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Impact of Sewage Water Used for Irrigation on Soil Characteristics and Heavy Metals Composition of some Grown Crops

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SOIL and plant samples were collected from Elgabal-Elasfar farm, irrigated with sewage water for more than 80 years and from Elkhanka area, irrigated with Nile water. Five soil profiles were dug to the depth of 160 cm and soil samples were collected from successive depths (0-5, 5-10, 10-20, 20-40, 40-80, 80-160 cm) to study the effect of sewage water on general characteristics of soils and heavy metals content of growing plants. The results show that the texture class of Elgabal-Elasfar soil changed from sandy clay loam to clay loam from 0 to 10cm layer and from sandy loam to sandy clay loam from 10 to 20 cm layer. Total carbonate concentration was slightly affected due to irrigation with sewage water. Organic matter content in the upper layers (0-20 cm) of Elgabal-Elasfar soil increased by 30 fold compared to the control. The pH values of soils irrigated with sewage water decreased by about one unit, particularly in the upper layers, while EC values increased to more than two fold compared to the control. The surface layer of Elgabal-Elasfar soil contained higher Fe, Zn, Cu, Co, Ni and Pb concentrations representing 9.0, 3.3, 10.6, 9.6, 6.9 and 3.2 times that of the control, respectively. Total Cu and Ni content in the plough layer of Elgabal-Elasfar soil exceeded the permissible limits according to the European Economic Commission, while DTPA-extractable Cu is considered excessive or toxic. Levels of heavy metals in edible parts of plants, *i.e.*, orange, bean, corn and clover grown on Elgabal-Elasfar soils were within the permissible limits. Copper content in shoots of plants grown on Elgabal-Elasfar soil was considered excessive or toxic. The levels of Fe and Cu concentrations in tissues of clover grown on Elgabal Elasfar soil exceeded the permissible limits. Cobalt concentration in shoots and seeds of broad bean irrigated with sewage water exceeded the normal range.

Keywords: Heavy metals, Sewage water, Contaminated soil, Edible parts.

In the last few years, the reuse of waste or low quality water became part of the extension program for maximizing the use of water resources. However, the uncontrolled application of such waters must have many unfavorable effects on both soils and plants grown especially in the long-term use. The hazard effects are mainly related to the soil properties and water quality, beside the types of growing crops.

Wastewater, mostly without pretreatment, has been used for a long period in the Elgabal-Elasfar area for production of grains, vegetables and fruit crops for human and animal consumption. This wastewater transports high amounts of potential toxic substances, including heavy metals (Abdel-Aal *et al.*,1991). Waly *et al.* (1987), Khalil (1990) and El-Tabey (1993) indicated that the continuous use of sewage effluent for irrigating Elgabal-Elasfar sandy soils decreased soil pH from 8.6 to 6.8. Sadek and Sawy (1989) reported that cation exchange capacity was increased by the continuous application of sewage water due to the increase of finer materials and organic matter content. Recently, El-Motaium and Badawy (2000) found that the Elgabal-Elasfar soil pH and calcium carbonate content decreased, while organic matter content increased for both rhizosphere and bulk soils as the irrigation period with sewage water increased.

Eid (1984), Sadik *et al.* (1987), Abdel-Sabour *et al.* (1995) and Mosalem (1997) found that the soil contents of total and available forms of Fe, Zn, Mn, Cu, Pb, Ni, Cd, Co and Cr within the upper 60 cm layer increased by increasing the period of irrigation with sewage water. Accumulation of these elements tended to be more obvious in the surface layers than in the sub-surface.

El-Nashar (1985) found that the level of heavy metals, Fe, Mn, Zn, Cu, Pb, Cd and Co in the leaves of fruits of navel orange, irrigated with sewage water (up to 60 year) in Elgabal-Elasfar farm were within the permissible limits and below the concentrations causing any toxic effects on plants and humans. El-Motaium and Badawy (2000) found that heavy metals were accumulated mainly in the roots of both cabbage plants and orange trees irrigated for 80 years with sewage water in Elgabal-Elasfar soil. In cabbage plants, heavy metals contents vary in different organs in the following order: roots> leaves> stems whereas for orange trees the order is as follows: roots> leaves> fruit peel> fruit pulp.

