



Accumulation and Translocation of Heavy Metals in Eggplant (*Solanum melongena* L.) Grown in a Contaminated Soil

Mohamed Ahmed Youssef, Asem Mohamed Abd El-Gawad

Department of Soils and Water, Faculty of Agriculture, Al-Azhar University, Assiut, Egypt

Email address:

Dr.mayoussef@yahoo.com (M. A. Youssef), Asem_11111@yahoo.com (A. M. Abd El-Gawad)

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Abstract: A pot experiment was conducted to investigate the effects of the rock phosphate application on accumulation and translocation of heavy metals from the soil to the roots, shoots and fruits of eggplant (*Solanum melongena* L.) grown in a sewage sludge amended soil contaminated with Cd, Pb and Ni were 30, 30 and 60 mgkg⁻¹, respectively. The obtained results demonstrated that the sewage sludge application caused a significance accumulation of metals in the fruits of eggplant. The concentrations of these metals in the fruits were in the order of: Pb > Cd > Ni. The fruits of eggplant were not safe for the human consumption, because the levels of heavy metals exceeded the permissible limits. These, heavy metals in different parts of eggplant can be ranked in the order of: roots > shoots > fruits, were (mgkg⁻¹). The soil-plant transfer factor (TF) showed that the order of uptake of metals by eggplant was: Cd > Ni > Pb. This calls for concern especially in the case of Pb and Cd which are highly toxic and of no known biological use. Therefore, Eggplant should not be cultivated in the farms and fields which use sewage sludge contaminated with heavy metals as an amendment.

Keywords: Translocation, Heavy Metals, Eggplant, Sewage Sludge, Rock Phosphate and Transfer Factor (TF)

1. Introduction

Worldwide environmental pollution is continuously increasing. The soil contaminated with heavy metals like lead (Pb), cadmium (Cd), boron (B), nickel (Ni) chromium (Cr), arsenic (As), molybdenum (Mo)...etc., has serious environmental problems since these metals are non-essential and toxic to plants and animals and have significant implications for human being health [1]. Some industrial emissions and agricultural activities due to various inputs such as fertilizers, metal based pesticides, sewage sludge, phosphorus compounds, insecticides, pesticides, fungicides, herbicides, transportation, tools practically increase the heavy metals level in the substrate [2]. The possible introduction of these elements has contributed to the increasing occurrence of heavy metals in the ecosystem through their direct ingestion from contaminated soils, consumption of vegetables grown on the contaminated soils or drinking wastewater that has percolated through such soils. Thereafter, the food chain (soil-plant-human or soil-plant-animal-human)

is an increasing human health concern through breakdown of cell membrane lipids due to the increased accumulation of reactive oxygen species [3-9].

Vegetables (eggplant, tomato, cucumber and pepper...etc.) constitute an important part of the human's diet. In addition, they are considered as a potential source of important nutrients, carbohydrates, proteins, and vitamins [10]. Eggplant, (*Solanum melongena* L.), is one of the most important vegetables worldwide. It ranks the fourth of world vegetable production after tomato, cucumber, and pepper. According to the Food and Agriculture Organization (FAO), a total production of 32,699,078 million tons of eggplants were produced on an area of 1,957,603 ha in 2008, more than 4 million tons of eggplants were produced on an area of 1,676,893 ha in 2009, and 46.8 million tons worldwide in 2011 [11-13]. In Egypt, eggplant is a common and popular vegetable and a major crop (1.1 million tons) grown in different areas. It is a good source of minerals, like other prominent solanaceous vegetables such as tomato, and hence, it is important for the human nutrition.

Many studies have reported negative or toxicity effects of the heavy metals. They are poisonous for macro and micro-organisms through their direct influence on the biochemical and physiological processes, reducing growth, deteriorating cell organelles, and preventing photosynthesis and in crop plants; they are of great concern due to the probability of food contamination with heavy metals through the soil-root interface [14-15]. Though the heavy metals are not essential for plant growth, they are readily taken up and accumulated by plants in toxic levels causing a toxic damage to cells and tissues as a result of the complex interaction of major toxic ions with other essential or non-essential ions [16-17].

Other sources of anthropogenic contamination (nonpoint) of soils include the applications of organic manures, sewage sludge, and long-term wastewater that cause a great concern. The main source of heavy metals and trace elements in sewage sludge is industrial wastewater and surface water runoff [18-20]. Although sewage sludge is a carrier of nutrients for the plant growth, its continued use over extended periods can have a negative impact on the environment due to content of the polluted organics, such as hormones, antibiotics, endocrine disruptors, and persistent organic pollutants (POP's). as well as toxic low-molecular-weight compounds as polychlorinated biphenyls (PCB), polynuclear aromatic hydrocarbons (PAHs) [21]. Heavy metal compounds that are present in the poorly stabilized sewage sludge, may act as chelating agents that cause toxic metals to be mobilized into the soil solution resulting in the accumulation of heavy metals in soils and their translocation to the various of leafy and other vegetable crops under cultivation, with heavy metals levels that exceed permissible limits [22-24].

