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Article

The impact of the investment period on soil and plant pollution by cadmium and nickel in Jableh city, in Lattakia Governorate

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Abstract

This research was conducted in Jableh city in the Latakia Governorate during 2019–2020 to study the level of pollution of the soils and plants of some greenhouses in Jableh city with the elements cadmium and nickel. Several greenhouses were randomly distributed in different areas in Jableh city based on the period of their investment (5, 10, 20, and 25 years), as the investment period was considered the variable factor between greenhouses. The homogeneity of greenhouse texture was taken into consideration as much as possible. Two-layer soil samples were collected (0–20 and 20–40 cm). Electrical conductivity, pH, the ratio of organic matter and the major basic elements (nitrogen, phosphorus, and potassium), and the total cadmium and nickel in the soil, plants, and cucumber fruits were determined. SPSS was used (completely randomized design). The results showed that there was pollution of greenhouse soils with the elements cadmium and nickel in a manner that is proportional to the increase in the period of investment. They also showed that the content of cadmium and nickel in cucumber fruits in the oldest houses exceeded the permissible limits. A strong positive second-degree significant (1%) correlation was observed between the available phosphorus and the total cadmium and nickel in the soil, and a strong correlation between the soil and plant content of these two elements and an increasing investment period.

Key words: greenhouses, pollution, cadmium, nickel, cucumber, Jableh

Résumé

En 2019–2020, les auteurs ont étudié le degré de pollution du sol et de la végétation par le cadmium et le nickel dans quelques serres de la ville de Jableh, dans le gouvernorat de Lattaquié. Des serres ont été choisies de façon aléatoire dans la cité, en fonction de la durée de l'investissement (5, 10, 20 ou 25 ans), ce paramètre étant considéré comme la variable applicable à ce type d'ouvrage. Les auteurs ont choisi des serres aussi homogènes que possible. Ils ont ensuite échantillonné le sol à deux profondeur (0–20 et 20–40 cm), puis déterminé la conductivité, le pH, la proportion de matière organique et celle des éléments de base (azote, phosphore et potassium), ainsi que la concentration totale de cadmium et de nickel dans le sol, les plantes et le fruit du concombre. Le programme SPSS (en mode entièrement aléatoire) a été retenu pour l'analyse statistique. Les résultats indiquent que la contamination du sol des serres par le cadmium et le nickel augmente proportionnellement avec la durée de l'investissement. On constate aussi que, dans les serres les plus anciennes, le teneur du concombre en cadmium et en nickel dépasse le seuil de tolérance. Les auteurs ont noté une nette corrélation significative (1 %) du deuxième degré entre la quantité disponible de phosphore et la concentration totale de cadmium et de nickel dans le sol, de même qu'une forte corrélation entre la teneur de ces deux éléments dans le sol et les plantes et l'augmentation de la durée de l'investissement. [Traduit par la Rédaction]

Mots-clés : serres, pollution, cadmium, nickel, concombre, Jableh

1. Introduction

Heavy metals are considered one of the most troublesome environmental pollutants due to their widespread, persistent toxicity and bioaccumulation in the food chain that severely threaten human health and environmental safety (Kabata-Pendias and Mukherjee 2007). It is difficult to avoid the accumulation of heavy metals in the soil resulting from increased agricultural production and human activities such as excessive use of mineral fertilizers, the addition of animal waste, irrigation with untreated sewage, and atmospheric sedimentation (Bai et al. 2015). Agriculture in greenhouses plays an important role in the production of vegetables and some economic crops outside the time of their normal growth, but compared with field agriculture, the high productivity

Table 1. Mechanical composition of control and greenhouse soils.

Depth	Mechanical composition	Control	Dwar Al Khateeb	Al Edyiah	Al Zuhairat	Al Burjan	Ras Al Ain
0–20	Sand	64.30	42.30	50.30	78.30	62.30	76.30
	Silt	15.70	25.70	21.70	13.70	19.70	11.70
	Clay	20.00	32.00	28.00	8.00	18.00	12.00
	Texture of soil	SCL	CL	SCL	LS	SL	SL
20–40	Sand	62.80	40.30	44.30	77.90	64.30	74.30
	Silt	15.20	25.70	26.70	13.00	15.70	11.70
	Clay	22.00	34.00	29.00	9.00	20.00	14.00

Note: SCL, sandy-clay loam; CL , clay loam; LS, loamy sand; SL, sandy loam.

in these greenhouses is maintained through intensive agriculture, diversification of crops, and the excessive use of chemical fertilizers. The problem of contamination of agricultural soils in greenhouses with heavy metals is one of the main environmental problems at present due to the addition of great quantities of chemical fertilizers to achieve high productivity (Gruda 2005), with these additions estimated to be 2–3.4 t/ha/year, in addition to the consumption of large quantities of pesticides (200 kg/ha/year) (Gil et al. 2004). These large additions of chemical fertilizers and pesticides in greenhouses compared with agricultural land degrade the chemical properties of the soil through increased soil acidity (Darilek et al. 2009), soil salinization (Kaplan et al. 2000), and accumulation of heavy metals in the soil (Martín et al. 2013) and an increase in the residual effect of pesticides in the soil (Murugan et al. 2013). The accumulation of heavy metals in the soil indirectly affects human health through their accumulation in foodstuffs, which makes them harmful and sometimes even toxic and not suitable for human consumption. Therefore, interest has begun to increase in the problem of heavy metal accumulation in greenhouse soils (Manzoor et al. 2018).