The objectives of this study were to evaluate the effect of using sewage water on the changes of some chemical characteristics and distribution of total, chemically available heavy metals to the depth of 160 cm in Elgabal-Elasfar soil as well as accumulation of such heavy metals in certain plant tissues of different crops.

Material and Methods

Soil and water sampling and analysis

Two irrigation water samples were collected. Characteristics of irrigation water are shown in Table 1.

TABLE 1. Chemical composition of the collected water samples (means of five values ± S.d).

Parameter		Location of water sources	
		Nile water (Ismailiya Canal)	Sewage water (Elgabal-Elasfar drain)
pH		7.11 ± 0.06	6.10 ± 0.03
EC, dS. m^{-1}		0.48 ± 0.05	1.03 ± 0.01
Fe		0.59 ± 0.18	2.58± 0. 11
Zn		0.09 ± 0.04	0.53 ± 0.16
Cu		0.02 ± 0.01	2.69 ± 0.18
Co		not detected	0.14 ± 0.03
Ni	mg.l^{-1}	0.07 ± 0.04	0.67 ± 0.12
Pb		0.05 ± 0.02	0.49 ± 0.15
Biological oxygen demand (BOD)		7.5	593.7
Total suspended matter		151	1487
SAR		1.78	3.51
adj .SAR		2.58	5.09
Class of salinity		No problem	Increasing problem
Class of alkalinity		No problem	Increasing problem

Soil samples from two sites were collected. The first site is Elgabal-Elasfar with a clay loam soil, *Typic Torripsamments*, which is irrigated from Elgabal-Elasfar drain. The second site, namely Elkhanka, has a sandy loam soil, *Typic Torripsamments*, and is irrigated from Nile water in the same area located two kilometers from Elgabal-Elasfar farm. The profiles of Elgabal-Elasfar soil were taken to represent the oldest farm (>80 years irrigated with sewage water). In each site, five soil profiles were dug to the depth of 160 cm and soil samples were collected from successive depths (0-5, 5-10, 10-20, 20-40, 40-80, 80-160 cm). The soil samples were air dried, crushed and finely ground, then sieved through a 2mm sieve and kept for analysis. Soil characteristics were determined using standard methods outlined by Jackson (1958) and Baruah and Barthakur (1997). Total heavy metals contents of Fe, Zn, Cu, Co, Ni and Pb were determined after digestion with hydrofluorici / perchloric acids mixture (Jackson, 1958). Chemically available forms of elements were evaluated by extracting the soil with DTPA according to Lindsay and Norveil (1978) and the metals in the extract were determined using an atomic absorption spectrophotometer.

Plant sampling and analysis

Plant leaves and orange fruit samples of orange trees (*Citrus sinensis* L.) also plant leaves of corn plants (*Zea mays L.*), broad bean (*Vicia faba* L.) and clover (*Trifolium alexandrinum L.*) plants grown on two fields of the two locations were collected as recommended by Jones *et al.* (1971). Grains of corn and seeds of broad bean were also collected at harvest. The collected plant samples were washed with tap water, 10^{-4} M HCl solution, and deionized water, then oven dried at 65°C for 48 hr. Plant materials were ground and mixed well. Orange fruits were peeled, juice was extracted, then subjected to heavy metals determination.

Results and Discussion

Soil general characteristics

Table 2 shows some physical and chemical properties of the soil samples. Results reveal that using sewage water in irrigation was more effective in changing soil texture of Elgabal-Elasfar. Values of clay content in the upper layers of (0-20cm) were relatively higher than those of the soil irrigated from Nile water (control). Texture class of Elgabal-Elasfar soil changed from sandy clay loam to clay loam in the (0-10cm) and from sandy loam to sandy clay loam (10-20cm), due to continuous irrigation with untreated sewage water for about 80 years. Results in Table 1 show a total suspended matter (organic + inorganic) of about ten times more in the sewage water compared to Nile water. These results agree with those of Abdel-Sabour *et al.*, (1995), Mosalem (1997) and El-Motaiuin and Badawy (2000) who found that the continuous irrigation with sewage water resulted in remarkable changes of clay content and organic matter, which might have been added to soils upon irrigation.