Eggplant grown on a soil contaminated with heavy metals absorbs and accumulates metals in roots, shoots, and fruit which might be harmful to human and organisms via the food chain [24]. Heavy metals cause various diseases to human being for example lead causes devastation health such as neurological damage, blood disorder, hypertension and renal impairment [25]. Increasing the heavy metal content in the soil also increases the heavy metal uptake by plants depending upon the soil type, plant growth stage and plant species [26]. Heavy metals absorbed by plant roots may their translocation and easily accumulate into the edible and aerial parts of the vegetables (roots, stems, leaves, fruits and seeds) of the dill, spinach and eggplant with heavy metals. Their content in the different parts of eggplant are arranged as: roots > fruits > stems [27]. The accumulated heavy metals in plant parts depend up on several factors such as plant type, root system, variety, concentrations of heavy metals in the soil and the nature and properties of the soil [28-31].

According to [32] chemical immobilization is an in situ remediation method where inexpensive chemicals are used to reduce contaminant solubility in the soil. Rock phosphate (RP) is used to reduce the bioavailability of the heavy metals (Cd, Ni, and Pb) [33]. The possible mechanisms for heavy metal immobilization in the soil involve both the surface complication of the heavy metal ions on the phosphate grains

and the partial dissolution of the phosphate amendments which precipitate the heavy metal-containing phosphates [34-35]. Also, [36] found that the phosphate-based minerals adsorb, chelate, or/and complex heavy metals in soils which they act as effective heavy metal immobilizing materials. Rock phosphate applications increase its the biomass yield and significantly reduce the availability of the heavy metals (Cd^{2+} , Pb^{2+} and Ni^{2+}) in the soil as well as effectively reduce the bio-accumulation and translocation of these metals in vegetables [37]. Rock phosphate can be used as an economic amendment in heavy metal polluted soils to reduce the contamination risk in surface and subsurface waters and in the same time, it provides the plants with phosphorus [38-45].

This study aims to investigate the effects of adding sewage sludge and rock phosphate on the accumulation and translocation of the heavy metals (Cd, Ni, and Pb) in different organs parts (roots, shoots and fruits) of eggplant, (*Solanum melongena L.*) grown in a contaminated soil.

2. Materials and Methods

A Pot experiment was conducted to investigate the growth and heavy metal uptake by eggplant (*Solanum melongena L.*) grown on a contaminated soil amended with the rock phosphate and sewage sludge. The soil used in the study was collected from the surface (0-30 cm) soil of the Agricultural Experimental, Faculty of Agriculture, AL-Azhar University, Assiut, Egypt, which is located at 27 12' 16.67" N latitude and 31 09' 36.86" E longitude during the summer season of 2017. Some soil properties of the experimental site were determined according to [46] and they are listed in Table 1.

Table 1. Some soil chemical properties of the experimental site.

Parameter	Value	Parameter	Value	
Particle size distribution	Sand(%)	22.28	Total heavy metals (mg kg ⁻¹)	
	Silt(%)	21.51	Cd	0.73
	Clay(%)	56.21	Pb	9.50
Texture grade	Silty clay loam	Ni	7.57	
pH Susp. (1:2.5)	7.96	DTPA-ext. heavy metals (mgkg ⁻¹)		
E. Ce (dSm ⁻¹)	0.96	Cd	0.05	
O.M (%)	1.63	Pb	0.57	
Soluble cations (cmol/kg soil)		Ni	0.08	
Ca ⁺⁺	0.75	Soluble anions (cmol/kg soil)		
Mg ⁺⁺	0.68	CO ₃ ⁻⁻	---	
Na ⁺	0.17	HCO ₃ ⁻	0.47	
K ⁺	0.21	Cl ⁻	0.67	
		SO ₄ ⁻⁻	0.60	

*Each value in this Table is the mean of 3 replicates.

The sewage sludge (SS) sample was collected from the sewage water treatment station at Arab-El-Madabegh, Assiut. The rock phosphate (RP) sample as a natural rock was obtained from Mangabad Super phosphate Factory, Assiut City. Some chemical characteristics of the rock phosphate and sewage sludge samples used in the study are presented in Table (2).

Table 2. Some chemical characteristics of rock phosphate and sewage sludge samples used in the study.

Materials	Total macro elements (%)			Total heavy metal (mg kg ⁻¹)			O.M (%)	E.C (dSm-1)	pH Susp. (1:2.5)
	N	P	K	Cd	Pb	Ni			
Rock phosphate	---	24.82	0.01	0.25	1.18	---	---	2.92	6.36
Sewage sludge	3.86	1.74	0.77	117.39	956.46	503.71	48.61	5.03	8.37

*Each value in this Table is the mean of 3 replicates.

