

Chemical Fractionation of Trace Elements in Soil Irrigated with Wastewater and Bioavailability of Cd and Ni for the Plant

Mostafa, M.A¹; El-Sebaay, A.S¹; Somaya Ahmed, H² and El-Sayed, M.H²

¹*Soils Dept., Fac.of Agric., Ain Shams Univ., Cairo, Egypt*

²*Soils, Water & Environment Res. Inst., ARC, Egypt*

Abstract

Pot Experiment was carried out under polluted conditions to study the chemical fractionation of trace elements in soil irrigated with wastewater for 0, 5, 30, 76 yrs as well as to evaluate the bioavailability of Cd and Ni for bean and barley plants. The fractionation of Cd, Ni, Pb, Zn and Cu in soils was investigated using four operationally defined fractions: water-soluble and exchangeable forms, organically bound, carbonate bound and residual fraction of metals. Results obtained declared that the reuse of wastewater in irrigation for different periods led to relatively increase the available forms, organically bound, and carbonate fractions of Zn, Cu, Ni, and Cd accumulations in the soil. Whereas, Pb available and organic fractions took an opposite trend. The studied elements varied between each other with respect to the superior fraction. Cadmium and nickel elements were mostly found in the residual fraction, whereas Zn and Pb tended to be associated, especially Pb, with the carbonate fraction, while Cu was concentrated in both of the organic and carbonate fractions. At the same time, bioavailability of Cd and Ni fractions for plant was associated with the available, organic and residual fractions in the soil and positively correlated with the accumulated Cd or Ni in both bean and barley shoots. In addition, reuse of wastewater in irrigation, on the long time, led to elevate the concentration of Cd and Ni in the non-residual fractions in the soil and subsequently their bioavailability for the growing plants.

Keywords: Cadmium – Nickel – Zinc – Copper – Irrigation -Wastewater – Bioavailability.

Introduction

Water deficiency particularly in arid and semi arid regions has led to the rapid increase in the application of the municipal wastewater to agriculture lands results in significant pollution of the environment. Soil native heavy metals and those added through application of wastewater react with soil particles producing several fractions (Shuman et al., 2001). Although partitioning of metals between soil and soil solution may be directly used to assess the environmental impacts of metals, the study of metals fractions in the soil gives more information regarding the fate of metals in the environment. Knowledge of the total contents of heavy metals present in soil horizons provides limited information about their potential behavior and bioavailability. Heavy metals are associated with various soil components in different ways, and these associations determine their mobility and availability (Kabata-Pendias and Pendias,

1992; Singh, 1997; Ahumada et al., 1999). Water-soluble and exchangeable forms are considered readily mobile and available to plants, while metals incorporated into crystalline lattices of clays appear relatively inactive. The other forms precipitated as carbonate, occluded in Fe, Mn, and Al oxides, or complexed with organic matter could be considered relatively active or firmly bound, depending upon the actual combination of physical and chemical properties of soil (Sposito et al., 1982; Shuman, 1985). Thus, soil texture (clay content), pH, organic matter, and Fe-Mn oxides have been found to be the most important soil properties and components influencing the labiality and biological uptake of heavy metals (Ma and Rao, 1997; Narwal and Singh, 1998; Karczewska et al., 1998). Generally, under natural conditions, only a small fraction of trace metals is present in plant-available form (Kabata-Pendias and Pendias, 1992). However in contaminated soils, up to 30 to 60% of heavy metals can occur in easily labile forms (Singh et al., 1995; Karczewska et al., 1998). Several reagents (e.g., CaCl_2 , NH_4OAc , NH_4NO_3 , and EDTA) have been used to extract the "mobile" or "bio-available" forms of heavy metals with single extraction procedures (He and Singh, 1995; Karczewska et al., 1998; Christensen and Huang, 1999). Single and sequential extractions provide information on potential mobility as well as bioavailability and plant uptake of trace elements (Shuman, 1990; Singh, 1997). Studies on the speciation of heavy metals in polluted soils using sequential extraction techniques have increased in recent years, because these simple techniques provide knowledge about metal affinity to the soil components and the strength with which they are bound to the matrix (Narwal et al., 1999). Unlike the single extraction technique, sequential extraction gives information about both mobile and stable fractions of metals in soil, which evaluates the actual and potential mobility of metals. Numerous fractionation techniques have been used for sequential extraction of heavy metals in soils (Sposito et al., 1982; Shuman, 1985). The techniques vary in the number of fractions extracted, as well as the order and kind of reagents used. In general, the fractionation schemes start with the weakest extractants and end with the strongest, most aggressive and separate five to seven metal fractions.