Total carbonate contents for Elgabal-Elasfar soil decreased with soil depth. Decreasing carbonate content may be attributed to the ability of $CaCO_3$ to dissolving of organic acids, naturally found in the sewage water and / or to microbial activities such as crenic, humic and fulvic acids (Kononova, 1961 and Tan, 1993).

TABLE 2. Total and DTPA-extractable heavy metals, mg. kg^{-1} in the studied soils as affected by source of irrigation and soil depth.

Location of soil samples	Depth (Cm)	Fe			Zn			Cu			Co			Ni			Pb		
		T#	Ext	A.I##	T	Ext	A.I	T	Ext	A.I	T	Ext	A.I	T	Ext	A.I	T	Ext	A.I
Elgabal-Elasfar	0-5	23240	40.40	0.17	145.1	25.72	17.73	159.6	18.45	11.56	43.10	2.18	5.06	72.78	2.92	4.01	95.20	4.15	4.36
	5-10	21153	32.00	0.15	127.2	24.63	19.36	153.4	17.92	11.68	38.30	1.72	4.49	68.14	1.86	2.73	88.17	3.89	4.41
	10-20	17643	25.22	0.14	123.9	19.82	16.00	147.1	17.57	11.94	35.85	1.27	3.54	63.25	1.82	2.88	82.26	2.63	3.20
	20-40	12471	19.29	0.15	116.4	11.61	9.97	139.3	14.85	10.66	27.81	1.05	3.78	56.83	0.76	1.34	76.87	2.39	3.11
	40-80	10493	12.16	0.12	105.1	9.43	8.97	126.1	9.82	7.79	24.30	0.87	3.58	49.07	0.48	0.98	68.34	1.26	1.84
	80-160	2764	8.73	0.32	92.01	3.17	3.45	118.9	4.66	3.92	22.18	0.45	2.03	41.16	0.25	0.61	64.25	0.14	0.22
Elkhanka (control)	0-5	2478	9.03	0.36	42.26	0.23	0.54	14.70	0.13	0.91	4.48	0.12	2.64	10.69	0.20	1.86	28.91	0.42	1.45
	5-10	2471	8.06	0.33	41.52	0.21	0.51	14.60	0.12	0.84	3.93	0.12	3.02	10.00	0.20	1.98	28.16	0.45	1.60
	10-20	2458	6.82	0.28	41.42	0.16	0.39	14.08	0.09	0.61	3.42	0.09	2.60	9.91	0.15	1.50	25.72	0.32	1.24
	20-40	2454	6.18	0.25	41.18	0.12	0.29	13.85	0.07	0.53	3.14	0.06	1.88	9.65	0.15	1.54	22.22	0.29	1.31
	40-80	2449	6.19	0.25	41.16	0.08	0.19	13.81	0.06	0.44	3.00	0.06	1.97	9.57	0.10	1.04	19.48	0.29	1.49
	80-160	2434	5.97	0.25	41.03	0.07	0.17	13.79	0.06	0.44	2.45	0.06	2.42	9.14	0.10	1.09	19.33	0.16	0.83

T and Ext means total and DTPA extractable heavy metals

A.I (availability index) = (Ext.) 100/T

From the obtained data, it is clear that the organic matter content generally increased due to irrigation with sewage water, but decreased with depth. Organic matter content in the upper layers (0-20 cm) of Elgabal-Elasfar soil showed about 30 fold increase relative to that of the control soil. These results are in agreement with those obtained by Abdel-Naim *et al.* (1982) and El-Nashar (1985).

The pH-values of Elgabal-Elasfar soil decreased for about one unit reaching 7.23. 7.27 and 7.34 in the upper 0-5, 5-10 and 10-20 cm layers, respectively. The drop in pH-values was only about half a unit in the lower layers. Such decrease could be attributed to the decomposition of organic materials of the sewage water and production of CO_2 and organic acids. Similar findings were also obtained by several authors (Khalil, 1990, El-Gendi *et al.*, 1997 and El-Motaium and Badawy 2000) who related the decrease in soil pH to using sewage water for irrigation.