The collected soil, rock phosphate (RP) and sewage sludge (SS) samples were air-dried, crushed with a wooden roller, sieved through a 2 mm and mixed. Plastic pots having 6 kgs of soil sample were prepared before adding rock phosphate and sewage sludge treatments. Two eggplant seedlings (4-5 leaves) of approximately 25 day-old were transplanted into each pot. The seedlings were irrigated and maintained in the pots for 5 weeks to observe their hardiness before adding a heavy metal solution to the pots. Then, the soil in the pots was artificially contaminated with Cd, Ni and Pb solutions of (3CdSO₄.8H₂O, NiSO₄.6H₂O and PbSO₄.9H₂O), respectively, which were applied to the pots in three equal doses each 15 days later. The applied levels of Cd, Ni, and Pb in the solutions were 30, 30 and 60 mg kg⁻¹, respectively.

Eight treatments of: T₁ control (non-contaminated), T₂ (Cd, Ni and Pb), T₃ (20 ton SS/fed.), T₄ (Cd, Ni and Pb+20 ton SS/fed. + 10 ton RP/fed.), T₅ (Cd, Ni and Pb + 40 ton SS/fed. + 10 ton RP/fed.), T₆ (Cd, Ni and Pb + 40 ton SS/fed. + 20 ton RP/fed.), T₇ (Cd, Ni and Pb + 60 ton SS/fed. + 20 ton RP/fed.) and T₈ (Cd, Ni and Pb + 60 ton SS/fed. + 40 ton RP/fed.) were used. The experiment was laid out in a completely randomized design (CRD) with three replication. A supplemental fertilization of N, P and K was applied at 50 % of the recommend level as ammonium nitrate (33.5 % N), superphosphate (15.5 % P₂O₅) and potassium sulphate (48 % K₂O), respectively; ammonium nitrate was applied at three equal doses.

The total fruit yield per pot was recorded at harvest (80 days). At that time root, shoot and fruit samples of eggplant were washed twice using tap water and rinsed using distilled water, oven-dried at 70 °C ground using a stainless steel mill, passed through a 0.5 mm sieve and kept for analysis. Heavy metal concentrations in plant samples were estimated by digesting 0.5g plant sample with a mixture of HNO₃ and

HClO₄ of a 5:1 ratio. The digested samples were cooled and filtered through Whatman No.42 filter papers and the volumes were made up to 100 ml using distilled water. The heavy metals were determined using Flame Atomic Absorption Spectrophotometer (FAAS) according to [47]. Translocation factor (TF) of each heavy metal was calculated to evaluate the risk extent and the relative translocation of these metals from the soil to other plant parts (roots and shoots) according [48].

Statistical analysis was carried out using MS Excel and SPSS software, version 15 the means and standard deviations (SD) of each heavy metal were calculated and differences (p < 0.05) among means were determined using Duncan's Multiple Range Test (DMRT). Pearson's correlation factor (r) for p ≤ 0.05 analysis was done to compare concentrations of the heavy metals in the soil and their accumulation in the roots, shoots and fruits.

3. Results

3.1. Yield Components of Eggplant

3.1.1. Fruit Yield

The data illustrated in Table (3) revealed that statistically significant differences in the average fruit yield of the eggplant existed among the treatments. Among the investigated treatments, the application of sewage sludge alone and heavy metals-sewage sludge mixture overcame in increase fruit yield. Moreover, it was clear that the benefit from application of the rock phosphate-sewage sludge mixture was greater than the application of the sewage sludge only. The results showed that all the treatments were positively affected on the fruit yield per pot compared to control T₁.

Table 3. Effect of the heavy metals, rock phosphate, and sewage sludge on fruit yield and yield component of Eggplant.

Treat.	Fruit yield (g/pot)	Roots (g/plant)		Shoots (g/plant)		Fruits (g/plant)	
		Fresh W.	Dry W.	Fresh W.	Dry W.	Fresh W.	Dry W.
T1	109.07d	3.49e	0.94e	7.31a	1.32a	43.63e	5.34a
T2	113.71d	7.24e	1.43e	16.22b	2.63a	47.38e	6.86a
T3	159.20c	24.84f	4.89f	48.32d	7.81b	64.98d	9.65b
T4	170.38c	27.91f	5.84f	52.15d	8.86b	68.05d	9.86b
T5	213.28b	47.63g	9.45b	98.01f	15.81c	67.77d	10.06b
T6	220.69b	49.21g	9.87b	99.32f	16.07c	89.35f	12.71d
T7	286.23a	77.65c	15.32a	153.41g	23.11d	117.79g	16.98e
T8	291.59a	78.17c	16.04a	157.71g	25.13d	118.31g	17.82e

Mean values in the same column followed by the same letters are not significantly different according to the Duncan's multiple range test (P < 0.05).

Sewage sludge applications led to a greater fruit yield at all application levels (20, 40 and 60 ton SS/fed.). The highest fruit yield (291.59 g/pot) was obtained with application of

treatment T₈ which increased the average fruit yield by 166.76% compared to the control, the applied sewage sludge associated with its enrichment with the plant essential

nutrients (both macro and micronutrients) that is important for the plant growth. The lowest fruit yield (113.71 g/pot) was recorded for treatment T₂ which increased the average fruit yield by 4.25% compared to the control. Some authors mentioned significant differences in the fruit yield of the eggplant between the applied sewage sludge and the control.

