusis, a beneficial toolin modern agricultural system. It is well documented as an organic solventand as a bioremediation treatment, since it could improvemetal stress tolerance in plants due to its important role in protection against oxidative damage throughincreasing activities of ascorbate and glutathione-recycling enzymes (Mastouri et al., 2012) as well asproducing auxins, ethylene, gibberellins, phytoalexins and phenols (López-Bucio et al., 2015). Moreover, *T.* canincreaseproline production and ROS scavenger activities (Hidangmayum and Dwivedi, 2018), in addition to enhanceroot biomass production and nutrient availability and efficiency. Generally, *T.* remodels or manipulates the plant immune response by reprogramming their transcriptome and proteome. Moreover, with increasing crop yields, agricultural intensity and less incorporationoforganicmatter back in to the soil, Si loss by plant uptake is more pronounced than its mineralization, resulting in Si depletion zone which makes Si now a quasi-essential element. Si as a fertilizer is applied to many crops in several countries for increased productivity and sustainable production. Moreover, it has beneficial effects on alleviating both biotic and abiotic stresses (Ma,2004). The most significant effects of silicon on metal toxicity are reducing the uptake through metal adsorption and inhibiting ROS production (Rizwan, 2012).

The current study aimed to figure out the deleterious effects of Pb and Cu on tomato as a highly consumed vegetable and to assess the ameliorative effects of organic fertilizer (FYM), *Tricchoderma* and Si as environmentally friendly, economical and sustainable alternatives.

Material and Methods

The experiments were carried out during summer seasons of 2017 and 2018 at Talkha Cityadjacent to El-Mansoura-Damietta highway and El Delta Company for Fertilizers and Chemical Industries (31°.05′N, 31°.38′E with an elevation of 7 meters above sea level), Dakahlia Governorate (Egypt's fourth largest governorate by population) to study the effectof farmyard manure, *Trichoderma ssp.* and siliconon mitigating the harmful effects of Pb and Cucontaminated soil on tomatoplant (*Solanumlycopersicum* L.), Super Strain BF1.Preceding the initiation of the experiment, soil samples at a depth of 0-50 cm were collected and analyzed (Cottenie et al.,1982). The soil analysis results are shown in Table 1. On 16th March, tomato seedlings (35 day-old) were transplanted in both seasons at 50 cm apart on one side of ridge of 4m long and 1m width with a capacity of 3 ridges. The experimental plot had a net area of 12m^2.

Soil amendments

Fertilization rates

For inorganic fertilization practice, a dose of 200kg /fed calcium superphosphate (15.5% P_2O_5) was added during soil preparation. While, nitrogen fertilizer was added in three doses; 150 and 200kg/fed as ammonium sulphate (20.6 % N) and 150 kg/fed as ammonium nitrate (33.5% N) at 30,60 and 90 days after trans planting, respectively. Potassium sulphate (48% K_2O) was added once at 90 days after transplanting at a rate of 100kg /fed. However, the application of mineral synthetic fertilizers may impose concern regarding the entry and toxic accumulation of HMs in agro-ecosystems as shown in Table 2. Pb and Cu contents in the mineral fertilizers used were determined by an atomic absorption spectrometer (GFAAS, Perkin Elmer PinAAcle 900T, Perkin Elmer Inc., Waltham, USA). As for organic fertilization, the calculated quantity of FYM (1.22 %N) to achieve the total N-fertilizer is 9.988 ton/fed. Chemical analysis of FYM is shown in Table 3. Fully decomposed farmyard manure was thoroughly mixed with the upper 20cm layer of the soil prior to planting.

TABLE1. Physical and chemical properties of the experimental soil .

Properties	Season 2017	Season 2018
	Physical analysis	
Clay %	48.2	47.9
Silt %	25.1	26.4
Sand %	26.7	25.7
Soil texture	Clay	Clay
	Chemicalanalysis	
***pH**	7.6	7.5
****EC(dSm^{-1})**	1.25	1.25
OM	1.86	1.93
$CaCO_3$	2.81	2.65
Available nutrients (ppm)		
N	46.3	44.6
P	15.6	14.9
K	298.0	302.0
Ions(meq/ 100g soil)		
$(HCO_3)^-$	1.50	1.66
Cl^-	3.9	3.01
$(SO_4)^{--}$	1.4	1.50
Heavy metals (mg/kg dw)		
Pb	313	235
Cu	77	79

*pH of 1: 2.5 (Soil: Water) water suspension, **EC of 1: 5 (Soil: Water) water extract.

TABLE 2. Heavy metals in samples of mineral fertilizers used in these experiments.

Fertilizer	Total (mg.kg^{-1})	
	Cu	Pb
Calcium super Phosphate	24.4	7.4
Ammonium nitrate	0.8	19.1
Ammonium sulphate	1.8	21.0
Potassium sulphate	2.1	22.0

TABLE 3. Chemical analysis of the farmyard manure used during seasons of 2017 and 2018.

Properties	pH (1:2.5)	EC (dS/m)	OM (%)	C:N ratio	N%	P%	K%	Total HMs content (mg.kg^{-1})		Available HMs (mg.kg^{-1})	
								Pb	Cu	Pb	Cu
2017	6.9	4.12	33.5	21 : 1	1.22	0.54	1.02	110.6	56.1	18.7	5.9
2018	7.4	4.17	35.2	20 : 1	1.22	0.55	0.98	98.4	43.3	22.3	5.8

Trichoderma inoculation

A liquid suspension of *Trichodermaharzianum* and *T. viride* inequal proportions was used as a mixture. The inoculum was provided from Research of Biological Nitrogen Fixation unit (BNF), Soil, Water and Environment Research Institute, Agricultural Research Center, Giza, Egypt. The fungus suspension (5ml) containing 1gm mycelium of each inoculum (10^{4-5} conidia/ml) was inoculated as plant-bed before transplanting.

Siliconfoliar spraying

K-silicate (K_2SiO_3: 11% K_2O and 22%SiO_2) was purchased from Technogreen Co., Cairo, Egypt. Also, it is preferable to dissolve K-silicate in warm water first before preparing the assigned concentration (300ppm). Tomato plants were foliar sprayed during the growth period starting at 20 days after transplanting and applied 15 days interval for 4 times, while tap water was sprayed and served as a control treatment. The normal agricultural practices for tomato cultivation under Delta conditions were followed according to the recommendations of Egyptian Ministry of Agriculture and Land Reclamation.