Results also show that the salinity of Elgabal-Elasfar soil increased in the upper 40 cm layer, reaching about 2.5 fold that of the similar layers of the control.

Heavy metals

Total content

Data given in Table 2 show the total amounts of Fe, Zn, Cu, Co. Ni and Pb in different layers of the investigated soils profiles. They reveal that the total content of these elements differs according to the water source used for irrigation. Generally, concentrations of such heavy metals in the two soils were higher in surface layers than in lower layers. However, the surface layer (0-5 cm) of Elgabal Elasfar soil contained 9.4, 3.4, 10.9, 9.6, 14.6 and 9.9 times more of Fe. Zn, Cu, Co, Ni and Pb, compared to the control soil. respectively. The magnitude of increase declines with depth. Increasing total amounts of heavy metals in a specific layer could be mainly due to repeated irrigation with wastewater, rather than to differences in the nature of soil origin. It is interesting to note that the pattern of distribution is somewhat similar to that of organic matter and clay content, which tended to accumulate through the surface soil layers. These results coincide with those of Veragra *et al.* (1986), Dumonter *et al.* (1990), Abdel-Aal *et al.* (1991) and El-Gendi *et al.* (1997) who found that irrigating sandy soil in the Abou-Rawash area with drainage water increased total Cu, Zn and Fe, which reached 125, 170 and 5 times that of the non irrigated one in the same area. It seems that the high permeability of the sandy soil in Elgabal-Elasfar farm, besides the colloidal state of the suspended matter, facilitates the downward movement of sewage effluent-born heavy metals (ionic, complexed with organic molecules and / or finely dispersed colloidal). Moreover, the uncontrolled surface irrigation system permits the excessive precipitation and downward movement of either the soluble or the colloidal phase of the metals.

Referring to permissible limits of heavy metals values in agricultural soils, considered by the European Economic Commission, Kăbata, Pendias & Pendias (1992) and Linzop (1987) reported; total Zn (150-300 ppm), Cu (50-l00ppm), Ni (30-50ppm) and Pb (50-100 ppm). The present data in the plough layer show that total Cu and Ni content in the sandy soil of Elgabal-Elasfar farm exceeded the permissible limits. This may be reflected on the amounts of chemically available forms, plant growth and composition of these elements.

DTPA-extractable heavy metals

Results given in Table 3 show the DTPA-extractable Fe, Zn, Cu, Co, Ni and Pb in the upper 20 cm of Elgabal-Elasfar soil as affected by irrigation with sewage water. Concentrations of such elements increased by about 4.1, 117, 159, 15.7, 12.0 and 9 fold that of control soil, respectively. The increasing extractability of the concerned heavy metals in Elgabal-Elasfar soil could be attributed to increasing the total contents, beside the relatively low pH values and increasing organic matter content in this soil. Most dissolution and precipitation processes of heavy metals were reported to be controlled by humus materials and soil pH (Barrow, 1986).

The ranges of DTPA-extractable Fe, Zn and Cu in soils in terms of $mg.kg^{-1}$ are considered adequate as reported by Rose and Wang (1998), which were 15-40, 30-5 and 0.5-1.5, respectively. Results of the investigated soils revealed that the concentrations of DTPA- Cu in the upper layers (0-20 cm) for Elgabal-Elasfar soil exceeded the adequate range, reaching the excessive or toxic levels, while DTPA-Fe and Zn in the same soils are still in the adequate range. The availability increasing of the heavy elements, mainly Co, Ni and Pb more than 10 times as compared to the control may be reflected on growth and quality of crops growing in the area.

TABLE 3. DTPA-extraetable heavy metals, mg. kg^{-1} in surface layer (0-20 cm) of the studied soils irrigated with sewage and Nile water.