3.1.2. Fresh and Dry Weight of the Plant Parts

The fresh and dry weights of the various parts (shoots, roots and fruits) of eggplant as affected by the different treatments are given in Table 3. The result showed that there were significant ($p < 0.05$) variations in the shoots, roots and fruits fresh and dry weight among the applied treatments they were greatly enhanced by sewage sludge application treatment. However, there were no significant ($p > 0.05$) variations by the application rates of rock phosphate with sewage sludge. All treatments increased the fresh and dry weights of the various parts of the eggplant. The application of T₈ gave the highest fresh and dry weight biomass in all plant parts; fresh root weight of 78.17 g/plant, a dry root weight of 16.04 g/plant, a fresh shoot weight of 157.71 g/plant, a dry shoot weight of 25.13 g/plant, a fresh fruit weight of 118.31 g/plant and a dry fruit weight of 17.82 g/plant. Other treatments were affected by heavy metal accumulations in plants due to the high sewage sludge level

had a tendency for higher heavy metal accumulation since the plant biomass was increased with increasing the sewage sludge application rate. However, the lowest values of fresh and dry weight of biomass in all plant parts were obtained from T₂.

3.2. Cadmium Contents of the Soil and Eggplant Parts

The mean total concentrations of cadmium (Cd) in the soil, roots, shoots, and fruits (edible part) of eggplant are given in Table (4). Permissible limits of heavy metals in the soil and vegetables (eggplant) are used in this study including, International guidelines [49-50] standards have been used for the comparison of the results.

3.2.1. Soil Cadmium Contents

The concentrations of Cd in the treated soil samples were generally higher than the permissible limits (PL) except for those T₁ (0.75 mg kg⁻¹) and T₃ (1.86 mg kg⁻¹) treatments (Table 4) that were lower than the PL of Cd (3 mg kg⁻¹). It is clear that T₂, T₄, T₅, T₆, T₇ and T₈ treatments exhibited a higher soil Cd contents compared to the control of T₁ and T₃. Their concentrations of soil Cd were higher than the toxic limit due to the application of 30 mg kg⁻¹ of Cd in the investigated treatments.

Table 4. Effect of rock phosphate and sewage sludge on soil and eggplant part Cd contents and its transfer factor (T.F).

Treat.	Soil Cd (mg kg ⁻¹)	Plant Cd (mg kg ⁻¹) Dry wt.			Cd transfer factor		
		Roots	Shoots	Fruits	Soil - Root	Root - Shoot	Shoot - Fruit
T1	0.75±0.02f	0.16±0.04f	0.10±0.02e	0.07±0.01e	0.21±0.05b	0.66±0.12a	0.65±0.06a
T2	27.95±1.15e	9.08±0.83e	3.05±0.33c	0.31±0.04c	0.33±0.03b	0.34±0.06c	0.10±0.03b
T3	1.86±0.39f	1.03±0.99a	5.54±0.55a	0.48±0.03a	0.55±0.04a	0.47±0.06b	0.09±0.01bc
T4	30.16±0.85d	10.41±0.87bc	4.98±0.19ab	0.18±0.02d	0.34±0.02b	0.48±0.04b	0.04±0.00ed
T5	31.24±0.09cd	9.87±0.04cd	4.78±0.31b	0.33±0.01c	0.32±0.00b	0.48±0.03b	0.07±0.01bcd
T6	31.64±0.41bc	8.30±0.89e	2.17±0.24d	0.10±0.02e	0.26±0.03b	0.26±0.02c	0.05±0.01ede
T7	32.55±0.64ab	11.14±0.31ab	5.26±0.59ab	0.42±0.04b	0.34±0.01b	0.47±0.06b	0.08±0.00bcd
T8	33.14±1.01a	10.21±0.07acd	4.83±0.10b	0.09±0.01e	0.31±0.01b	0.47±0.01b	0.02±0.00e
PL*	3-6	0.1-1.5			nd	nd	nd

Mean of (n=3) ± Standard Deviation, within column followed by the same letters are not significantly different according to Duncan's multiple range test ($P < 0.05$).

* Permissible Limits (PL) Guideline of EU, (2006) and WHO/FAO, (2007).

3.2.2. Plant Part Cadmium Contents

The Cd contents of eggplant ranged from 0.16 to 11.14 mg kg⁻¹ in the roots, from 0.10 to 5.54 mg kg⁻¹ in the shoots and from 0.07 to 0.48 mg kg⁻¹ in the fruits sample (Table 4). The content of Cd of eggplant fruits in all treatments were above the critical limits (0.1-1.5 mg kg⁻¹) and thus they might be a threat for the consumers. The results showed that the plants absorbed Cd easier from T₃ treatment soil than the control reflecting the ease mobility of Cd in this treatment. There were significant variations ($p < 0.5$) in the plant of Cd contents when the soil was contaminated with sewage sludge.