Experimental design

The experiment was laid out in a complete randomized block design (RCBD) with 3 replicates. The experiment consisted of two factors as follows:Tow Si foliar spraying levels (without or 300ppm) and 6 soil amendments:

- 100% CF
- 50% FYM(4.994ton/fed.)
- 100% FYM (9.988ton/fed.)
- 100% CF + *T*.
- 50% FYM (4.994ton/fed.) + *T*.
- 100% FYM (9.988ton/fed.) + *T.*

Data recorded

Vegetative growth, total chlorophyll of leaf and fruit yield characteristics

A sample of three plants was taken randomly from each experimental plot after80 days from transplanting to determine plant height (cm) and dry weight/plant (g). Moreover, total chlorophyll of leaf was determined as described by Von Wettstein (1957). At harvesting stage, number of fruits/plant was recorded and total yield (the weight of fruits of all harvests) as kg/plot was recorded, then total yield as ton/fed was estimated.

HMs contentsinroots, shoots and fruits

Pb and Cu contentsin different plant organs (roots, shoots and fruits) were analyzed by atomic absorption spectrometry (GFAAS, Perkin Elmer PinAAcle 900T, PerkinElmer Inc., Waltham, USA). HMs were determined in roots and shoots samples at 120 days after transplanting andin fruits (sample of 10 tomato fruits/plot) at breaker stage. Roots, shoots and fruits samples were oven dried at 70°C until constant weight, and then the dried samples were ground in a stainless-steel grinder to a fine powder. Afterward a weight of 0.1 g of dried samples was wet digested, the acid digested solution was used to measure Pb and Cu contents.

HMs accumulating capacities

Tomato plant may have the potential to accumulate metals, so the bio-concentration factor (BCF) and translocation factor (TF) were estimated for HMs uptake capacities. BCF is a ratio between a metal content within the plant organs to a total metal content in the soil. However, the TF is a ratio between a metal content within a plant organ to a metal contentin another plant organ.BCF and TFwere calculated according to Liu et al. (2009) using the following formula :

$$\mathrm{BCF} = \frac{\mathrm{Cplant}}{\mathrm{Csoil}}$$

$$\mathrm{TF} = \frac{\mathrm{C\ (shoots\ or\ fruits)}}{\mathrm{C\ (root\ or\ shoots)}}$$

Where: C is the concentration of metal in different plant organs.

If BCF ≤ 1.00, it indicates that the plant can only absorb but not accumulate metal.

If BCF > 1.00, it indicates that the plant may have potential to accumulate metal.

Relative reduction of Pb and Cu TF was calculated as follow:

$$\text{Relative response of TF \%} = \frac{\text{Pb or Cu TF of control} - \text{Pb or Cu TF of treatment}}{\text{Pb or Cu TF of control}} \times 100$$

Fruit quality

At red ripe stage, a sample of 10 fruits per experimental plot were randomly harvested and used for determining total soluble solid (TSS) (°Brix) using a hand refractometer, acidity % by a pH meter and vitamin C according to the methods described in (AOAC, 2000). Also, taste index was calculated using the equation proposed by Navez et al. (1999)

$$\text{Taste index} = \frac{\text{Brix degree}}{20 \times \text{Acidity}} + \text{Acidity}$$

Economic Performance

Based on market prices, economic performance of tomato plants (gross return, treatment cost, total variable cost, net return and benefit-cost ratio) was calculated as average of the two seasons according to Boardman et al. (2001).

Statistical analysis

The obtained data were subjected to statistical analysis of variance (ANOVA) using CoStat statistical analysis system (Version 6.303, Co Hort, USA, 1998-2004). Mean comparisons were performed using Duncan's Multiple Range Tests at 5% level of probability according to the procedures reported by Snedecor and Cochran (1982). Moreover, correlation between fruit yield and either BCF of Pb or Cu andbetween taste index and either TF of Pbor Cu were analyzed.

Results and Discussion

Vegetative growth traits, total chlorophyll of leaf and yield characteristics

Data in Table 4 indicate that both foliar spraying of 300ppm Si and soil amendment treatments alleviate the adverse effects of Pb and Cu pollution on leaf chlorophyll content and vegetative growth and yield characteristics. The most pronounced results ofsoil amendments were obtained with 100% FYM+*T.* followed by 50% CF + 50% FYM+ *T.*, except fortotal chlorophyll of leaf in the 2nd season where the difference did not reach to the significance at 5% level.

Concerning the interaction between Si application and soil amendments, data revealed that all assigned treatments enhanced vegetative growth and yield attributes and total chlorophyll of leaf. The treatment of Si foliar spraying +100% FYM+*T.* followed by Sifoliar spraying + 50% FYM+*T.* were superior to the other treatments, except for total chlorophyll of leaf in the 1st season, where the highest value was recorded by the treatment of Sifoliar spraying +100% FYM+*T.* followed by Si foliar spraying + 50% FYM+*T.* inoculation.

Shabana et al. (2012) found significant reductions in most of studied vegetative and yield traits of tomato and bean plants grown under pollution conditions. Hladun et al. (2015) and Alaboudi et al. (2018) found that Cu and Pbadversely affected the fresh and dry weights of sunflower (*Helianthus annuus.* L.) and radish *(R. sativus)* shoots. The exposure to excess levels of HMs reduces plant growth and yield due to the inhibition of photosynthesis, nutrient assimilation and cell division (Arellano et al., 1995, Sharma & Dubey, 2005 and Sanaa, 2015) as well as physiologically inhibition of active enzymes (Gadd, 2007) and mineral metabolism (Janas et al., 2010).

TABLE 4. Vegetative growth, total chlorophyll of leafand yield parameters as affected by silicon spraying and soil amendments of FYM and *Trichoderma ssp.* on tomato plant grown under contaminated soil conditions during seasons of 2017 and 2018.