Environmental pollution, especially by chemicals, is one of the most effective factors in the destruction of the biosphere components. Among all chemical contaminants, trace elements are to be of a specific ecological, biological, and/or health significance. Accumulation of heavy metals in agricultural soils has become a major concern for food crop production. Of these metals, cadmium and nickel are recognized as two of the most hazardous ones which are not essential for plant growth (Kabata-Pendias and Pendias, 1992). Cadmium and nickel -are mainly added to the soil through various anthropogenic sources such as industrial wastes, automobile emissions, mining activity, fertilization, pesticides, sewage effluent and sewage sludge applications (Ma and Rao, 1997).

The most health hazards, of great concern and which are due to chemicals in wastewater, arise from contamination of field crops by heavy metals. These metals are taken up from soils and bioaccumulated in crops, causing damage to plants when reaching high levels and under certain conditions becoming toxic to human and animals feed on metal-enriched plants.

Mermut et al (1996) found a significant positive relationship between the total content of trace elements and the percent of clay in the soil. They suggested that the major portion of the trace elements is adsorbed by silicate clay minerals in cationic form Ni has become a serious pollutant that is released in the emission from metal processing operations and from the increasing combustion of coal and oil. Under Egyptian conditions, Helal et al. (1996) found that the Langmuir isotherms were appropriate for Cd adsorption by eleven different types of soils (alluvial, calcareous and desertic sandy). They concluded that cadmium adsorbed on alluvial and calcareous soils was partially irreversible. Sum of the amount desorbed in four successive extracts of 0.5 M CaCl₂ solution was found to represent 57 and 61% of those adsorbed by alluvial and calcareous soils, respectively. Desorption of Cd increased as the pH decreased. The amount of Cd desorbed at both pH 5.0 and 7.5 was found to represent 27.7 and 11.8% of that adsorbed, respectively.

Kabata-Pendias and Pendias (1992) stated that solubility of soil Ni is inversely related to the soil pH. Nickel sorption on Fe and Mn oxides is specially pH-dependent, probably due to NiOH is preferentially sorbed and also the surface charge on sorbents is affected by pH. Alloway (1995) found that soils containing free CaCO₃ can sorb Cd and reduce its bioavailability. The same author mentioned that Cd in fulvic acid solutions extracted from sewage sludges was only weakly bound (less strongly than Zn and Ni), but variations could occur in different sludge- derived fulvic acids. Kasimov et al. (1996) found that the fulvic acids at low concentrations enhanced adsorption of nickel due to the formation of soluble metal-organic complexes. Evidently, in the mineral soil horizons, the forms of Ni which are low-soluble, tightly sorbed on sesquioxides and clay minerals dominated. In the organic horizons, increasing the mobility of Ni is mainly due to the formation of complexes with the soil organic matter. It is important to evaluate the availability and mobility of heavy metals to establish environmental guidelines for potential toxic hazards and to understand chemical behavior and fate of heavy metals contaminants in soils. Therefore, the sequential extraction used in this study is useful to indirectly assess the potential mobility and bioavailability of heavy metals in the soils (Ma and Rao, 1997). However, little attention has been paid to the fate and chemical behavior of heavy metals in agriculture lands irrigated with wastewater in arid and semi arid regions. Therefore, the main objective of this study was to study the chemical fractionation of trace elements in soil as well as bioavailability of Cd and Ni for the plants.

Materials and Methods

Soil Properties

Four surface soil samples (0-20cm) representing different location of El-Gabal El-Asfar farm , which is located at 25 Km north-east of Cairo, and irrigated with wastewater for 0, 5, 30, 76 yrs have selected for the current investigation. Some physical and chemical characteristics of the used soil sample are shown in Table (1).