In all the parts (roots, shoots and fruits) of eggplant, the mean contents of Cd values are ranked in the order of roots > shoots > fruits. Cadmium in all plant parts reached levels that were higher than the maximum PL (0.1 mg kg⁻¹).

3.2.3. Transfer and Translocation Factors

The transfer factor (TF) or mobilization ratio of Cd from the soil to eggplant roots (TSR) and this translocation factor of Cd from roots to shoots (TRS) and from shoots to fruits (TSF) were calculated and shown in Table (4). The average TF of Cd content from the soil to eggplant roots (TSR) was found to be in the order of T₃ (0.55) > T₄ (0.34) = T₇ (0.34) > T₂ (0.33) > T₅ (0.32) > T₈ (0.31) these values were higher compared to control (0.21). It could be attributed to their relative translocation rate of Cd roots of eggplant increased in all treatments with increasing of concentrations of Cd soil to very high levels of Cd are accumulated by the plants. In case of the translocation factor from roots to shoots (TRS), it was in the order of T₄ (0.48) = T₅ (0.48) > T₃ (0.47) = T₈ (0.47) = T₇ (0.47) > T₂ (0.34) > T₆ (0.26). The TF from shoots to fruits (TSF) exhibited highest values of 0.33, 0.10 and 0.09 Cd in T₁, T₂, and T₃ treatments, respectively. However, the

lower TF value from shoots to fruits (0.04) for Cd was recorded T₄ and T₈ treatments. Regarding the translocation of heavy metals from roots to the aerial parts of the plants, some heavy metals, such as Cd, move easily in plants and retain less strongly in the soil and hence they are more mobile than other metals.

3.3. Lead Contents of the Soil and Eggplant Parts

The mean concentrations of lead (Pb) (mg kg⁻¹) in the soil as well as in the roots, shoots and fruits of eggplant are given in Table 5.

Table 5. Effect of rock phosphate and sewage sludge on soil and eggplant part Pb contents and its transfer factor (T.F).

Treat.	Soil Pb (mg kg ⁻¹)	Pb (mg kg ⁻¹) Dry wt.			Pb transfer factor		
		Roots	Shoots	Fruits	Soil - Root	Root - Shoot	Shoot - Fruit
T1	10.89±0.67g	3.12±0.23e	0.88±0.08d	1.22±0.05e	0.29±0.03f	0.28±0.02a	1.39±0.13a
T2	55.50±0.49e	30.00±1.64d	3.41±0.32a	5.09±0.30b	0.54±0.03e	0.11±0.01b	1.50±0.18a
T3	22.28±0.50f	42.70±0.81a	3.83±0.27a	5.98±0.24a	1.92±0.02a	0.09±0.00c	1.56±0.05a
T4	58.36±0.57d	39.09±0.61b	1.41±0.10c	1.96±0.23d	0.67±0.00bc	0.04±0.00e	1.40±0.24a
T5	59.99±1.45c	41.00±1.74ab	3.82±0.20a	5.28±0.55b	0.68±0.04b	0.09±0.01c	1.38±0.07a
T6	61.29±0.67bc	35.12±2.69c	1.25±0.28cd	2.10±0.22d	0.57±0.05de	0.04±0.01e	1.78±0.55a
T7	62.40±0.49ab	38.70±1.64b	2.71±0.33b	4.30±0.49c	0.62±0.03cd	0.07±0.01d	1.61±0.34a
T8	63.20±0.85a	35.21±0.08c	1.17±0.14cd	2.16±0.08d	0.56±0.01e	0.03±0.00e	1.85±0.19a
PL*	100-300	0.3 – 5.0			nd	nd	nd

Mean of (n=3) ± Standard Deviation, within column followed by the same letters are not significantly different according to Duncan's multiple range test (P < 0.05).

* Permissible Limits (PL) Guideline of EU, (2006) and WHO/FAO, (2007).

3.3.1. Soil Lead Contents

The concentrations of Pb in all treated the soil samples were generally lower than the Permissible Limits of Pb (100 mg kg⁻¹). On the other hand, in all parts of eggplant, Pb levels were higher than the PL which is (0.3 mg kg⁻¹). The results clearly exhibited that soil samples treated with T₈ and T₇ exhibited Pb contents of 82.55 and 82.77 % above the control, whereas the Pb contents of T₂, T₃ and T₄ treated soil samples were near the control, high concentrations of Pb in all soil treatments might be due to high contents of Pb in the soil caused by the application of sewage sludge.

3.3.2. Plant Part Lead Contents

In general, the increase Pb in the parts (roots, shoots and fruits) of eggplant was consistent with the Pb concentration in the soil. The results showed that lead content of eggplant grown in T₃ amended soil was higher than that of the control due to the higher available Pb concentration in the T₃ treated soil higher.