Parameter		Plant height (cm)		Dry weight (g/ plant)		Total chlorophyll of leaf (mg/g fw)		No. of fruits/plant		Total yield (ton/ fed)	
Treatments		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Si Treatment	Conrol	56.3 b	56.8 b	36.4 b	41.5 b	5.38 b	5.26 b	12.6 b	15.1 b	13.46 b	15.94 b
	Si(300ppm)	68.1 a	76.8 a	50.3 a	54.3 a	5.85 a	6.17 a	15.2 a	16.9 a	14.92 a	14.41 a
Soil amendments	CF	43.2 f	47.4 f	22.4 f	22.3 f	4.41 f	5.32 ab	10.33 e	14.5 d	12.52e	13.43d
	50%FYM	58.4 c	59.0 e	35.9 d	46.6 c	5.16 e	4.68 b	13.67 c	15.3 c	13.52 d	14.67c
	FYM	50.4 e	62.1 d	32.7 e	44.6 d	5.31 d	5.88 ab	12.0 d	14.7 d	12.65 e	14.15cd
	CF+*T.*	57.2 d	70.8 c	38.3 c	29.7 e	6.1 c	5.73 ab	13.67 c	15.3 c	14.06 c	14.71c
	50%FYM+*T.*	80.8 b	77.7 b	58.1 b	65.1 b	6.2 b	6.28 a	16.0 b	17.2 b	15.6 b b	16.34b
	FYM+*T.*	83.7 a	83.5 a	72.6 a	79.1 a	6.6 a	6.40 a	17.67 a	19.2 a	16.83a	17.93 a
Interaction											
Without Si	CF	39.0 j	42.1 k	18.5 j	21.1 k	3.32 j	4.13c	9.67 g	14.0 e	12.22 j	13.4fg
	50%FYM	53.1 f	48.0 i	31.6 g	41.1 f	4.51 i	5.07abc	12.0 e	15.0 d	13.16 gh	14.8de
	FYM	40.0 i	45.1 j	30.2 h	39.2 g	5.02 h	5.17abc	10.0 fg	14.0 e	12.05 j	12.98g
	CF+*T.*	51.1 g	60.0 g	32.3 g	26.3 i	6.10 d	5.40abc	11 .67 e	14.0 e	13.00hi	13.48fg
	50%FYM+*T.*	75.0 c	70.3 f	44.7 d	50.2 e	6.50 b	5.80abc	14.33 cd	15.3 d	14.32e	15.3de
	FYM+*T.*	80.2 b	75.1 e	61.0 c	71.2 c	6.81 a	6.00abc	17.67 a	18.3 b	16.03c	16.57bc
Si (300ppm)	CF	47.4 h	52.8 h	26.4 i	23.5 j	5.50 g	6.50 a	11.0 ef	15.0 d	12.83i	13.28fg
	50%FYM	63.7 d	70.0 f	40.3 e	52.0 d	5.8 e	4.30 bc	15.33 bc	15.7 d	13.87f	14.33ef
	FYM	60.8 e	79.1 d	35.2 f	50.0 e	5.60 f	6.60 a	14.0 d	15.3 d	13.24g	15.4cde
	CF+*T.*	63.2 d	81.6 c	44.3 d	33.1 h	6.10 d	6.01 ab	15.67 b	16.7 c	15.11d	15.93cd
	50%FYM+*T.*	86.5 a	85.1 b	71.4 b	80.0 b	5.81 e	6.77 a	17.67 a	19.0 b	16.88b	17.38b
	FYM+*T.*	87.1 a	92.0 a	84.1 a	87.1 a	6.30 c	6.80 a	17.67 a	20.0 a	17.62a	19.28a

CF: 100% chemical fertilizers; FYM: 100% farmyard manure; *T.*: *Trichoderma* inoculation; fed: feddan (4200m^2).
Means followed by the same letter(s) within each column are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.05$.

The alleviated effects of assigned treatments on growth yield and chlorophyll parameters may be attributed to some operating mechanisms which might be led to decrease HMs uptake and/or decrease their translocation from roots to shoots and fruits as shown later in Table 6 and Fig. 3. Concerning K-silicate application, specific roles of Si in abiotic stress tolerance as antioxidant may contribute to its importance inactivation of antioxidant enzymes (superoxide dismutase and catalase), reducing lipid oxidation of cell membranes and stimulation ROS scavenging capacity (Elkhatib et al., 2017; Yavas and Unay, 2017). Also, Si may be able toaccumulate HMs in silicate forms (nontoxic). In addition, Si has important roles in increasing RNA, DNA and chlorophyll synthesis and in maintaining plant water status. In other word, the enhancement effects of Si on stressed tomato could be the sum of enhancement of growth, chlorophyll, and many antioxidant enzymes and inhibiting H_2O_2 activity (Hassan et al., 2017) which were consequently reflected on the yield production. The role of potassium as a component ingredient in K- silicate in assisting the processes that ensure carbon assimilation and transportation to the fruits cannot be ignored (Nesreen et al., 2011).

Moreover, *T.* strains are known as plant growth promoting fungi. They are able to produce various bioactive secondary metabolites, which stimulate plant growth and increase plant tolerance against abiotic stress i. e. environmental stressesthrough increased root growth, nutrient uptake and inducing protection against oxidative stress. *T. harzianum* enhanced photosynthesis and growth rates, reduced electrolyte leakage and lipid peroxidation rates (Ghorbanpour et al., 2018) and ameliorated HMs stresses by inducing physiological protection against cellular damages in tomato (Hidangmayumand Dwivedi, 2018). *T.* inoculated sunflower mitigates the phytotoxic effects of Pb^{+2} by increasing antioxidant enzymes level (Devi et al.,2017) and/or accumulation and translocation to leaves (Téllez-Vargas et al., 2017). On the other hand, the yield response to organic manure application could be attributed to improve physical, biological and chemical properties of the soil resulting in better supply of nutrients to the plants. Angelova et al. (2013) stated that the content of bioavailable metal species whichis an indicative of HM simmobilization could be reduced by organic matter enrichment.