Experimental work:

Pot experiment was carried out under greenhouse conditions at Soil, Water & Environment Res. Inst., Giza Governorate to evaluate the bioavailability of Cd and Ni forms under polluted conditions when the bean and barley plants are subjected to the high levels of Cd and Ni concentrations.

Selected seeds of bean (*vicia faba* L. CV Giza 2) as a dicotyledonous plant and barley (*hordeum vulgar* L. CV Giza 123) as a monocotyledonous plant were soaked in deionized water for 24 hs. Eight bean seeds and twenty barley ones were sown in plastic pots having dimensions of 30 cm diameter and 25 cm height and filled with 5 kg soil. Conventional basic fertilizers were added to soil before cultivation at the recommended rates according to Egyptian Ministry of Agriculture (20 and 30 kg N fed as ammonium sulphate, 30 and 15 kg P fed as super phosphate and 50 kg K as potassium sulphate fed for both faba bean and barley, respectively). Pots were arranged in a completely randomized block design with three replications for each treatment

Table 1 Selected chemical and physical properties of the soil materials irrigated with wastewater different periods

soil sample	Particle size distribution %				Texture	pH (soil paste)	EC (ds/m)	Total CaCO ₃ %	Total O.M,%
	C.Sand	F.Sand	Silt	Clay					
control	79.2	10.9	2.3	7.6	Sand	7.00	4.80	0.41	0.10
5 year	43.0	26.9	3.2	26.9	Sand Clay loam	7.62	2.11	0.45	1.56
30 year	42.5	32.5	2.8	22.2	Sand Clay loam	7.02	2.27	0.55	2.74
76 year	42.2	27.6	7.5	22.7	Sand Clay loam	6.12	1.95	0.20	6.11

After full emergency (7 days), Cd and Ni were added for bean plants (6 seedling pot-1) at the rates of 0, 8, 16 and 32 mg kg⁻¹ soil as Cd-acetate and Ni-sulphate respectively. On the other hand, the rates of 0, 7, 14 and 28 mg Cd or Ni kg⁻¹ soil were added for barley plants (15 seedling pot-1) Cadmium and Ni were added to soil of each pot (on volume base) immediately before irrigation with tap water to reach about 70% of soil field capacity.

Plant (shoot) samples of both bean and barley after 70 days from sowing were collected, oven-dried at 70 °C, ground and dry weight was recorded, samples were then stored in plastic bags for required analysis as previously mentioned. Soil samples were also air-dried, crushed, passed through a 2 mm sieve, mixed thoroughly and stored in clean suitable containers until chemically analyzed.

Mechanical analysis were determined by Piper (1950), Field capacity, Calcium carbonate percentage, Soil reaction (pH value), Electrical conductivity and soluble ions in the extract of soil-water saturated paste were determined as described by Black (1965) Cadmium and nickel fractionations as well as some other trace elements in the soil samples were determined using sequential chemical extraction procedure according to McGrath and Cegarra (1992).

Trace Metal Fractionation:

The procedure of McGrath and Cegarra (1992) was selected for this study is designed to separate heavy metals into four operationally defined fractions: water-soluble and exchangeable, organically bound, carbonate bound and residual fraction of metals. Three grams of soil were weighed and placed in a 50-ml polycarbonate centrifuge tube. The following extractions were made sequentially.

(i) water-soluble and exchangeable fractions of metals (extractable with 30 ml 0.1M CaCl₂ for 16h and centrifuged at 30000×g for 20 min, the weight of the tube and its contents was carefully recorded and the supernatant was decanted then the weight of the wet residue in the tube was recorded); (ii) organically bound metals (extractable with 30 ml 0.5M NaOH for 16h centrifuged as before, decanted and weights recorded then the supernatant was digested in 20 ml of aqua regia (4:1); (iii) carbonate bound (extractable with 30 ml 0.05M Na₂EDTA for 1 h, followed by centrifugation, decanting and weighing ; (iv) residual fraction of metals extracted by hot acids dried and digested in aqua regia, filtered and made up to 20 ml in 5% (v/v) HCl.