The content of Pb in the fruit (edible part) of eggplant samples were above the PL and thus it might be a threat for the consumers. The highest Pb level in the edible part (5.98 mg kg⁻¹) that is above the PL was recorded for T₃ treatment. At the same time, the Pb concentration in fruits was 2 times higher than the maximum permissible limit; there were significant variations (p < 0.5) in the plant Pb content when the soil was amended with sewage sludge. Vegetables have greater potential for accumulating Pb in their edible parts than other crops, due to their higher transpiration rate [25]. In all eggplant parts (roots, shoots and fruits), on the basis of the mean values, the Pb concentration in the different parts of eggplant can be arranged in the order of roots > fruits > shoots. Lead reached a higher level than that PL. The results showed that the highest concentration of Pb in eggplant parts was found in the roots.

3.3.4. Transfer and Translocation Factors

On the basis of these results, the translocation factor (TF) value allows the estimation of the capacity of the studied plants to absorb Pb from the soil. It also reflects the quantity and movement speed of Pb from soil application of various sludge doses to the above-ground parts of plants. In naturally Pb contaminated soil, the soil to root and root to shoot TF values increase with decreasing the Pb concentration in the soil. The TF of Pb from the soil to root (TSR) showed a higher value (1.92) with T₃ treatment. It was lower for all treatments in this soil that could be attributed to their relative transpiration rate of Pb. The lowest TF value of (0.29) was found the control (T₁). The root to shoot translocation factor (TRS) of Pb had the highest value (0.28) for T₁ and lowest one (0.03) for T₈. The shoot to fruit translocation factor (TSF) of Pb was the highest value (1.85) in the plants grown in the T₈ treated soil and the lowest TF value (1.38) in those grown in T₅ treated soil. [36] indicated that RP can reduce the phytoavailability of Pb in the soil due to Pb immobilization. Lead contents of both roots and shoots significantly decreased with increasing the applied level of RP. Regarding the translocation of heavy metals from roots to the aerial parts of the plants, some heavy metals, such as Pb, move easily in plants and retain less strongly in the soil and hence they are more mobile than other metals. In addition, eggplant in this research may be used in the heavy metal phytoremediation because its TF values were higher than 1, especially in case of shoot to fruit.

3.4. Nickel Contents of the Soil and Eggplant Parts

The mean concentrations of nickel (Ni) in the soil as well as in the roots, shoots and fruits of eggplant are shown in Table 6.

Table 6. Effect of rock phosphate and sewage sludge on soil and eggplant part Ni contents and its transfer factor (T.F).

Treat.	Soil Ni (mg kg ⁻¹)	Ni (mg kg ⁻¹) Dry wt.			Ni transfer factor		
		Roots	Shoots	Fruits	Soil - Root	Root - Shoot	Shoot - Fruit
T1	6.28±0.28e	0.15±0.03c	0.04±0.01e	0.01±0.01f	0.02±0.01b	0.28±0.10a	0.37±0.26c
T2	34.38±1.99c	3.17±1.20b	0.25±0.04c	0.07±0.01e	0.09±0.04b	0.09±0.04b	0.30±0.03c
T3	8.55±0.68d	4.82±1.22a	0.36±0.07a	0.19±0.01a	0.57±0.17a	0.08±0.04b	0.54±0.07c
T4	38.49±1.32b	2.51±0.43b	0.32±0.01de	0.12±0.01bc	0.07±0.01b	0.02±0.01b	0.37±0.49a
T5	39.12±1.13b	3.31±0.38b	0.28±0.01bc	0.09±0.01de	0.08±0.01b	0.09±0.01b	0.32±0.03c
T6	38.19±0.21b	2.95±0.04b	0.09±0.02d	0.04±0.01f	0.08±0.00b	0.03±0.00b	0.41±0.12c
T7	39.23±0.45b	3.60±0.31b	0.31±0.02ab	0.14±0.02b	0.09±0.01b	0.09±0.01b	0.44±0.06c
T8	41.61±1.33a	2.36±0.23b	0.17±0.01de	0.11±0.03cd	0.06±0.01b	0.03±0.00b	0.65±0.36b
PL*	75 -150	0.4 - 2.5			nd	nd	nd

Mean of (n=3) ± Standard Deviation, within column followed by the same letters are not significantly different according to Duncan’s multiple range test (P < 0.05).

* Permissible Limits (PL) Guideline of EU, (2006) and WHO/FAO, (2007).

3.4.1. Soil Nickel Contents

The concentrations of Ni in all treated soil samples were generally lower than the PL of Ni (75 mg kg⁻¹). The results clearly indicate that the highest soil concentration of Ni was recorded for T₈ treatment which was 84.91 % above the control, high concentrations of Ni in the soil treatments might be due to high contents of Ni in the applied sewage sludge. The lowest soil concentration of Ni was obtained from T₃ treatment.