Research on the sources of heavy metal contamination of greenhouse soils is still limited. Some research has relied on the pollution index and geochemical accumulation factors to distinguish between natural sources of pollution and exogenous sources of human activity (Tomlinson et al. 1980; Müller and Anke 1994; Sterckeman et al. 2006; Bourennane et al. 2010). Therefore, to avoid the risks of accumulation of these metals in greenhouse soils, and to achieve sustainability in the use of agricultural soils in greenhouses, it is crucial to study and evaluate the level of these heavy metals in the soil and plants, the extent of their toxicity, and the knowledge of their potential sources.

2. Research justifications

Recently, reliance on protected agriculture has begun to a large extent in some areas of the Syrian coast, including the Jableh region, but this has been accompanied by excessive and irrational use of chemical fertilizers and agricultural pesticides without taking into account the negative effects of these agricultural practices on the chemical properties of the soil and the quality of agricultural products, to make a quick profit for the farmer (the investor) while disregarding all health, ethical, and technical considerations for the use of chemical compounds in agriculture.

3. Research objectives

The objective of this study was evaluation of the content of and pollution with cadmium and nickel of the soils, plants, and cucumber fruits in some greenhouses in Jableh city.

4. Materials and methods

4.1. Study area

The study was conducted on some greenhouses in Jableh city, which is located in Lattakia Governorate in northwestern Syria (35.36°N, 35.93°E), 25 km south of Lattakia, with an area of 91.51 km^2. The city overlooks the Mediterranean Sea and rises 26 m above sea level.

4.2. Climatic conditions

Jableh region is subject to a Mediterranean climate, which is characterized by relatively hot summers and rainy winters. Snow falls on its mountains in the winter, and the rainfall rate is 825 mm/year.

4.3. Soil

The greenhouses' soil is calcareous soil transferred from the Banias region, which Van Leer called the Mediterranean red soil, Mollisol (Van leer 1965), taken at a depth of 0–40 cm and mixed with the surface layer of the greenhouses' soil in different proportions from one greenhouse to another.

4.4. Study methodology

Several greenhouses distributed randomly in different areas of Jableh city were selected based on the period of investment (5, 10, 20, and 25 years), where the investment period was considered the variable factor between the greenhouses. The homogeneity of the soil texture of the greenhouses was also taken into account as much as possible (sandy loam to loam sandy), in addition to choosing the same agricultural crop in the greenhouse, which was the cucumber (class Prince). The environmental conditions within the greenhouse were almost homogeneous as this study included the following areas: (1) control soil, it was the soil collected from the Banias area at a depth of 0–40 cm; (2) Dower Al Khateeb, the investment period was five years; (3) Al Eidiya, the investment period was 10 years; (4) Al Zuhairat, the investment period was 20 years; (5) Al Burjan, the investment period was 25 years; and (6) Ras Al Ain, the investment period was 25 years (Table 1).

Table 2. Soil pollution assessment according to the geochemical accumulation index (Müller and Anke 1994).

The value of the indicator	0>	1>0<	2>1<	3>2<	4>3<	5>4<
Evaluation	Unpolluted	Unpolluted to moderately polluted	Moderately polluted	Moderately to highly polluted	Highly polluted	Severely to highly polluted

4.5. Cultivation and fertilization

For the control, cucumber seedlings were planted in October in plastic pots (three replicates) with a capacity of 10 kg outside the greenhouse and were fertilized at 200 kg/ha of ammonium nitrate, 150 kg/ha of potassium sulfate, and 300 kg/h of superphosphate (Al Shater and Al Balkhi 2017). In the greenhouses, planting was carried out at the same time and they were usually fertilized with a compound fertilizer (nitrogen, phosphorus, and potassium) (20, 20, 20) at an average rate of 10 kg every 10 days for an average area of 500 m^2 and sulfur fertilizers (SO_3 with microelements) at a rate 2 kg every 10 days.

4.6. Irrigation

The control was watered from Al Sin River. As for the greenhouses, they used artesian wells using the drip irrigation method. On the control, insecticides and fungicides were sprayed every 15 days and when needed.

4.7. Collection of soil samples

At the end of the agricultural season, individual soil samples were collected from each greenhouse and the control pots at depths of 0–20 and 20–40 cm, and then the individual samples were mixed at each depth to obtain composite samples. The samples were transferred to laboratories of the Arab Center for Studies of Dry Areas and Arid Lands, where they were dried aerobically, filtered through a sieve with holes of 2 mm, and then kept in plastic containers.

5. Research methods

The pH measurement was conducted using a pH meter with a soil–water suspension (1:2.5) (Conyers and Davey 1988). The salinity measurement was conducted using electrical conductivity (EC) in a soil–water extract (1:5) (Rhoades 1996). The mechanical analyses were done by following Gee and Bauder (1986). Organic matter (OM) was determinded using the modified wet oxidation method of organic carbon using potassium dichromate (N_1) in the presence of concentrated sulfuric acid, then titration using ferric sulfate ($N_{0.5}$) (Walkley and Black 1934). The total nitrogen in the soil was obtained by digestion using the Kieldahl method, by digesting the sample using concentrated sulfuric acid (Jones 2001). The available potassium K_2O (mg/kg) was extracted using ammonium acetate (N_1) at an extraction ratio of 1:20, and then the potassium was measured using a flame spectrophotometer (Jackson 2005). The available phosphorous (P) was obtained using the Olsen method, by extraction with a sodium bicarbonate solution ($N_{0.5}$) and then the determination of phosphorus using a spectrophotometer at a wavelength of 660 nm (Olsen et al. 1954). The total cadmium and nickel in the soil and plants was measured by wet digestion using aqua regia and atomic absorption spectrometry (Jones 2001).