Location of soil samples	Fe	Zn	Cu	Co	Ni	Pb
Elgabal-Elasfar	32.50	23.39	18.00	1.72	2.20	3.56
Elkhanka (Control)	7.97	0.20	0.11	0.11	0.18	0.40

Effect of irrigation with sewage water on heavy metals contents of growing crops in the area

The impact of 80 years application of untreated sewage effluent of Elgabal-Elasfar drain on the amount of DTPA-extractable Fe, Zn, Cu, Co, Ni and Pb and the quality of perennial citrus trees are shown in Fig. 1. The extractability of the above-mentioned elements in Elgabal-Elasfar soil increased, compared to the control as mentioned above. For the concentrations of those elements in citrus trees, the magnitude of increase in the leaves ranged from the double to about 6 times for all elements with the highest increase for Co. Such increase was reflected on the concentration of these elements in the peel and juice, particularly Pb, followed by Ni and Zn. Results indicate that the edible part (juice) is highly rich in heavy metals. The obtained data for Pb in citrus leaves were generally lower than those reported by Mosalem (1997) for citrus trees, grown for 52 years in Elgabal-Elasfar it seems. Whereas, the determined Fe, Zn, Co and Pb contents in juice were less than those in juice of orange trees grown on Abou Rawash farm and determined by Selem *et al.* (2000). The differences could be a function of management practices applied and the variety grown.

For the winter crop (broad bean) the concentration of the studied elements in the leaves showed high increase in broad bean leaves, (Fig. 2). The magnitude of increase in heavy metals content is arranged in the following order: CO > Ni > Pb > Cu > Fe > Zn and this was reflected in the concentration of these elements in the edible bean seeds. Again, results indicate that the bean seeds of plant grown in Elgabal-Elasfar soils are rich in Co, Ni, and Pb content. It appears that broad beans, grown in Elgabal-Elasfar accumulated more Fe and Ni, but less amount of Zn, Cu, Co and Pb compared to those found for broad beans grown in the industrial area of Helwan, as found by Badawy and Helal (1997). Such variation could be related to differences in location and source of irrigation water and consequently the variation in the ratio of those elements in the soils.

For the fodder crop (clover), the concentration increased about 18 and 22 times for Ni and Co and about 6 times for Pb, while Zn increased to about 5