3.4.2. Plant Part Nickel Contents

The Ni contents in all parts of eggplant Ni was lower than its PL which is (0.4 mg kg⁻¹) except Ni in roots that was higher than the PL. The results also, showed that Ni content in all parts of eggplant that was grown in T₃ treated soil was higher than that of the control. [50] studied the impact of sewage sludge on Ni of the soil, vegetables edible portions. Found the Ni content of the aerial parts of vegetables grown in T₃ treated soil was lower than that of the roots it was 13 times above the PL of Ni. In all parts of eggplant, the mean values of Ni can be arranged in the order of roots > shoots > fruits. Nickel reached a higher level than PL. the highest concentration of Ni in eggplant parts was observed in the roots.

3.4.3. Transfer and Translocation Factors

The translocation factor (TF) of Ni is an indicator that helps to understand the mobility of Ni in plants [51]. In this study, all TF values (TSR), (TRS) and (TSF) of eggplant were lower than 1 (Table 6) means that Ni had a low transfer from roots to shoots

and from shoots to fruit of eggplant. The TF of Ni for TSR showed a higher value (0.57) for T₃ treatment. It had lower values in all investigated treatments due to their relative transpiration rate Ni. It exhibited the lowest value (0.02) in the control (T₁). A higher value of TSF (0.28) was found in the plant grown on treated soil T₁ and a lowest value (0.02) in those grown in T₄ treated one. The higher value of TSF (0.65) was found in the plants grown on the T₈ treated soil and lowest one (0.32) was in those grown on T₅ treated one. [52] studied that phytoremediation potential of three plants grown in contaminated soil and found that all TF values were lower than 1. So, eggplant could be grown on Ni contaminated soils because due to their lower TF values than 1 in all plant parts. The content of Ni in eggplant roots samples were above the PL. It may be dangerous for consumption. The highest Ni content of the roots (4.82 mg kg⁻¹) was recorded for T₃ treatment. At the same time, it was 12 times higher than the maximum permissible limits.

3.5. Evaluation of the Cd, Pb and Ni Contamination in the Studied Soil

Metals in soils exert a decisive impact on the quality of soil and its use in food production. [53] used the contamination factor (CF) and the degree of contamination (DC) to asses soil contamination through comparing the mean metal concentration of soil to the mean metal background value. Four contamination categories were defined according to [54].

Table 7. The soil contamination factor of Cd, Pb and Ni as affected by rock phosphate and sewage sludge applications.

Treat.	Evaluation of soil Cd		Evaluation of soil Pb		Evaluation of soil Ni	
	Contamination factor	Degree of contamination	Contamination factor	Degree of contamination	Contamination factor	Degree of contamination
T1	0.00±0.00	---	0.00±0.00	---	0.00±0.00	---
T2	37.12±1.53e	VC	5.09±0.05e	CC	5.47±0.32c	CC
T3	2.47±0.52f	MC	2.05±0.05f	MC	1.36±0.11d	MC
T4	40.06±1.12d	VC	5.36±0.05d	CC	6.13±0.21b	VC
T5	41.49±0.11cd	VC	5.51±0.13c	CC	6.23±0.18b	VC
T6	42.01±0.55f	VC	5.63±0.06bc	CC	6.08±0.03b	VC
T7	43.23±0.85ab	VC	5.73±0.05ab	CC	6.24±0.07b	VC
T8	44.02±1.37a	VC	5.80±0.08a	CC	6.62±0.21a	VC

*Mean of (n=3) ± Standard Deviation, within column followed by the same letters are not significantly different according to Duncan’s multiple range test (P < 0.05).

**Low contamination (LC) = CF< 1, moderate contamination (MC) = 1 ≤ CF<3, considerable contamination (CC) = 3 ≤ CF<6 and very high contamination (VC) = CF ≥ 6.

Data in Table (7) show the contamination factor (CF) of Cd, Pb and Ni in all treated soil sample which the CF of Cd ranged from 2.47 to 44.02. In these soil samples, the CF of Pb varied from 2.05 to 5.80 and that of Ni had the range of 1.36 to 6.62. Therefore, the results clearly showed that the highest contamination degree of Cd, Pb and Ni was found in the T8 treated soil sample.

4. Discussion

The data illustrated in Table (3) indicated that the highest fruit yield as the application of the sewage sludge may be its enrichment with the plant essential nutrients that is important for the plant growth. The results are in agreement with [55, 27]. However, the lowest values in all plant parts were obtained when soils contaminated with heavy metals alone. [56] found that the application of 7.5 and 15.0 kg/m² of sewage sludge increased the biomass of the above ground plant parts. These results are consistent with those reported by [26, 30 - 31]. As well as through the data in Table (4) showed that the vegetables grown in soils contaminated with heavy metals have a greater accumulation of heavy metals than those grown in uncontaminated soils [24]. Sewage sludge applications are considered the main inputs of Cd to agricultural soils, [57]. These results are comparable with those other earlier studies of [41-42, 44-45].