5.1. Geochemical accumulation index

The geochemical accumulation index (I_{geo}) proposed by Müller and Anke (1994) (Table 2) is widely used to assess the potential risks of heavy metal pollution from human activities (mineral fertilizers, pesticides, fungicides, and irrigation water). This indicator is calculated by the following equation:

$$I_{geo} = \log\left[\frac{C_n}{(1.5 \times B_n)}\right]$$

where I_{geo} is the geochemical index of the deposition of the mineral element N, C_n is the concentration of metal n in the soil (mg/kg), B_n is the basic geochemical concentration of mineral N (the average control content of element N), and "log" is the decimal logarithm.

5.2. Contamination factor

The contamination factor (CF) was calculated according to the following equation (Tomlinson et al. 1980):

$$\mathrm{CF} = \frac{C_n}{C_m}$$

where C_n is the concentration of metal n in the soil (mg/kg) and C_m is the average control content of element n.

5.3. Statistical analysis

The SPSS statistical analysis program (complete random design) was used and the analysis of variance F-test was used to determine whether there were significant differences between the averages of the items measured in the greenhouses, and then the averages of the greenhouses were arranged according to the least significant difference (LSD) test, at the level of significance of 5%.

6. Discussion

6.1. Chemical properties of soils (Table 3)

Soil pH was classified as light to medium alkalinity on all horizons and in all the greenhouses' soils according to the USDA (1993). The salinity of the soil varied from one greenhouse to another and varied between the surface layer and the subsurface layer. It was higher in the surface layer than in the subsurface layer. The control soil (0.16 dS/m) and the

Table 3. Some chemical properties of the control and greenhouse soils.

Greenhouse	Depth (cm)	pH (1:2.5)	EC (1:5) (dS/m)	OM (%)	N (%)	P (mg/kg)	K (mg/kg)
Control	0–20	8.09	0.16	1.49	0.071	6.60	159
	20–40	8.11	0.16	1.36	0.067	5.12	142
Dower Al Khateeb	0–20	7.85	0.65	3.01	0.233	74.90	215
	20–40	7.86	0.56	2.34	0.177	49.20	164
Al Eideyah	0–20	7.83	0.55	3.12	0.218	228.40	482
	20–40	7.89	0,21	2.32	0.149	102.90	408
Al Zuhairat	0–20	7.67	0.77	2.94	0.169	194.70	758
	20–40	7.73	0.54	2.28	0.133	123.40	387
Al Burjan	0–20	7.68	1.28	3.48	0.193	362.20	832
	20–40	7.77	0.63	3.20	0.173	227.80	681
Ras Al Ain	0–20	7.74	1.31	3.64	0.233	373.40	1597
	20–40	7.79	0.84	2.66	0.165	224,20	799

Al Eidiya soil (surface 0.55 dS/m – subsurface 0.21 dS/m) were not saline. Low salinity was recorded in the surface of Al Khateeb soil (0.65 dS/m) and its subsurface was not saline (0.56 dS/m), whereas a high soil salinity was recorded, especially in the surface layer, in the soils of Al Burjan and Ras Al Ain as the conductivity reached 1.31 dS/m, according to the evaluation following FAO (2007). There was a discrepancy in the OM content among the greenhouses' soils compared with the control, as well as between the surface layer and the subsurface layer, as it ranged from 1.36% to 1.49% in the control soil in the surface and subsurface layers, respectively, and was 3.64% in the surface layer of the Ras al Ain soil and 3.20% in the subsurface layer of the Al Burjan soil. Its percentage ranged from low in the control soil to very high in the greenhouses' soils and the surface and subsurface layers, according to Tyurin (1965).

The average total nitrogen content in the surface and subsurface horizons ranged between 0.071% and 0.067% in the control soil and 0.165% and 0.233% in the Ras Al Ain soil, respectively. It is also noted that there was a discrepancy in the average of the total nitrogen content among the greenhouses' soils and between the surface and subsurface horizons, where high nitrogen was observed in the surface horizon compared with the subsurface horizon. The level of total nitrogen in the soil was classified between average in the control soil and very high in the rest of the greenhouses' soils (FAO 2006). The available potassium content of the greenhouses' soils ranged between 142 and 159 mg/kg in the control soil and 799 and 1597 mg/kg in the Ras Al Ain soil in the surface and subsurface layers, respectively; the level of available potassium in the soil according to FAO (2006) was low in the control soil, medium in the Dweir Al-Khateeb soil, high in the Al-Eidiya soil, and very high in the Al Zuhairat, Al Burjan, and Ras Al-Ain soils. The average content of available phosphorus in the surface and subsurface layers of the greenhouses' soils ranged between 5.12 and 6.60 mg/kg in the control soil and 73.40 and 224.23 mg/kg in the Ras Al Ain soil, respectively. There was a discrepancy between the available phosphorus content among the greenhouses' soils, as the content was higher in the surface layer than in the subsurface layer. As measured according to the method of Olsen et al. (1954), the level of available phosphorus in the soil was low in the control soil and very high in all of the greenhouses' soils, in both the surface and subsurface layers.

6.2. Total cadmium and nickel content in soils

As shown in Fig. 1, in the surface and subsurface horizons the total cadmium values ranged between 1.05 and 1.15 mg/kg in the control soil and 2.61 and 3.50 mg/kg in the Ras Al Ain soil, respectively. There was a slight increase in the total cadmium content of the greenhouses' soils in the surface horizon compared with the subsurface horizon when comparing the average total cadmium content of the greenhouses' soils with the total cadmium levels in the world's soils (Table 4). According to Kabata-Pendias and Pendias (1992), documented in Sezgin et al. (2004), it is noted that the average total cadmium content of soils (Ras al Ain, Al Burjan, and Al Zuhairat) exceeded the permissible limit after nearly 20 years of investment and excess additions of mineral fertilizers.