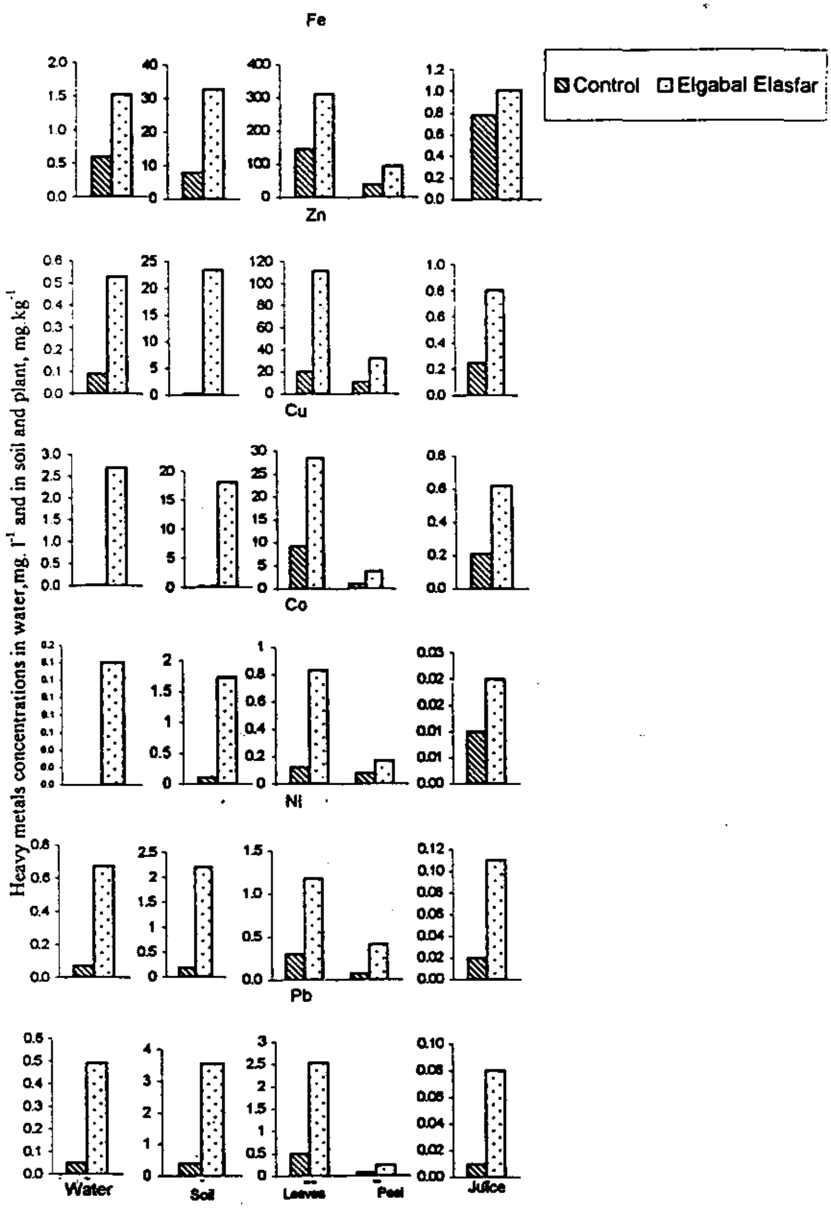
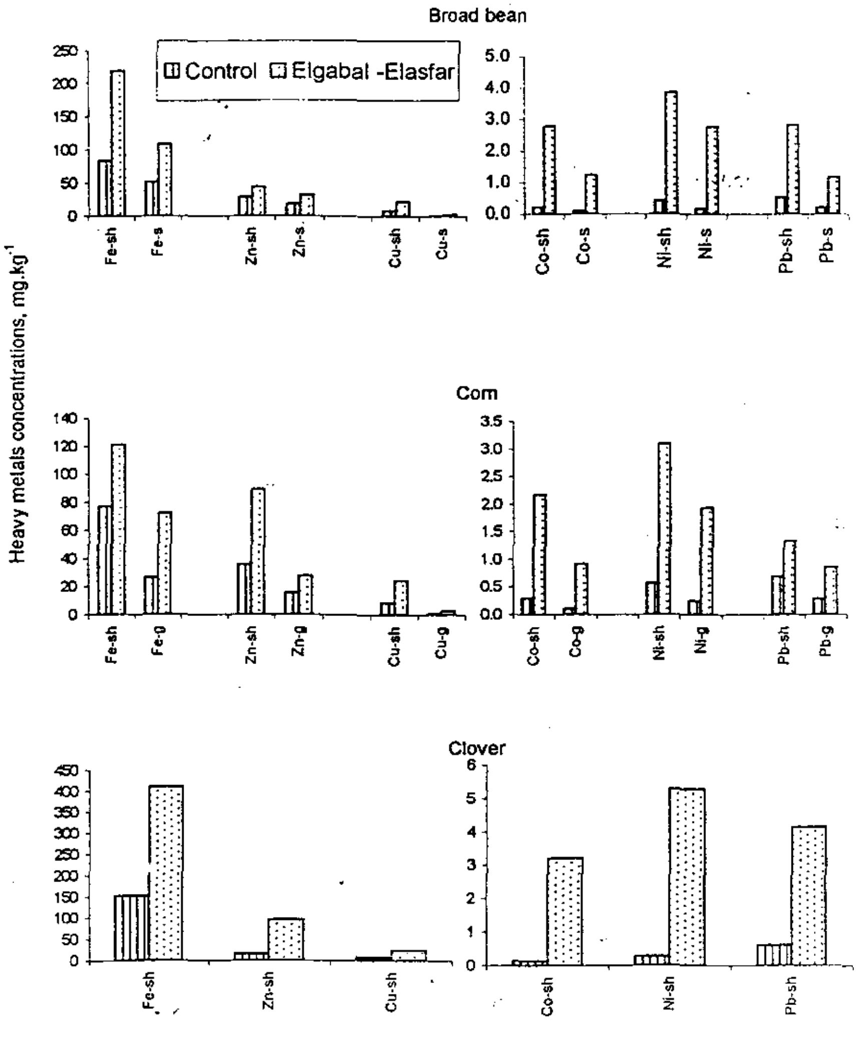


Fig. 1. Heavy metals concentrations in water, soils and organs of orange trees in Elkhanka (control) and Elgabal-Elasfar area as affected by sewage water application.



sh = Shoots g = Grains s = Seeds

Fig. 2. Heavy metals concentrations in bean, corn and clover plants as affected by sewage water application.

times. For clover the values of Fe, Zn, Co, Ni and Pb were lower, but Cu content was higher than that reported by Badawy and Helal (1997).