Heavy metal content

The effects of Si foliar spraying and soil amendments of FYM and *T.* fungi on HMs content (Pb and Cu) in roots, shoots and fruits of tomato plants are shown in Table 5 and Fig.1. As a result of the higher mobility of Cu than Pb, Cu content was following the descending order: shoots > roots > fruits, while Pb one was : roots > shoots > fruits. Foliar spraying of Siat a rate of 300ppm and soil amendments with FYM and *T.* significantly decreased HMs contents in different tomato plant organs compared with untreated plants. Regarding the interaction between Si foliar spraying and soil amendments, the results clearly show that the highest contents of HMs were observed in roots, shoots and fruits of tomato plants that were amended only with chemical fertilizers (CF), whereas the lowest contents were occurred with plants sprayed by Si and soil amended with FYM+ *T.* inoculation followed by Si foliar spraying and soil amended with 50% FYM + *T.* In addition, Si foliar spraying combined with soil amendments, particularly FYM + *T.* significantly decreased Pb and Cu contents in fruits compared with other treatments and did not exceed the maximum permissible levels (10 and 20 $mg.kg^{-1}$ dw for Pb and Cu, respectively) (Fig. 1).

Radwan and Salama (2006) and Bagdatlioglu et al. (2010) are in accordance with these results. They revealed that the high contamination found in vegetables might be closely related to the pollutants in farm soil, irrigation water and ambient air or due to pollution from the highway traffic. Anagawa et al. (2019) stated that tomatoes grown near the industrial activityare as and highway traffic contain higher levels of HMs than that far from it. HMs could be accumulated in the plant organs more than the maximum permissible levels (MPL), the threshold limit values proposed by FAO/WHO (2001) in mg/kg plant dry weight, (Bagdatlioglu et al., 2010 and Shabana et al., 2012), particularly in conventional cultivation.Commercial fertilizers,pesticides and other synthetic chemicals are used repeatedly to enhance the agricultural crops productivity which unfortunately increased HMs accumulation in soil and plants (Bagdatlioglu et al., 2010 and Osma et al., 2012).

TABLE 5. Pb and Cu contents in roots and shoots of tomato plant grown under contaminated soil conditionsas affected by silicon spraying and soil amendments of FYM and *Trichoderma* during seasons of 2017and 2018.

Parameters		Pb (mg.kg^{-1}dw)				Cu (mg.kg^{-1}dw)			
		Roots		shoots		Roots		shoots	
Treatments		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Si Treatment	Conrol	272 a	210 a	130 a	92a	94 a	98 a	132a	146 a
	Si(300ppm)	225 b	117 b	93b	60 b	66 b	71 b	86 b	97 b
Soil amendments	CF	398 a	274 a	179 a	141 a	122 a	129 a	175 a	186.3a
	50%FYM	285 c	220 b	142 b	102 b	96 b	99 c	142 b	157 b
	100%FYM	221 d	168 c	94 c	55 d	77 d	76 d	91 d	103d
	CF+*T.*	315 b	118 d	132b	76 c	92 c	103 b	113 c	127c
	50%FYM+*T.*	152 e	115 d	76 c	55 d	54 e	57 e	83 e	94 e
	1FYM+*T.*	119 f	89 e	47 d	28e	38 f	43 f	52 f	64 f
Interaction									
Without Si	CF	410 a	318 a	212 a	174 a	133 a	138 a	200 a	212a
	50%FYM	320 d	270 b	161 b	123 b	100 c	103 d	147 d	163c
	100%FYM	210 h	151 f	99 ef	57h	80 e	78 h	80 d	93g
	CF+*T.*	341 c	235 c	130cd	90d	103 c	115 c	155 b	172 b
	50%FYM+*T.*	198 i	167 e	111def	77f	83 e	82 g	130 c	142e
	FYM+*T.*	150 j	120 g	67g h	33 j	63 g	71 j	85 h	96g
Si (300ppm)	CF	387 b	230 d	145bc	109 c	111 b	120 b	151 c	161 c
	50%FYM	250 f	170 e	123cde	81 e	91 d	95 e	137 e	152 d
	100%FYM	231 g	85 i	90fg	53 i	74 f	74 i	101g	113 f
	CF+*T.*	289 e	100 h	133bcd	62 g	81 e	90 f	72 j	81 h
	50%FYM+*T.*	105 k	63 j	41h i	33 j	25 h	31 k	36 k	46 i
	FYM+*T.*	87 l	58 k	26 i	22 k	12 i	15 l	19 l	32 j

CF: 100% chemical fertilizers; FYM: 100% farmyard manure; *T.*: *Trichoderma* inoculation.

Means followed by the same letter (s) within each column are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.05$.