The results of the statistical analysis of the average values of total cadmium in the soil showed that the soils of all the greenhouses were significantly superior to the control soils, in direct proportion to the increase in the investment period (Fig. 1). The percentage increase in total cadmium content in the surface horizon of the greenhouses' soils compared with the control was as follows: 204%, 183%, 166%, 143%, and 125% in the Ras Al Ain, Al-Burjan, Zuhairat, Al Eidiya, and Dower Al-Khatib soils, respectively. The percentage increase in the subsurface horizon compared with the control was as follows: 157%, 149%, 140%, 133%, and 94% in the Al Burjan, Ras Al Ain, Al Zuhairiyat, Al Eidiya, and Dower Al-Khatib soils, respectively. The percentage increase in the total cadmium content of the greenhouses' soils in the surface horizon from the maximum was as follows: 2%, 9%, and 17% in the Al Zuhairat, Al Burjan, and Ras Al Ain soils, respectively. The values of the geochemical accumulation index (Müller and Anke 1994) showed that the greenhouses' soils were not polluted to moderately polluted (Table 5; Table 6).

The values of the CF (Tomlinson et al. 1980) showed that the soils of all the greenhouses were moderately polluted with cadmium, whereas the surface horizon of the Ras Al Ain soil was highly polluted (Table 7).

Fig. 1. The average total cadmium content of greenhouses' soils (mg/kg). Lowercase letters indicate significant differences between the different treatments. [Colour online]

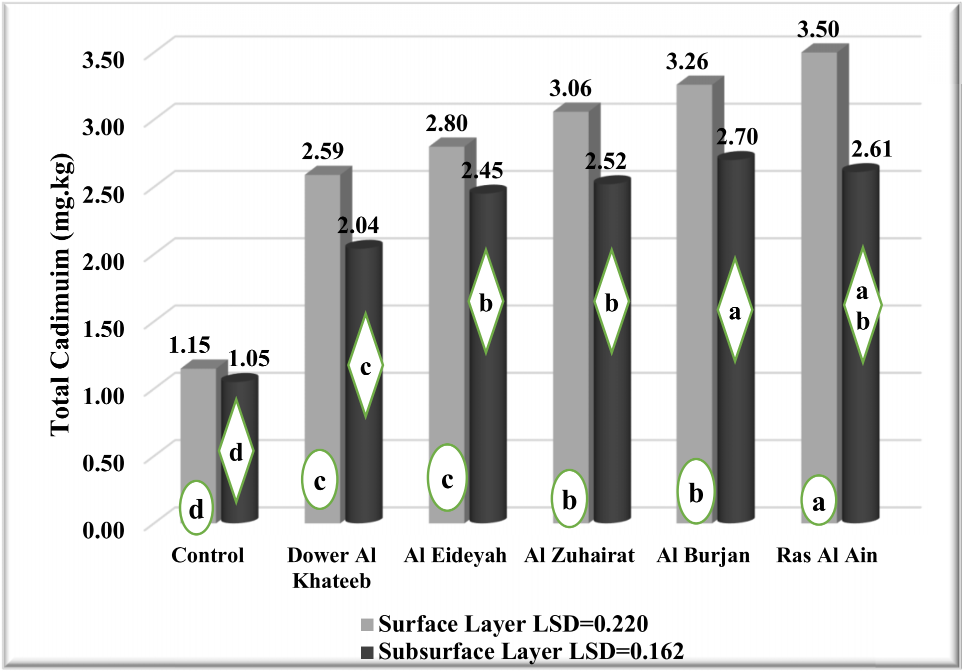


Table 4. Total soil cadmium levels in the soil (Kabata-Pendias and Pendias 1992; documented in Sezgin et al. 2004).

Element	Normal concentration	Acceptable value	Maximum
Cd (mg/kg)	0.1–1	3	3

Cadmium pollution, especially in Ras Al Ain and Al Burjan, is attributed to the frequent and intense use of phosphate fertilizers in which this element was present in the form of impurities (FAO 2009).

Figure 2 shows that the total nickel content in the surface and subsurface horizons of the greenhouses' soils ranges between 38.13 and 40.90 mg/kg in the control soil and 147.50 and 154.40 mg/kg in the Ras Al Ain soil, respectively. It is also noted that there was a slight increase in the total nickel content of the greenhouses' soils in the surface horizon compared with the subsurface horizon.

When comparing the average content of total nickel in the greenhouses' soils with the levels of total nickel in the world's soils (Table 8), according to Fabis (1987), as documented in Sezgin et al. (2004), it was noted that the total nickel content in the surface and subsurface horizons of all the greenhouse's soils exceeded the maximum allowed.

The results of the statistical analysis of the average values of total nickel in the surface and subsurface horizons of the soil showed that all the greenhouses' soils were significantly superior to the control soils and that the values were directly proportional to the increase in the investment period. The percentage increase in the total nickel content in the surface horizon of greenhouses' soils compared with the control was as follows: 278%, 223%, 219%, 172%, and 53% in the Ras Al Ain, Al Burjan, Zuhairat, Al Eidiya, and Dower Al Khatib soils, respectively. The percentage increase in the subsurface horizon compared with the control was as follows: 287%, 233%, 210%, 209%, and 52% in the Ras Al-Ain, Al Burjan, Al Zuhairat, Al Eidiya, and Dower Al-Khateeb soils, respectively.

The percentage increases above the maximum in the total nickel content in the surface horizon and subsurface horizon of the greenhouses' soils were as follows: 25%, 123%, 161%, 164%, and 209% and 16%, 135%, 137%, 154%, and 195% in the Dower Al Khateeb, Al Eidiya, Al Zuhairat, Al Burjan, and Ras Al Ain soils, respectively.