Cadmium in all plant parts exceeded limits allowed by an increase with 8 times higher than the maximum permissible limits in the roots. It is considered a mobile element, easily absorbed by roots, transported to shoots and uniformly distributed in plants [58]. The results showed that the highest concentration of Cd in the eggplant was observed in the roots, especially in the soil amended with T₃. In this corresponding, the Cd concentrations in the shoots and roots of various vegetable crops increased with the increasing Cd concentrations in the growth medium. Moreover, roots Cd increased more sharply than shoot one. These results agree with those of [59, 27]. These might be due to the higher mobility of Cd with a natural occurrence in the soil [60]. Also, [36] reported that the addition of rock phosphate (RP) significantly decreased metal contents in both roots and shoots of *Lolium prene* L, which may be an indirect evidence for the PR mechanism in immobilizing heavy metals. As for the translocation of heavy metals from roots to the aerial parts of the plants, most heavy metals are quickly moved from roots to shoots and its retainer less strongly in the soil. These results coincide with those of [61-62, 45, 56]. In addition, in this study, eggplant should not be used in the heavy metal phytoremediation because its TF values were lower than 1 and it might not be safe for human consumption. Moreover, [63] indicated that the variations in the transfer factor among different vegetables may be attributed to the differences in the contents of metals in the soil and differences in element uptake by different vegetables.

As for the Pb in Table (5) it was found that the higher the concentration, roots > fruits, [50] found that the

concentration of Pb in the edible portions of some vegetables grown on sewage sludge amended soil was above the safe limit in 28 % of the samples. The present results are in an agreement with those of [64, 24, 66, 27]. The reduction in shoot Pb concentration may be connected with the plant growth stimulation by Pb and the subsequent dilution of Pb in the plant tissue as well as the translocation the inhibition of Pb from roots to the shoots. [45] showed that rock phosphate is a potential remediation material for Pb contaminated soils through the significant reduction of bioaccumulated and translocated Pb in the plant tissues. This finding is comparable with that of [59, 27]. And the translocation of heavy metals from roots to the aerial parts of the plants. These results coincide with those of [61, 65, 45, 56]. Moreover, [63] reported that the variations in the transfer factor among different vegetables may be attributed to the differences in the contents of metals in the soil and differences in element uptake by different vegetables.

Regarding the Ni shown in Table (6) found that the lowest soil concentration of Ni and aerial parts of eggplant grown in 20 ton SS/fed. treatment. [37] found that the solubilization concentration of Ni in soils decreased with increasing the added amount of rock phosphate, these results also agree with those of [5-6, 66, 7, 2, 11, 17, 9].

In all parts of eggplant, the mean values of Ni can be arranged in the order of roots > shoots > fruits. Nickel reached a higher level than PL. the highest concentration of Ni in eggplant parts was observed in the roots. It may be attributed to the microbial activity around in the roots. Similar results were reported by many scientists [59, 28, 25, 57, 67, 30-31].

It's finally illustrated that the mean concentrations of Pb in the studied soil samples were lower than those of [49-50] permissible limits (PL) of agricultural soils, the concentrations of Pb in the eggplant fruits were higher than the plant (PL).

5. Safety of Consumers

The PL [49-50] for Cd, Pb and Ni in plants had a range of 0.1-1.5, 0.3-5 and 0.4-2.5 mg kg⁻¹ dry weight, respectively. The results of Cd, Pb and Ni concentrations in fruits were shown in Tables (4, 5 and 6) for all treatments. The highest Cd, Pb and Ni concentrations in the fruits were 0.48, 5.98 and 0.19 mg kg⁻¹ dry weight fruit, respectively in the plants grow in T₃ treated soil. Both Cd and Pb concentrations in fruits exceeded the standards. Thus, consumers should not eat eggplant grown on Cd, Pb and Ni contaminated soils, cadmium Cd contaminated vegetables are known to result in bone fracture, diarrhea, stomach pains and severe vomiting, reproductive failure, damage of central nervous system and DNA, as well as development.

6. Conclusion

Soil contamination associated with sewage sludge

additions increases the levels of Pb, Cd, and Ni intake of the vegetables and soils. Monitoring of heavy metals in vegetables tissues is essential in order to prevent excessive build-up of these metals in the human food chain. This study was conducted to investigate the heavy metals content in a sewage sludge amended soil and eggplant grown on this soil. The results indicated that the Pb, Cd, and Ni levels in the sewage sludge amended soil were higher than the safety limits. The levels of Pb and Ni in soil samples were lower than the PL but in eggplant, the content of Pb and Cd were higher than the permissible limits. It heavy metals may be absorbed directly from sewage sludge whereas their accumulation in soil is relatively slow. The concentration of Pb and Cd was more in the roots than fruits. The Pb and Cd levels in plant parts were arranged in the order of roots > shoots > fruits. The lead and cadmium were highly toxic metals and could be accumulated and transferred to the food chain. It is recommended that the retention of the heavy metals by the rock phosphate application in the contaminated soils could reduce their contamination risk in the edible portions of vegetables.

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