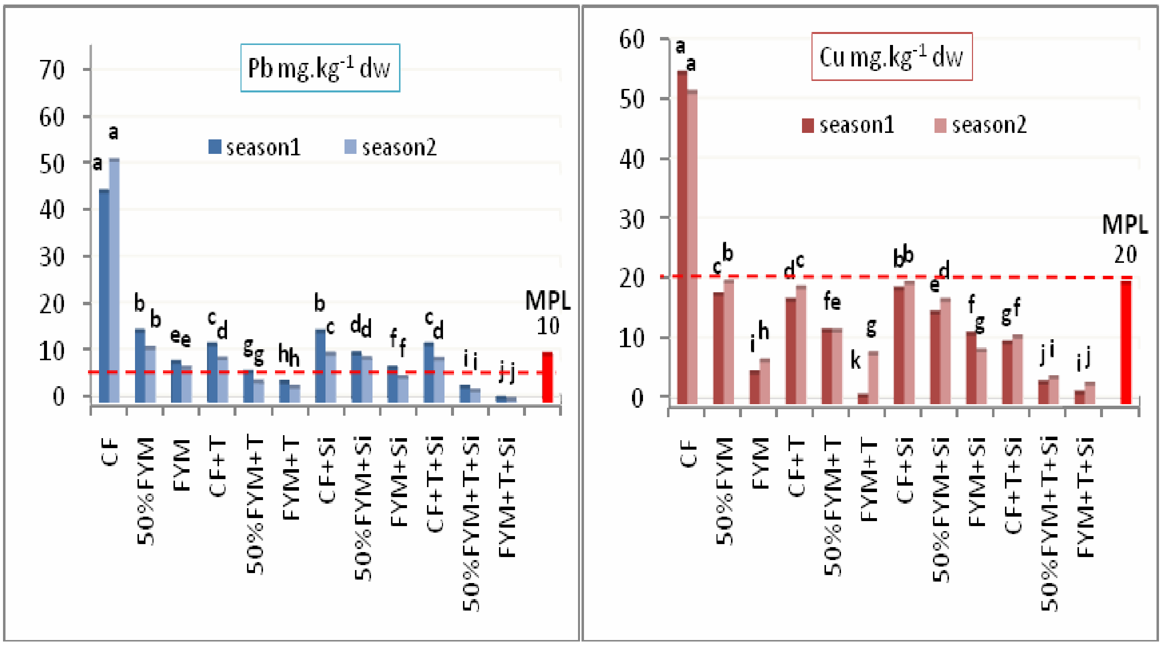

Fig. 1. HMs content in tomato fruits as affected by silicon spraying and soil amendments of FYM and *Tricchoderma* compared with maximum permissible level (MPL).

Pb concentration in roots was higher than that in shoots due to its lower mobility in both soil and plant (Podlesakova et al., 2002 and Hladun et al., 2015). The most significant effect of silicon on Cu toxicity is by reducing uptake and root-to-shoot translocation and by increasing Cu adsorptionas well as its roles as an antioxidant under abioticstresses. In addition, organic amendments led to an effective immobilization of both Pb and Cu (Angelova et al., 2013).

Heavy metal accumulating capacities

Data in Table 6 clearly indicate that the bio-concentration factor (BCF) in plant and translocation factor (TF) in tomato fruits of both Pb and Cu were significantly decreased by foliar spraying of Si at a rate of 300 ppm in both seasons, except for TF of Cu, where no significant difference was observed during both seasons. However, the quantity of mobile forms of HMs i.e., available forms depended on the type and the rate of soil amendments, FYM significantly decreased BCF and TF of Pb and Cu, especially when combined with *T.* inoculation. The interaction effects also clear that under conventional cultivation, tomato plant may have the potential to translocate HMs to fruits and accumulate metal in the plant since the BCF > 1.0. Whereas, the plant can only absorb but not accumulate metal due to organic and biological treatments and Si application, which reduced BCF to less than 1.00.

Figure 2 obviously clear that sharp reductions in TF of Pb and Cu in all treatments under the conditions of this study relative to conventional production system. The treatment of FYM+*T.* combined with Si foliar spraying was superior in these respects. On the other hand, negative correlations between BCF of Pb and Cu from one side and total yield (ton/fed.) to another side are shown in Fig. 3. The obtained results were significant in both cases at a confidence level of 95%, with determination coefficients (R^2) of 0.622 and 0.241, respectively, indicating a reversal of HMs accumulation in tomato plant and fruit yield.

When investigating whether a plant is a hyper-accumulator of a metal, both BCF and TF are considered (Sanaa, 2015). Murtić et al. (2018) found that the low accumulation of HMs in tomato fruits is the result of synergy of different plant defense mechanisms that limiting or reducing HMs transport from root to fruits. Cu had the higher TFs and BCFs indices, especially in the low level of metal in the soil compared to Pb, which was mostly immobile in the plant (Hladun et al., 2015; Alaboudi et al., 2018). Therefore, Cu accumulated in all plant organs, while Pb is highly concentrated in the roots. However, essential copper and non-essential lead competes for the same transmembrane carrier (Sanaa, 2015). The most significant effect of silicon is reducing HMs toxicity by activating ROS scavengers (Yavas and Unay, 2017). In addition, Kabata- Pendias (2010) found that organic matter adsorbs HMs e.g. Cu, Zn, Pb and Cd, which generate stable forms and lead to their accumulation in organic formulation in soil. Moreover, organic matter e.g. poultry and cow manures not only improves the physical characteristic and the nutrient status of soils significantly, but also reduces HMs availability, leading to lower plant uptake by HMs immobilization (Anglelova et al.,2013).

TABLE 6. Pb and Cu accumulating capacities of tomato plant grown under contaminated soil conditions as affected by silicon spraying and soil amendments with FYM and *Trichoderma* during seasons of 2017 and 2018.

Parameters		Bioconcentration factor (BCF)				Translocation factor (TF)			
		Pb		Cu		Pb		Cu	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Si Treatment	Conrol	1.33 a	1.35 a	3.19 a	3.34 a	0.10a	0.13a	0.110a	0.121a
	Si (300ppm)	1.04 b	0.78b	2.10 b	2.27 b	0.08 b	0.09 b	0.105a	0.109a
Soil amendments	CF	1.94 a	1.90 a	4.34 a	4.45 a	0.158a	0.19a	0.160 a	0.185a
	50%FYM	1.40 b	1.41b	3.30 b	3.49 b	0.087c	0.10 d	0.116abc	0.118c
	FYM	1.03 c	0.76 d	2.28 d	2.37 d	0.080d	0.11c	0.071 c	0.076e
	CF+*T.*	1.47 b	1.08 c	2.84 c	3.09 c	0.106b	0.12b	0.127ab	0.123b
	50%FYM+*T.*	0.74 d	0.74 e	1.88 e	2.01 e	0.064 e	0.06e	0.091bc	0.o88 d
	FYM+*T.*	0.54 e	0.50 f	1.22 f	1.43 f	0.047f	0.05 f	0.083bc	0.091 d
Interaction									
Without Si	CF	2.13 a	2.31a	5.04a	5.09a	0.212a	0.293a	0.192a	0.245a
	50%FYM	1.58 c	1.72b	3.44d	3.63d	0.093d	0.092f	0.122ab	0.123c
	FYM	1.01 e	0.92g	2.14h	2.25i	0.081 e	0.125c	0.062b	0.075g
	CF+*T.*	1.54 d	1.42d	3.57c	3.88b	0.092d	0.101e	0.11b	0.111d
	50%FYM+*T.*	1.00 e	1.06f	2.93f	2.99f	0.054h	0.053h	0.092b	0.085 f
	FYM+*T.*	0.71 g	0.67i	2.02i	2.21h	0.07g	0.090f	0.082b	0.085f
Si (300ppm)	CF	1.75 b	1.49c	3.65b	3.81c	0.104c	0.093f	0.127ab	0.124c
	50%FYM	1.22 e	1.11e	3.16e	3.34e	0.081e	0.114d	0.109b	0.112d
	FYM	1.05 f	0.61j	2.43g	2.48g	0.078ef	0.095ef	0.08b	0.077g
	CF+*T.*	1.39 d	0.73h	2.12h	2.31h	0.12b	0.144b	0.143ab	0.135b
	50%FYM+*T.*	0.48 h	0.42k	0.83j	1.02j	0.073fg	0.066g	0.089b	0.091ef
	FYM+*T.*	0.36i	0.34l	0.42k	0.64k	0.023i	0.014i	0.084b	0.096e