For the annual summer crop (corn) about the same sequence in increasing contents of the studied elements was found in both leaves and edible parts of corn (grains). The increases in such elements are in the following order: CO > Ni

> Zn > Pb > Fe. Results found for corn seeds indicated that the concentrations of Cu, Co, Ni and Pb were lower, whereas those of Fe and Zn were higher than those reported by Badawy and Helal (1997). Again, differences mentioned for both corn seeds and clover could be related to differences in variety, soil properties, management practices and source of irrigation water.

Conclusion

From the above-mentioned results, it can be concluded that the long term use of untreated sewage water for irrigating plants on Elgabal-Elasfar soil caused a dramatic increase in the content of heavy metals in the soil. Plants grown on this soil showed a high concentration of these elements in their tissues, including the edible parts. Differences found for accumulation of Fe, Zn, Cu, Co, Ni and Pb could be attributed to the season of growth, soil properties and management practices applied. It seems necessary that the sewage effluent needs to be treated before discharging in the drain systems. Such sources of water could only be used to grow trees, for only wood production but not vegetable crops.

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تأثير استخدام مياه الصرف الصحى فى الرى على خواص التربة ومحتوى بعض المحاصيل النامية بها من العناصر الثقيلة

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تم جمع عينات أراضى ونباتات من مزرعة الجبل الأصفر والتى تروى بمياه الصرف الصحى منذ اكثر من ٨٠ عام وكذلك من منطقة الخانكه التى تروى بمياة نهر النيل للمقارنة، حيث عملت قطاعات أرضية لعمق ١٦٠ سم وأخذت عينات على أعماق صفر-٢٠، ٢٠-٤٠، ٤٠-٨٠، ٨٠-١٦٠ سم لدراسة تأثير الرى بمياه الصرف الصحى على خواص التربة ومحتواها من العناصر الثقيلة وكذلك محتوى النباتات النامية من تلك العناصر.

وقد أوضحت النتائج ما يلى:
تغير قوام تربة الجبل الأصفر خاصة فى الطبقات السطحية (صفر-١٠سم) من الطمى الطينى الرملى إلى الطمى الطينى، من الطمى الرملى إلى الطمى الطينى الرملى فى الطبقة (١٠-٢٠ سم) كما حدث تغير طفيف فى محتوى هذه الأرض من كربونات الكالسيوم نتيجة استخدام مياه الصرف الصحى فى الرى وزاد محتواها من المادة العضوية حيث وصل الى ٣٠ ضعف الموجود بتربة الخانكه بينما انخفضت قيم الأس الهيدروجينى بمقدار الوحدة خاصة فى الطبقة السطحية. أدى استخدام مياه الصرف الصحى فى الرى إلى زيادة تركيز الأملاح فى التربة فقد وصلت قيم التوصيل الكهربى إلى ضعفين المقدر فى تربة الخانكه أما بخصوص العناصر الثقيلة فقد احتوت الطبقة السطحية لتربة الجبل الأصفر على تركيزات من عناصر الحديد، الزنك، النحاس، الكوبالت، النيكل، الرصاص بلغت ٠.٩، ٢.٣، ٦.٠، ١.٦، ٩.٩، ٦.٩، ٢.٣ أضعاف على الترتيب مقارنة بأرض الخانكه كما اتضح زيادة الكميه الكلية من عنصرى النحاس والنيكل عن الحدود المسموح بها فى طبقة الحرث بتربة الجبل الأصفر.

كانت تركيزات معظم العناصر الثقيلة في الأجزاء التى تؤكل من البرتقال والذرة والفول والبرسيم داخل الحدود المسموح بها ، بينما كان تركيز النحاس في الأجزاء الخضرية للنباتات النامية في أراضي الجبل الأصفر تزيد عن الحدود السامة وكذلك زاد تركيز كل من الحديد والنحاس فى البرسيم عن الحدود المسموح بها بينما كانت تركيزات الكوبالت في المجموع الخضري والبذور لنبات الفول البلدي أعلى من المسموح به .