In steps (i), (ii), and (iii) represent the total weights of tube and contents of solid and liquid phases minus the weight of tube, the residue were taken to represent the exact weight (in g) or volume (cm³). The weights (in g) of the wet residues minus 3 g sample were assumed to be equal to the volume extractant remaining (r) in the residue after decanting the supernatant, and were used to correct the metal concentration in the subsequent extracts. All supernatant were clear solutions, and very little soil was lost during the procedure. The amount of metal (in g) in each of the extract was calculated as follows:

$$(i) C_1V_1 \quad (ii) C_2(V_2+r_1) - C_1r_1 \quad (iii) C_3(V_3+r_2) - C_2r_2 \quad (iv) 20C_4 - C_3r_3$$

Where C_n = concentration (μg cm⁻³) in sequential extract n; V_n = volume (cm³) of supernatant n ; r_n = volume (cm³) of extract entrained in the pellet from extract n. Concentration of Cd and Ni and some other trace elements were determined in all of the solutions by inductively coupled plasma emission spectrometry (ICP 400 Perkin Elmer) with U-5000 at ultrasonic nebulizer unit.

Results and Discussion

Data presented in table (2) show that Cd was mostly concentrated in the residual fraction compared to the other fractions. The percentage of Cd in the residual fraction decreased gradually from 81.8% in the soil irrigated with wastewater for 5 yrs to 48.9% in the soil irrigated for 76 yrs. However, the percentage of Cd in the residual fractions increased gradually as the irrigation periods increased from 5 to 76 yrs. This means that about 18.2, 41.2 and 51.1% of the Cd in the soil irrigated for 5, 30 and 76 yrs with wastewater respectively were associated with the available, organic and carbonate fractions. The later fraction being the greatest one. However, the percentage of Cd recovered by CaCl₂ (available form) increased, compared to organic and carbonates fractions; as a result of increasing the time of irrigation up to 76 yrs (figure 8).

Table (2): Distribution of some trace element fractions in soil as affected by different affected by different irrigation periods with wastewater.

Periods of irrigation with wastewater (year)	Trace element concentration in soil (ppm)				
	Cd	Ni	Pb	Zn	Cu
Available form					
0	0.01	0.364	0.057	0.156	0.057
5	0.014	0.231	0.255	0.083	0.069
30	0.037	0.337	0.046	0.762	0.115
76	0.17	0.932	n.d	12.2	0.220
LSD (0.05)	0.048	0.261	0.521	0.184	0.089
Organic fraction					
0	0.017	0.815	0.003	1.22	0.35
5	0.017	1.240	0.019	2.55	9.30
30	0.042	2.46	0.763	15.4	27.80
76	0.108	4.83	4.97	54.00	60.80
LSD (0.05)	0.05	1.13	0.908	5.88	12.6
Carbonate fraction					
0	0.046	0.815	0.04	0.93	0.40
5	0.152	2.250	19.40	43.00	7.92
30	0.471	4.050	88.40	153.00	31.50
76	0.860	4.920	208.00	342.00	64.40
LSD (0.05)	0.257	1.720	54.00	16.50	6.63
Residual fraction					
0	0.235	1.64	0.344	2.95	0.60
5	0.826	7.42	0.175	28.30	5.04
30	0.785	6.49	0.123	40.80	8.52
76	1.090	9.53	8.740	96.10	21.90
LSD (0.05)	0.256	1.51	1.620	5.26	2.36

n.d= not detected

The magnitude percentage of Cd available form, organically bound and carbonate bound in irrigated soil with wastewater for 30 yrs was, generally, about twice its corresponding values in irrigated soil for 5 yrs. But, increasing the irrigation period up to 76 yrs increased the Cd available form in soil to about 5 times as compared to irrigation for 5 yrs. At the same time, Cd accompanied with organic matter and carbonate was nearly three fold the corresponding values in irrigated soil for 5 yrs. This

means that the bioavailability of Cd in the soil increased as a result of the irrigation time with wastewater was progressed. These results agreed with the observations of McGrath and Cegarra (1992), and Ma and Rao (1997).