CF: 100% chemical fertilizers; FYM: 100% farmyard manure; *T.*: *Trichoderma* inoculation.
Means followed by the same letter(s) within each column are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.05$.

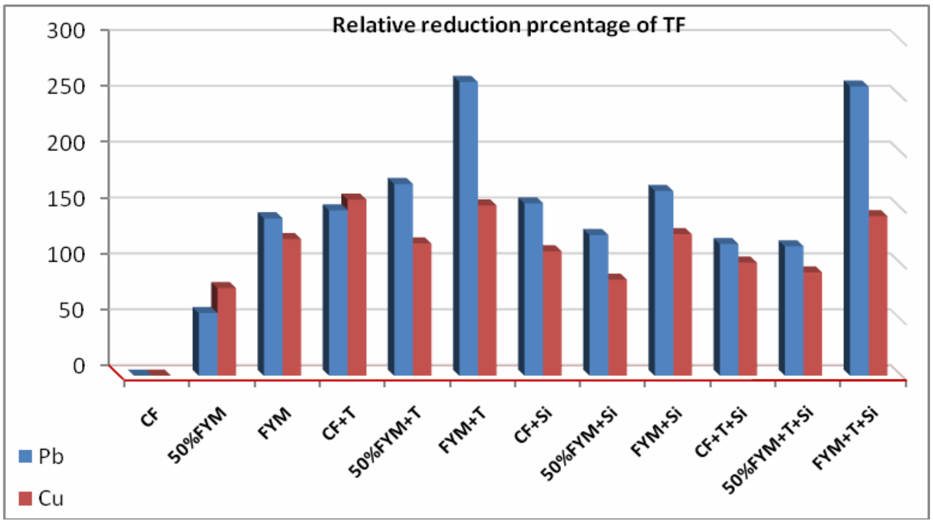

Fig. 2. Relative reduction percentage of Pb and Cu translocation factor for both Pb and Cu to tomato fruits as affected by Si foliar spraying and soil amendments of FYM and *Trichoderma* under contaminated soil soil conditions (average of the two seasons).

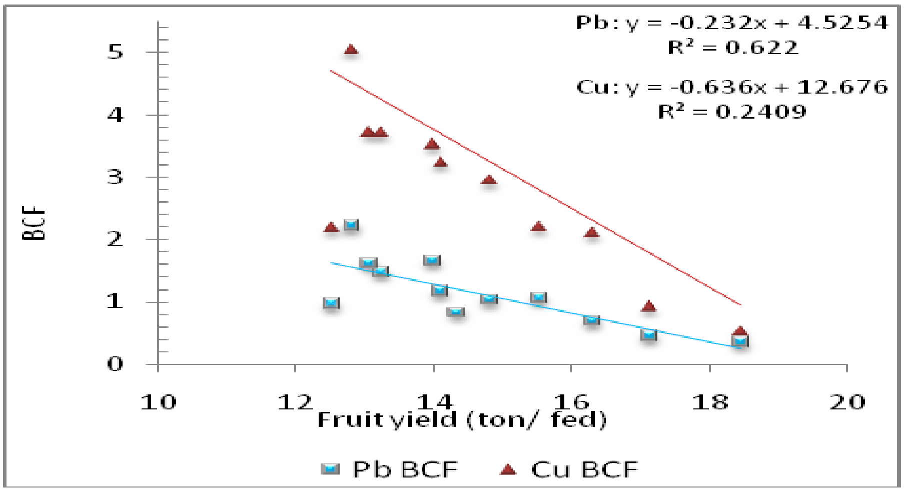

Fig. 3. Correlation between tomato fruit yield (ton/fed.) and BCF of Pb and Cu (average of the two seasons).

Fruit quality

Data in Table 7 indicate that foliar spraying of Si at 300ppm enhanced tomatofruit quality i.e. TSS, acidity and Vitamin C contents as well as taste index, a sensory attribute, under Pb and Cu contaminated soil conditions, except for acidity% in the 1st season where the increment did not reach the significance at 5% level. Concerning soil amendments, Table 7 illustrates that soil amendments with FYM enhanced tomatofruit quality and taste index. The most pronounced one was the treatment of FYM with or without *T.* inoculation, except for acidity % in the 1st season where no significant difference was observed between treatments. It is of interest to mention that tomato fruit is considered tasty when taste index is higher than 0.85(Navez et al.,1999).

The interaction effects also reveal that all assigned treatments improve fruit quality and taste index of tomato plant grown in contaminated soil, except for acidity % and taste index in the 1st season where the difference did not reach to the significant level at 5%. The lowest records were obtained with conventional cultivated plants i.e. chemically fertilized plants. However, the highest records were obtained with organic fertilized plants, especially those inoculated with *T.* and foliar sprayed with 300ppm Si.

Moreover, negative correlations between TF of either Pb or Cu and taste index are shown in Fig. 4. At a confidence level of 95%, the results are significant in both correlations with determination coefficients (R^2) of 0.436 and 0.527, respectively, indicating a reversal of HMs translocation to fruits and fruit taste.

Copper bio- concentration and translocation coefficients were higher than those of lead under experimental conditions of this study may be due to its lower concentration in the soil as previously shown in Table 1 and higher mobility compared with Pb.