The values of the I_{geo} (Müller and Anke 1994) showed that the greenhouses' soils were not contaminated to moderately polluted (Table 9) with the element nickel, whereas the values of the CF (Tomlinson et al. 1980) showed that the oldest greenhouses' soils in Al Zuhairat, Al Burjan, and Ras al-Ain were highly contaminated with nickel (Table 10).

The pollution of total nickel may be attributed to the excessive use of mineral fertilizers, especially phosphates, and pesticides, as it is included in the chemical composition of some pesticides, in addition to heavy metals such as cadmium, lead, and copper. (FAO 2009).

6.3. Total cadmium and nickel in cucumber leaves

6.3.1. Total cadmium in cucumber leaves

As shown in Fig. 3, the average total cadmium content in cucumber leaves ranges between 0.51 mg/kg in control plants

Table 5. Soil pollution assessment pollution factor.

The value of the indicator	1>	3>1≤	≤3>6	6<
Evaluation	Low pollution	Moderate pollution	High pollution	Very high pollution

Table 6. The values of the geochemical accumulation index for cadmium in the surface and subsurface horizons according to Müller and Anke (1994).

Depth (cm)	Dower Al Khateeb	Al Eidyiah	Al Zuhairat	Al Burjan	Ras Al Ain
0–20	0.18	0.21	0.25	0.28	0.31
Evaluation			Unpolluted to moderately polluted		
20–40	0.11	0.19	0.20	0.23	0.22
Evaluation			Unpolluted to moderately polluted		

Table 7. The contamination factor values for cadmium in the surface and subsurface horizons (Tomlinson et al. 1980).

Depth (cm)	Dower Al Khateeb	Al Eidyiah	Al Zuhairat	Al Burjan	Ras Al Ain
0–20	2.25	2.43	2.66	2.83	3.04
Evaluation	Moderately polluted	Moderately polluted	Moderately polluted	Moderately polluted	Highly polluted
20–40	1.94	2.33	2.4	2.57	2.49
Evaluation	Moderately polluted	Moderately polluted	Moderately polluted	Moderately polluted	Moderately polluted

Fig. 2. The average total nickel content of the greenhouses' soils. [Colour online]

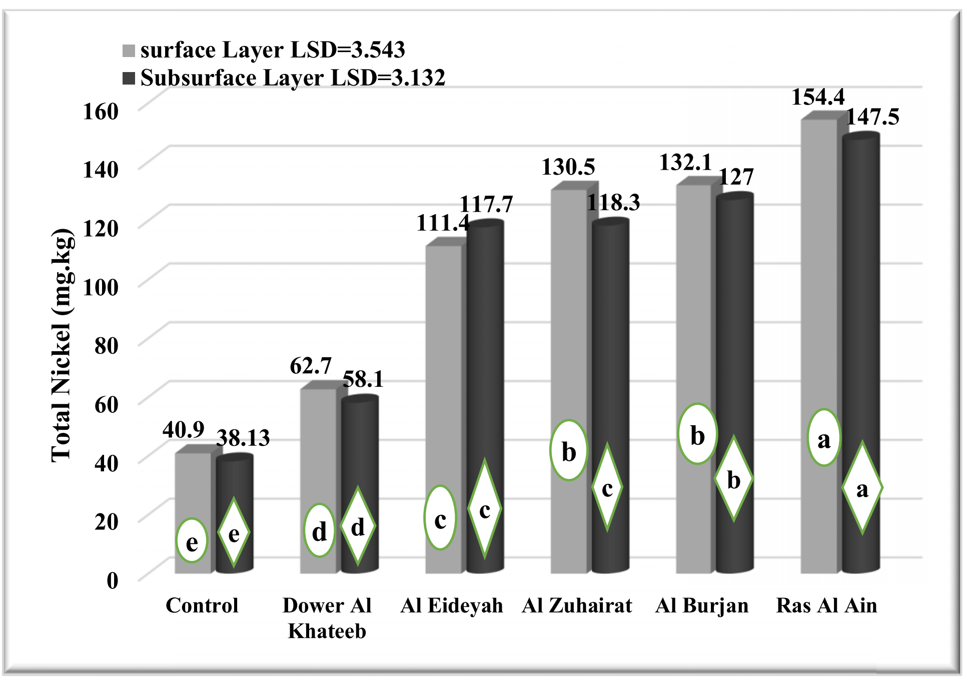


Table 8. Total nickel levels in the soil (documented in (Sezgin et al. 2004).

Element	Normal concentration	Acceptable value	Maximum
Ni (mg/kg)	10–50	50	50

and 3.05 mg/kg (dry weight) in Ras al Ain plants when comparing the leaves' total cadmium content with the average cadmium in the tissues of mature leaves of plants (Kabata-Pendias and Pendias 1992). Table 11 shows that the cadmium content is within the limits of sufficiency as well as the absence of toxicity with cadmium metal.

Table 9. The values of the geochemical accumulation index for nickel in the surface and subsurface horizons according to Müller and Anke (1994).

Depth (cm)	Dower Al Khateeb	Al Eidyiah	Al Zuhairat	Al Burjan	Ras Al Ain
0–20	0.009	0.25	0.32	0.33	0.40
Evaluation	Unpolluted to moderately unpolluted				Highly polluted
20–40	0.007	0.31	0.32	0.35	0.41
Evaluation	Unpolluted to moderately unpolluted				

Table 10. The contamination factor values for cadmium in the surface and subsurface horizons (Tomlinson et al. 1980).