In respect of Ni, obtained data in table (2) declare that Ni distribution among the fractions in the soils irrigated with wastewater for different periods followed, to a great extent, the same trend of Cd. The residual fraction was by far the most important fraction for Ni in the soil under all conditions of irrigation. More than 45% of the Ni resided in the residual fraction with the order being; residual (45- 66.6%) > carbonate (20.2-30.4%) > organic (11.1-23.9%) > available (2.1-10.1%) (table 2 and figure 8). This order was, mostly, consistent with the results obtained by McGrath and Cegarra (1992) and Wang et al. (1997). The large proportion of Ni in the residual fraction could be attributed to that Ni has the highest crystal field stabilization energy of the common divalent metals, and thus has a high potential to be enriched in clay minerals Wang et al. (1997). In the soil irrigated with wastewater for different periods of time (5, 30 and 76 yrs), data also show that Ni associated with organic matter was 1.5, 3.0 and 6 times its concentration in the control soil (virgin soil), respectively. This may be attributed to increasing the organic matter content in soil with increasing irrigation periods with wastewater (table 1). However, Ni carbonate form in soil irrigated with wastewater for 5, 30 and 76 yrs was about 2.8, 5 and 6 folds its concentration in the control soil, whereas Ni in the residual fraction was about 4.5, 4.0 and 6.0 times in the same order. On the other hand, no significant differences were obtained for Ni available form after 5 and 30 yrs of irrigation as compared to the corresponding value in the control soil, except in case of 76 yrs of irrigation where a significant difference was encountered (Table 2).

For Pb, obtained data in table (2) show that over 94% of Pb was associated with the carbonate fraction in soils irrigated with wastewater although it was concentrated in the residual fraction (77.6%) in the control soil (virgin soil). At the same time, less than 6% of total Pb was accompanied with the organic, residual and available fractions, indicating that very low concentrations of Pb present in the soluble and exchangeable fractions (available), which was not detected in the soil irrigated with wastewater for 76 yrs. These results are in coincidence with the observations of McGrath and Cegarra (1992) who declared that Pb extracted from sludge-amended soils was not sufficiently bioavailability to be taken up by the grown crops. They suggested that Pb moves poorly through the soil-plant pathway.

Concerning the Zn, data in table (2) showed, to a great extent, a significant positive effect for irrigating the soil with wastewater for different periods on the fractionation of Zn in the different sizes. It is evident that Zn carbonate fraction was predominate in soil irrigated with wastewater compared to the unirrigated soil. The distribution of Zn among the fractions, in soil irrigated for 5-76 yrs can be arranged in the following order: carbonate (58-72.9%)> residual (19-38.2%) < organic (3-10.7%)> available (0.15-25%). These results are in agreement with those obtained by McGrath and Cegarra (1992) who found more than 40% of Zn associated with carbonate fraction in sludge-treated soils. The sum of Zn in the available, organic and carbonate fractions reached 43.9% in the virgin soil increased to 80.9% in irrigated soil with wastewater

for 76 yrs, indicating that Zn in irrigated soils may be highly available for growing plants.

Concerning the different Cu fractions distribution in the soil, data presented in table (2) indicate that almost similar results were obtained as previously found for Cd, Ni and Zn where Cu fractions in the soil irrigated with wastewater were, generally, increased with increasing the irrigation periods up to 76 yrs. It is obvious also that copper was mostly concomitant with both of organic and carbonates fractions compared to the other ones. In other words, Cu fractions in irrigated soils with wastewater took the following decreasing order: Cu carbonate (28.3-46.4%) \approx Cu organically bound (24.8-41.6%) > residual (12.5-42.6%) > Cu available form (0.2-4.3%). This finding means that the proportion of Cu remaining in the residual fraction and available form in irrigated soils with wastewater was the smallest one. These results are consistent with those obtained by McGrath and Cegarra (1992) who found 30% or more of Cu in sludge-treated soils was associated with the organic fraction. The major association of Cu with the organic fraction in the soils irrigated with wastewater may be attributed to high formation constants of organic-Cu complexes (McGrath and Cegarra, 1992 and Ma and Rao, 1997). In addition, increasing the non-residual fractions of Cu from 57.4% in the virgin soil to 77.4, 87.5 and 85.2 % in the soil irrigated with wastewater for different periods, namely, 5, 30 and 76 yrs, respectively, reflected the bioavailability of Cu for the growing plants in these soils.