In accordance with these results, Stamatakis et al. (2003) and Elkhatib et al. (2017) found that application of Si led to an increase in TSS, vitamin C and Ca in tomato fruits. Hassan et .al. (2017) also foundthat chemical fertilizer rich in soluble nitrogen could cause a decrease in the ascorbic acid content, probably because of increasing the plants' leaf density, which promoted more shading over the fruits. The taste of the fruits as a sensory attribute is an important consumer quality parameter and a difference between conventional and organic fertilized tomatoes could be perceived by smell or taste with high reliability.

Economic Performance

The economic feasibility of tomato grown under Pb and Cu contaminated soil as affected by Si foliar spraying and soil amendments with FYM, mineral fertilizers and *Trichoderma* inoculum during seasons of 2017 and 2018 are presented in Table 8. The obtained results showed that the highest value of both net return (16615 LE. fed^{-1}) and benefit-cost ratio (2.50) was obtained by 100% FYM + *T.* and 300ppm Si foliar spraying, followed by 50% FYM + *T.* and Si application (13715 LE. fed^{-1}) compared with other treatments. Therefore, these treatments are considered more economical for tomato production under the conditions of the present study.

TABLE 7. Tomato fruit quality as affected by silicon spraying and soil amendments of FYM and *Trichoderma* under contaminated soil conditions during seasons of 2017and 2018.

Parameters		TSS (°Brix)		Acidity (%)		VC (mg/100 gfw)		Taste index	
Treatments		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Si Treatment	conrol	4.35 b	4.7 b	0.54 a	0.51 b	22.4 a	22.72 b	0.94 b	0.97 b
	Si (300ppm)	4.85 a	5.4 a	0.55 a	0.57 a	21.3 b	25.7 a	0.99 a	1.04 a
Soil amendments	CF	3.5 e	4.45 e	0.54 a	0.53 c	18.7 f	21.18 e	0.88 f	0.95 e
	50% FYM	4.35 c	4.85 d	0.55 a	0.53 c	21.6 d	23.1 c	0.95 d	0.99 d
	FYM	5.4 a	5.2 b	0.50 a	0.55ab	25.7 a	26.6 a	1.02 b	1.02 b
	CF+*T.*	4.2 d	5.0 c	0.56 a	0.53 c	19.3 e	21.75 d	0.93 e	1.0 cd
	50% FYM+*T.*	4.7 b	5.15 b	0.57 a	0.53 c	22.6 c	25.82 b	0.98 c	1.01 bc
	FYM+*T.*	5.5 a	5.55 a	0.56 a	0.56 a	23.3 b	26.75 a	1.05 a	1.06 a
Interaction									
Without Si	CF	3.4 f	4.1 h	0.52 a	0.50 d	18.3 j	20.13 h	0.85 a	0.91h
	50% FYM	4.2d	4.5 g	0.52 a	0.50 d	21.1 f	22.2 g	0.92 a	0.95g
	FYM	5.3 bc	5.0 e	0.53 a	0.52c	25.4 c	26.13 c	1.03 a	1.0 ef
	CF+*T.*	3.8 e	4.5 g	0.55 a	0.50 d	18.8 i	19.3 i	0.89 a	0.95g
	50% FYM+*T.*	4.3 d	4.6 g	0.56 a	0.50 d	22.9 d	23.47 f	0.94 a	0.96g
	FYM+*T.*	5.1 c	5.3 cd	0.55 a	0.53 c	28.0 a	25.13 d	1.01 a	1.03cd
Si (300ppm)	CF	3.6 ef	4.8 f	0.56 a	0.56 b	19.1 h	22.23 g	0.90 a	0.99f
	50% FYM	4.5 d	5.2 d	0.58 a	0.56 b	22.0 e	24.0 e	0.97 a	1.02de
	FYM	5.5 b	5.4 bc	0.47 a	0.57ab	26.0 b	27.07 b	1.01 a	1.04 cd
	CF+*T.*	4.5 d	5.5 b	0.56 a	0.56 b	19.8 g	24.2 e	0.96 a	1.05 bc
	50% FYM+*T.*	5.1 c	5.7 a	0.57 a	0.58 a	22.2 e	28.17 a	1.01 a	1.07 ab
	FYM+*T.*	5.9 a	5.8 a	0.57 a	0.58 a	18.5 j	28.37 a	1.08 a	1.08 a

CF: 100% chemical fertilizers; FYM: 100% farmyard manure; *T.*: *Trichoderma* inoculation.
Means followed by the same letter(s) within each column are not significantly different according to Duncan's Multiple Range Test at $p \leq 0.05$.

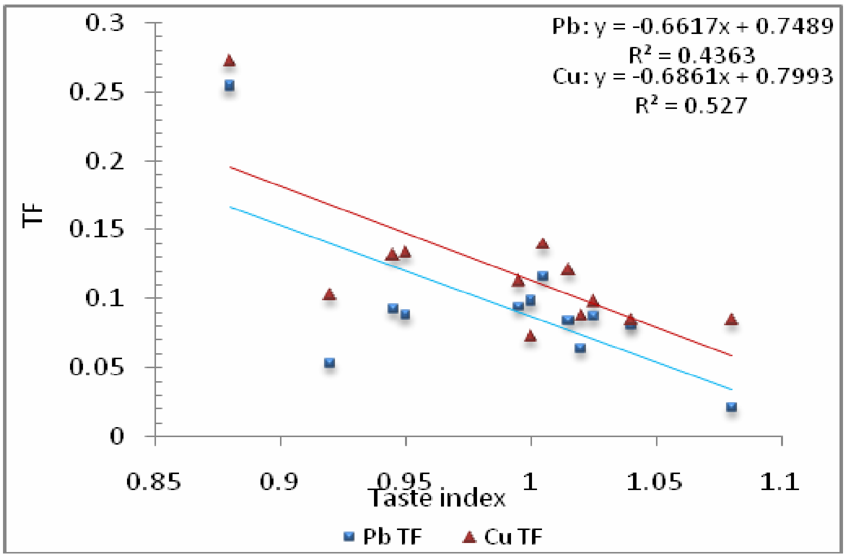

Fig. 4. Correlation between taste index and TF of Pb and Cu in tomato fruit (average of the two seasons).