Depth (cm)	Dower Al Khateeb	Al Eidyiah	Al Zuhairat	Al Burjan	Ras Al Ain
0–20	1.53	2.72	3.19	3.23	3.78
Evaluation	Moderately polluted	Moderately polluted	Highly polluted	Highly polluted	Highly polluted
20–40	1.52	3.09	3.10	3.33	3.87
Evaluation	Moderately polluted	Highly polluted	Highly polluted	Highly polluted	Highly polluted

Fig. 3. The average total cadmium content in cucumber leaves (mg/kg, dry weight). [Colour online]

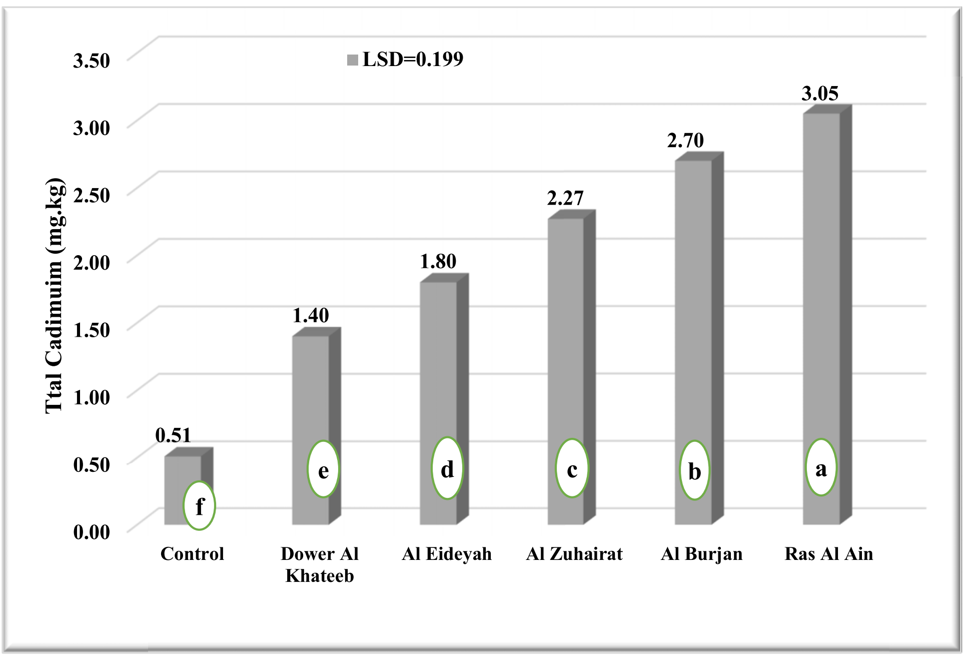


Table 11. Range of normal and potentially toxic concentrations of cadmium in mature leaf tissues of plants (Kabata-Pendias and Pendias 1992).

	Normal	Toxicity	Endurance
Cd (mg/kg)	0.05–0.2	5–30	3

The results of the statistical study of the average total content of cadmium in cucumber leaves (mg/kg, dry weight) showed that, in all the greenhouses, it exceeded that of the control plants in direct proportion to the increase in the investment period of the greenhouses. It is also noted that the average content of cadmium in leaves in Ras Al Ain and Al Burgan had higher values than the rest of the leaves of the greenhouses' plants due to the presence of cadmium in these greenhouses.

Figure 4 shows that the average content of total nickel in cucumber leaves ranges between 0.58 mg/kg in control plants and 2.92 mg/kg (dry weight) in Ras Al Ain plants when comparing the total nickel content of leaves with the average nickel content in the tissues of mature leaves of plants. Table 12 shows that the content in the leaves of cucumber plants in the control and greenhouses was sufficient and there was no toxicity of nickel metal (Kabata-Pendias and Pendias 1992).

The results of the statistical study of the average content of total nickel in cucumber leaves (mg/kg) in dry weight showed that the content in cucumber leaves in all the greenhouses was superior to that in the leaves of the control plant in direct proportion to the increase in the investment period of the greenhouses (Fig. 4). The lack of significant nickel accumulation in the leaves despite the contamination of the sur-

Fig. 4. The average of the total nickel content in cucumber leaves (mg/kg, dry weight). [Colour online]

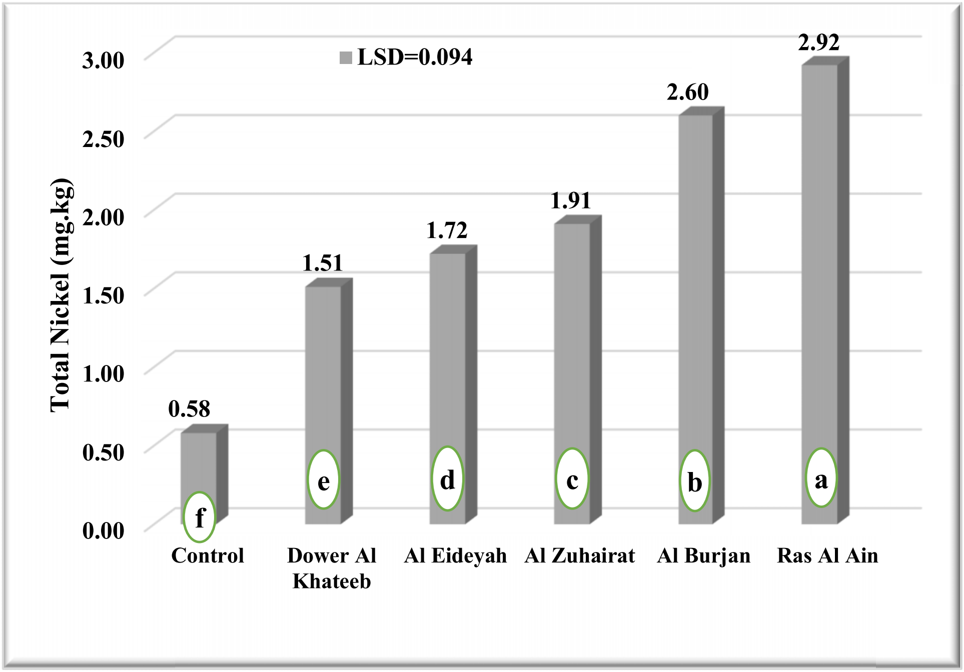


Table 12. Range of normal and possible toxic concentrations of nickel in mature leaf tissues of plants (Kabata-Pendias and Pendias 1992).