From the previous discussion it can be concluded that, the reuse of wastewater in irrigation for different periods of time relatively led to increase the available, organic and carbonate fractions of Zn, Cu, Ni and Cd in the soil whereas Pb available and organic fractions took an opposite trend. The studied elements varied between each other with respect to the superior fraction. Cadmium and nickel elements were mostly concentrated in the residual fraction, whereas Zn and Pb tended to associated, especially Pb, with the carbonate fraction. In this concern, Cu was, to a great extent, equally concentrated in both of the organic and carbonate fractions. In other words, the percentage of non-residual fraction ranged from 77.4 to 87.5% for Cu, 61.8 to 80.9% for Zn, 33.4 to 52.8% for Ni and 18.2 to 51.1% for Cd as a result of irrigation with wastewater for different periods, indicating that the concerned elements are more mobile in irrigated soil with wastewater which reflected on the growing plants in these soils

Bioavailability of Cd and Ni for plant:

Increasing Cd concentration in the soil led to increase its different forms (available, organic, carbonate and residual), consequently the accumulation of Cd in faba bean shoots was relatively increased (figure 1). This finding may be attributed to increasing the bioavailability of non-residual fractions due to irrigation with wastewater for different periods as previously mentioned. However, the bioavailability of Cd available form for the growing plants was, in general, more pronounced (R^2 ranged from 0.76 to 0.90 depending on the irrigation period with wastewater than the other forms). In this respect, the bioavailability of the different fractions of Cd under faba bean cultivation generally decreased in the following order: available > carbonate >

organic > residual. For the control soil, virgin soil, only two positive correlations were achieved between Cd concentration in faba bean and both of Cd available form ($R^2=0.9$) and carbonate bounded ($R^2 = 0.88$). These results probably due to treating the soil with different concentrations of Cd in available form and soil physical and chemical properties where it is sandy texture and poor in its organic matter content (table 1).

It is obvious also that the obtained data in figure (2) showed positive significant correlations between different fractions of Cd in the soil and its accumulation in barley shoots. Bioavailability of Cd associated with the available, carbonate and organic fractions for the plant was more pronounced than that accompanied with the residual one where R^2 of the abovementioned non residual fractions of Cd concentration in the plant tissue ranged from 0.65 to 0.91, 0.67 to 0.86, and 0.6 to 0.86, respectively, as the irrigation period with wastewater increased from 5 to 76 yrs. These results confirmed the aforementioned results of Cd chemical fractionation where the percentage of non residual fractions increased with increasing the irrigation period up to 76 yrs.

With respect to Ni bioavailability for bean, data illustrated in figure (3) showed positively increase in Ni accumulation in the faba bean shoots with increasing the different Ni-fractions in soil. In this concern, significant correlations were, to a great extent, encountered between Ni concentration in the plant tissue and Ni associated with different fractions, especially for the soil irrigated for 76 yrs (figure 3). Apart from the control soil, bioavailability of Ni available form gradually increased as the irrigation period increased up to 76 yrs (R^2 ranged from 0.28 to 0.83), whereas for the other Ni forms (organic, carbonate and residual) was still high. These results emphasized the previous data of Ni fractionations in soil.

Concerning the Ni bioavailability for barley plants, almost similar results as previously obtained for faba bean were existed, where its accumulation in the barley shoots positively increased as a result of increasing the different Ni fractions in the soil, i.e., available, organic, carbonate and residual, (figure 4). Bioavailability of all Ni fractions in soils irrigated with wastewater for 0, 5, and 76 yrs were significant for barley plants, except few cases. However, non significant correlations were observed between Ni accumulation in the barley plant tissue and its different fractions in soil irrigated for 30 yrs.

In general, both Cd and Ni concentrations relatively increased in the faba bean and barley shoots by increasing their levels in the soil. On the other hand, Cd and Ni accumulation in the two plant tissues relatively reduced, except in case of Cd in barley as the irrigation period increased up to 76 yrs. In this respect, Ni was accumulated in the barley more than Cd probably due to the fact that Ni was highly mobile in the plant, and leaves being the major sink in the shoots for Ni during vegetative growth, as well as to higher content of Ni in the virgin soil regardless the addition of Ni to the soil.