TABLE 8. Economic feasibility study for tomato cultivation under contaminated soil condition as affected by silicon spraying and soil amendments of FYM and *Trichoderma*.

Treatments	Total yield (ton/fed) (1)	Gross return (£E/fed) (2)	Treat. cost (£E/fed) (3)	Total variable cost (£E/ fed) (4)	Net return (£E/fed) (5)	Benefit cost Rate (6)	Order
100% CF	12.81	19215	3050	12210	7005	1.57	10
50%FYM	13.98	20970	2120	11280	9690	1.86	6
100% FYM	12.52	18780	1200	10360	8420	1.81	8
100% CF+*T.*	13.24	19860	3450	12610	7250	1.57	10
50%FYM+*T.*	14.81	22215	2520	11680	10535	1.90	5
100% FYM+*T.*	16.3	24450	1600	10760	13690	2.27	2
100% CF+Si	13.06	19590	3350	12510	7080	1.57	10
50%FYM+Si	14.1	21150	2420	11580	9570	1.83	7
100%FYM+Si	14.33	21495	1500	10660	10835	2.02	4
100%CF+*T.*+ Si	15.52	23280	3750	12910	10370	1.80	9
50%FYM+*T.*+Si	17.13	25695	2820	11980	13715	2.14	3
100%FYM+*T.*+Si	18.45	27675	1900	11060	16615	2.50	1

(1) tomato yield as average of two seasons, (2) Gross return as yield (ton fed-1) x 1500 LE ton-1, (3) Treatment cost was calculated according to the following prices: Calcium Super phosphate =100 LE / 50 kg, Ammonium nitrate=160 LE /50 kg, Ammonium sulphate= 200 LE / 50 kg, Potassium sulphate= 300LE / 25 kg, Farmyard manure (FYM) =120LE / ton, Si=70LE/kg, (4) Total variable cost (LEfed^{-1}) including: Treatment cost plus land leasehold, transplants, labors and other agricultural practices, which equal nearly 9160LEfed^{-1}. (5) = (2)-(4). (6)= (2)/ (4).

It is noteworthy to draw attention that the Pb contaminated fruits were produced with 100% chemical fertilizer treatment even with the application of *T.* and Si (Fig. 1). Therefore, under the current research conditions, it is advisable not to use the mineral fertilizersforheal thier fruits production.

Conclusion

The concentration of HMs in plants varies depending on plant species, metal physiochemical characters and soil conditions. Under the conditions of the current investigation, the translocation and accumulation rates of Cu were higher than that of Pb. Tomatoes are considered medium tolerant to HMs and at the same time, showed an important phytoremediation potential of contaminated soils by means of HMs phytostabilization preferentially in roots and low translocation rates to the edible organ (fruits). Tomatoes can be effectively, safely and economically produced under Pb and Cu-contaminated clay soil conditions provided some appropriate treatments are followed. Under these conditions, Si, FYM and *Trichoderma* significantly reduced the deleterious effects of HMs on tomato plant growth, yield and fruit quality, particularly HMs content in the fruit. The most effective recommendation was foliar spraying with 300ppm Si and soil amendments with 100% FYM+*T.* to obtain a satisfactory yield with heal thier and good quality fruits.

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التأثيرات المحسنة للسماد العضوى والترايكودرما والسيليكون على إنتاجية الطماطم وجودتها تحت ظروف التربة الملوثة

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اجريت هذه الدراسة خلال فصلى الصيف لعامى ٢٠١٧ و ٢٠١٨ فى مدينة طلخا بمحافظة الدقهلية ، مصر بالقرب من طريق المنصورة- دمياط السريع و شركة الدلتا للأسمدة والصناعات الكيماوية حيث يزيد مستوى كل من الرصاص والنحاس عن الحد المسموح به فى التربه. وكان الهدف من البحث هو تخفيف الآثار الضارة للعناصر الثقيلة على الطماطم (هجين سوبر سترين بى) حيث تم إجراء ١٢ معاملة تمثل التفاعل بين معاملتى الرش الورقى بالسليكون وهما الكنترول (الرش بالماء) و ٣٠٠ جزء فى المليون و ٦معاملات أرضية كما يلى:١٠٠٪ أسمدة كيماوية (CF)، ٥٠٪ سماد بلدى (FYM)، ١٠٠٪FYM ، ١٠٠٪CF + المعاملة بفطر الترايكودرما ٥٠٪ FYM+ الترايكوديرماو ١٠٠٪ FYM + الترايكوديرما .وقد أظهرت النتائج تثبيط العناصر الثقيله لنمو نباتات الطماطم وخفض محصول وجودة الثمار كما تراكمت فى الاجزاء النباتيه الى حد خطير و قد تبع تركيزها الترتيب التنازلى التالى: جذور> أفرع > ثمار للرصاص وأفرع > جذور> ثمار للنحاس. كما أظهرت النتائج أيضا التأثير المحسن للرش بعنصر السليكون و المعاملات الأرضية بمفردهما أو معا على صفات إرتفاع النبات، الوزن الجاف للنبات، محتوى الأوراق من الكلوروفيل الكلى، عددالثمار/النبات،المحصول الكلى/فدان والتأثير المثبط لتركيز كل من الرصاص والنحاس فى أعضاء النبات المختلفة وكذلك لمعامل التركيز الحيوى للعنصر (BCF)ومعامل إنتقال العنصر(TF). وكانت أعلى المعاملات فى هذا الصدد معاملة ١٠٠٪ سماد بلدى+ ترايكودرما + سليكون حيث أدت إلى زيادة العائد .كما لوحظ وجود علاقة عكسية بين محصول الفدان و معامل التركيز الحيوى لكل من الرصاص والنحاس وبين معامل التذوق و معامل إنتقال كل من الرصاص والنحاس. ولقد أعطت معاملة١٠٠ ٪ سماد بلدى +ترايكودرما +سليكون أفضل نمو ومحصول وجودة للثمار فى ظروف التربة الملوثة بالعناصر الثقيلة مقارنة بباقى المعاملات.

الكلمات الدالة : الطماطم، الرصاص، النحاس، معامل التركيز الحيوى ، السماد البلدى، فطر الترايكودرما، عنصر السليكون.