	Normal	Toxicity	Endurance
Ni (mg/kg)	0.1–5	10–100	50

face layer of the soil (0–20 cm) with nickel may be due to the extension of the roots to deeper, less contaminated layers. The nontoxicity of plants to nickel may be attributed to the plants' ability to tolerate nickel. Valdares et al. (1983) demonstrated that there was no decrease in the yield of crops grown in calcareous soils fertilized with sewage sludge containing 200 w/kg of nickel.

6.4. Cadmium and nickel in cucumber fruits

6.4.1. Cadmium in cucumber fruits

Figure 5 shows the average content of cadmium in cucumbers (mg/kg, wet weight).

The average content of cadmium ranges between 0.021 mg/kg for cucumber fruits in the control and 0.076 mg/kg for cucumber fruits in Ras al Ain (Fig. 5). The results of the statistical study of the average content of total cadmium (mg/kg, fresh weight) in cucumber fruits showed that the content of cadmium in cucumber fruits of all the greenhouses was superior to that in the control fruits in direct proportion to the increase in the investment period of the greenhouses, where the content of cadmium in cucumber fruits in Ras Al Ain and Al Burjan exceeded those of the rest of the greenhouses. This may be due to the contamination of the soils of these two greenhouses with cadmium, 3.26 and 3.50 mg/kg, respectively.

When comparing the content of cadmium in cucumber fruits from the control and greenhouses with the permissible limit (0.05 mg/kg, wet weight) according to the standards of the European Commission (2006), it was noticed that the concentration of cadmium exceeded the permissible limit in both Ras Al Ain and Al Burjan, which indicates the presence of slight contamination of cucumber fruits with cadmium metal as a result of the plant's absorption of cadmium from the soil due to the frequent addition of phosphate fertilizers (on average every 10 days) in which it was present in the form of impurities (FAO 2009).

When comparing the concentration of cadmium in different plants grown on unpolluted land, the highest concentration of cadmium was in leafy vegetables such as spinach and lettuce. When plants grow in contaminated soils, cadmium accumulates in the roots, and in light of this study, it was also found that cadmium accumulated even slightly in cucumber fruits, which may pose a threat to human health, considering that the World Health Organization has set the maximum permissible limit for cadmium intake from food of 57–71 mcg/person/day (400–500 mcg/person/week; FAO/WHO 2003).

6.5. Nickel in cucumber fruits

Figure 6 shows the average nickel content of cucumbers (mg/kg, wet weight).

The average nickel content ranges between 0.045 mg/kg for the control cucumber fruits and 0.127 mg/kg for cucumber fruits in Ras Al Ain (Fig. 6). The results of the statistical study of the average content of total nickel (mg/kg, fresh weight) in cucumber fruits showed that for all greenhouses it exceeded

Fig. 5. The average cucumber cadmium content (mg/kg, wet weight) (LSD 0.004). [Colour online]