From the abovementioned results, it can be said that, Cd or Ni associated with the available, organic, carbonate and residual fractions in the soil was mostly significantly correlated with the accumulation of Cd or Ni in both faba bean and barley shoots. The relatively variation in the bioavailability of both elements for the concerned two plants may be attributed to the variation in the plant genotype (Kabata-Pendias and Pendias, 1992), mobility and solubility of the element which is depending on its

chemical form (Ma and Rao, 1997) as well as chemical and physical properties of the soil. In addition, reuse of wastewater in irrigation, on the long time, led to elevate the concentration of Cd and Ni in the non-residual fractions in the soil and subsequently their bioavailability for the growing plants (bean and barley plants).

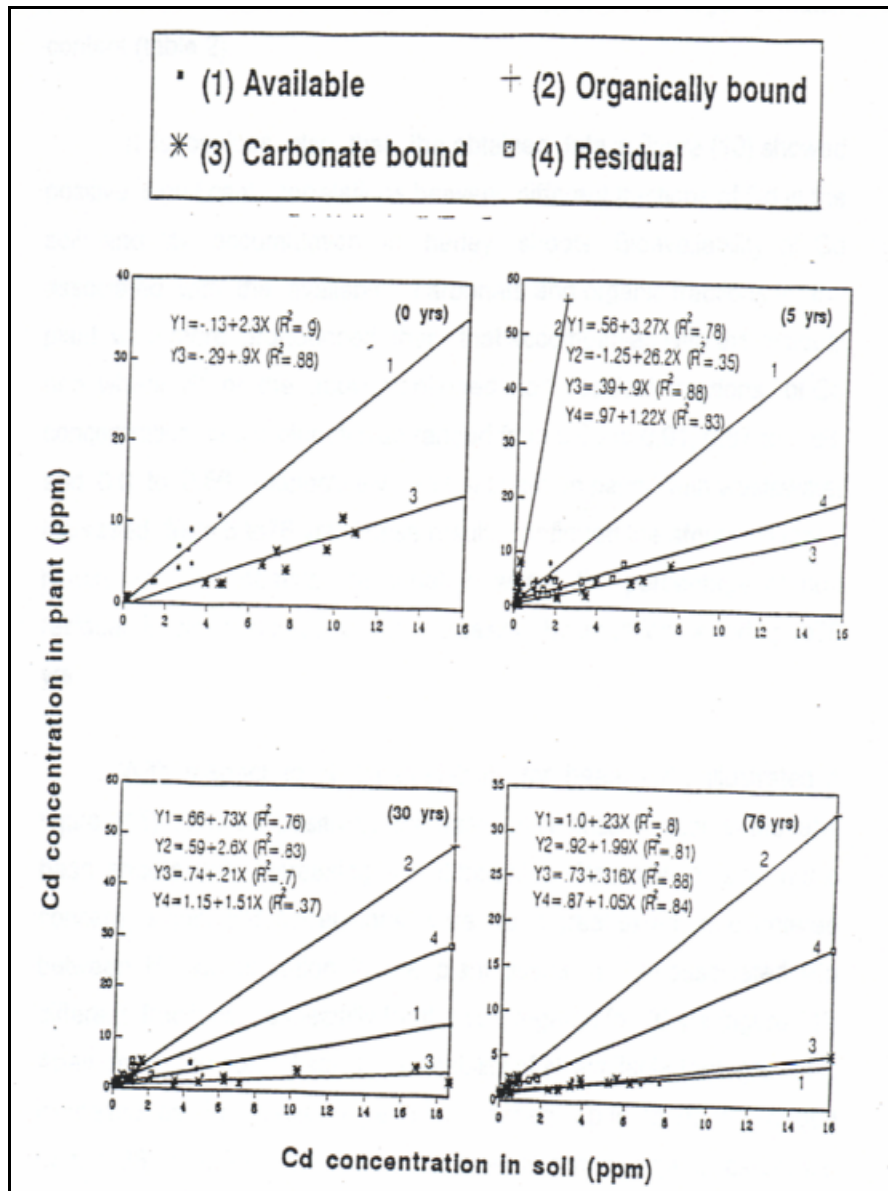


Figure (1) Influence of cadmium fractions in soil irrigated with wastewater for different years (0, 5, 30 and 76 yrs) and treated with various concentrations of Cd^{2+} on its accumulation in faba bean shoots.