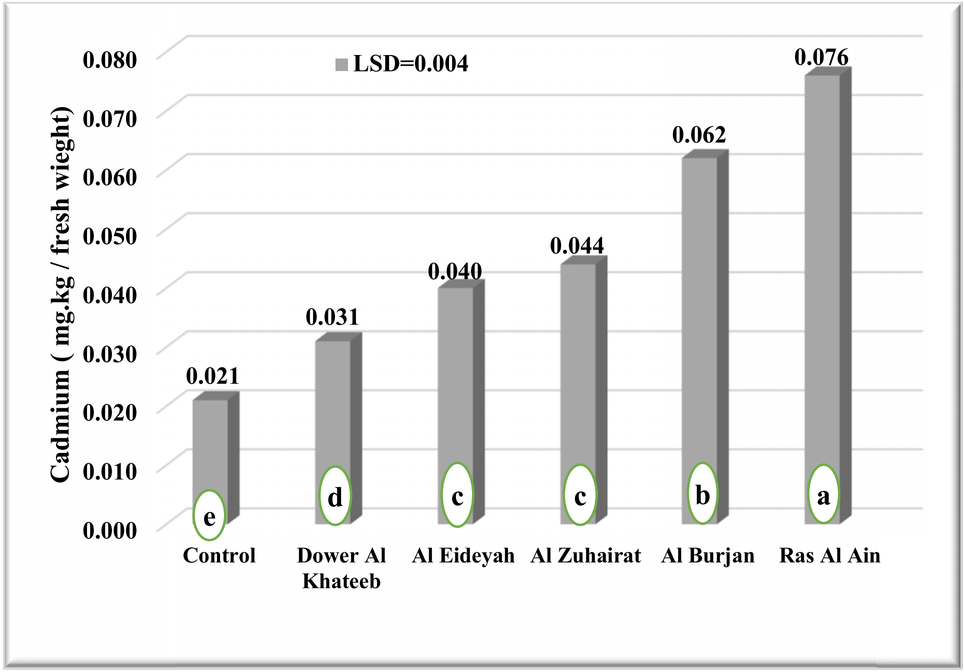
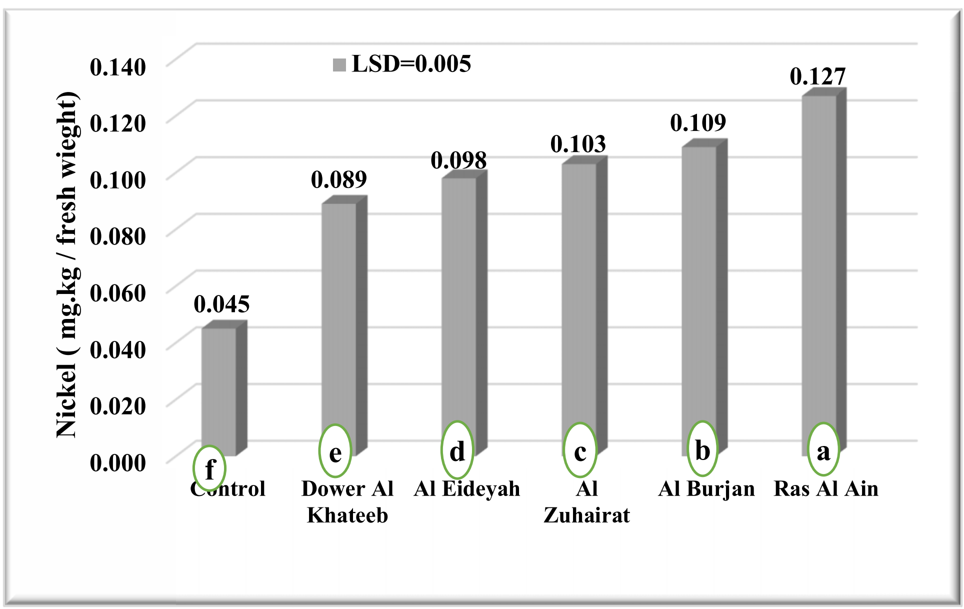


Fig. 6. The average nickel content of cucumbers (mg/kg, wet weight) (LSD 0.005). [Colour online]



that of the control fruits in direct proportion to the increase in the investment period of the greenhouses.

When comparing the content of nickel in cucumber fruits from the control and those of the greenhouses with the permissible limit (0.086 mg/kg) according to the Food Standards Agency (2009), it was noted that the concentration of nickel exceeded the permissible limit in all the greenhouses, which indicates the presence of slight contamination. Cucumber fruits contain nickel as a result of the plant's absorption of nickel from the soil, due to its presence in high concentrations in the soil as mentioned previously.

This may pose a risk to human health, considering that the World Health Organization has set the maximum allowable intake of nickel in food at 57–71 mcg/person/day (400–500 mcg/person/week; FAO/WHO 2003).

The Pearson correlation coefficient (*r*) between the available phosphorus (mg/kg), total cadmium and nickel in the soil (mg/kg), total cadmium and nickel in leaves (mg/kg), total

Table 13. Correlation coefficient (Pearson's *r*) between available phosphorus (mg/kg), total cadmium and nickel in soil (mg/kg), total cadmium and nickel in leaves (mg/kg), total and cadmium and nickel in fruits (mg/kg), and investment period.

Investment duration	Ni (leaves)	Cd (leaves)	Ni (fruit)	Cd (fruit)	Ni (total)	Cd (total)	P (available)	*r*
							1	P (available)
						1	0.86**	Cd (total)
					1	0.91**	0.93**	Ni (total)
				1	0.91**	0.84**	0.95**	Cd (fruit)
			1	0.89**	0.92**	0.98**	0.89**	Ni (fruit)
		1	0.96**	0.95**	0.96**	0.95**	0.95**	Cd (leaves)
	1	0.98**	0.96**	0.96**	0.92**	0.94**	0.96**	Ni (leaves)
1	0.93**	0.96**	0.86**	0.92**	0.95**	0.86**	0.93**	Investment duration

$*$LSD = 0.01. $**$LSD = 0.05.

cadmium and nickel in fruits (mg/kg), and investment period is shown in Table 13.

The results of the Pearson correlation coefficient showed a strong positive significant correlation between the available phosphorus and total cadmium and nickel in the soil, which may indicate the contamination of phosphate fertilizers with these heavy metals (Robert 2014). It was also observed that there was a strong, significant correlation between total cadmium and nickel in the soil and cadmium and nickel in both the leaves and fruits of cucumber, which indicates that the absorption of these two elements by the plant and their accumulation in the leaves and fruits was directly proportional to their percentage in the soil, which may reduce the validity of the fruits for human consumption in the event of exceeding permissible limits.

There was a strong positive significant correlation between the available phosphorus and total cadmium and nickel in the soils and plants, indicating that increasing the investment period leads to a direct accumulation of cadmium elements, which is consistent with Lv et al. (2019).

7. Conclusions

Greenhouses' soils were polluted with cadmium and nickel in direct proportion to the increase in the investment duration. The level of cadmium and nickel in cucumber fruits in greenhouses whose investment period exceeded 20 years exceeded the permissible limits, increasing the acidity slightly in the soil with the increase in the investment duration.

8. Recommendations

Greenhouses' soils should be analyzed before carrying out fertilization operations to assess the content of mineral elements. A complete and balanced fertilization system should be followed for vegetable crops in greenhouses to ensure the presence of a sufficient, and not excessive, amount of nutrients to obtain the optimum yield and quality, to avoid or reduce the loss of fertilizers, especially nitrate, and to reduce environmental pollution.

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