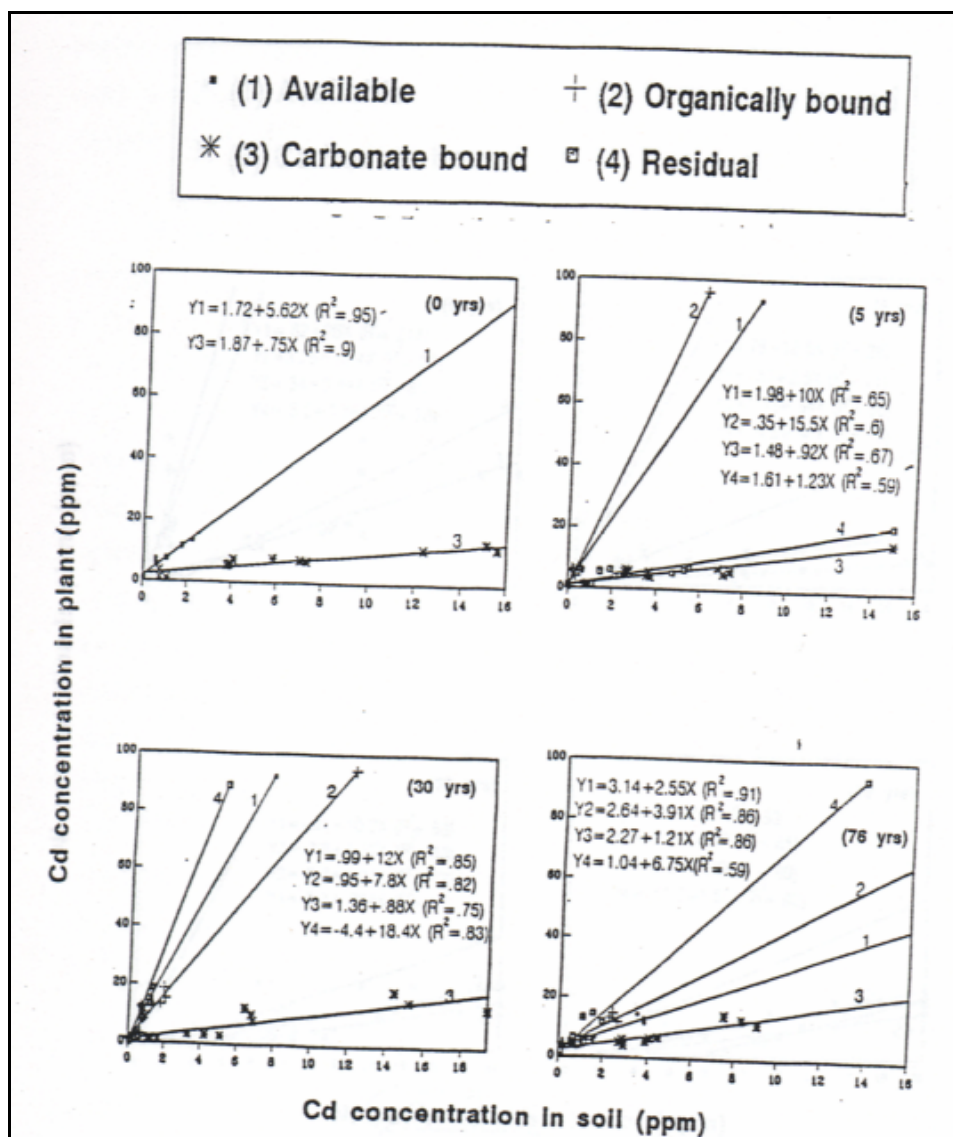


Figure (2) Influence of cadmium fractions in soil irrigated with wastewater for different years (0, 5, 30 and 76 yrs) and treated with various concentrations of Cd²⁺ on its accumulation in barley shoots.

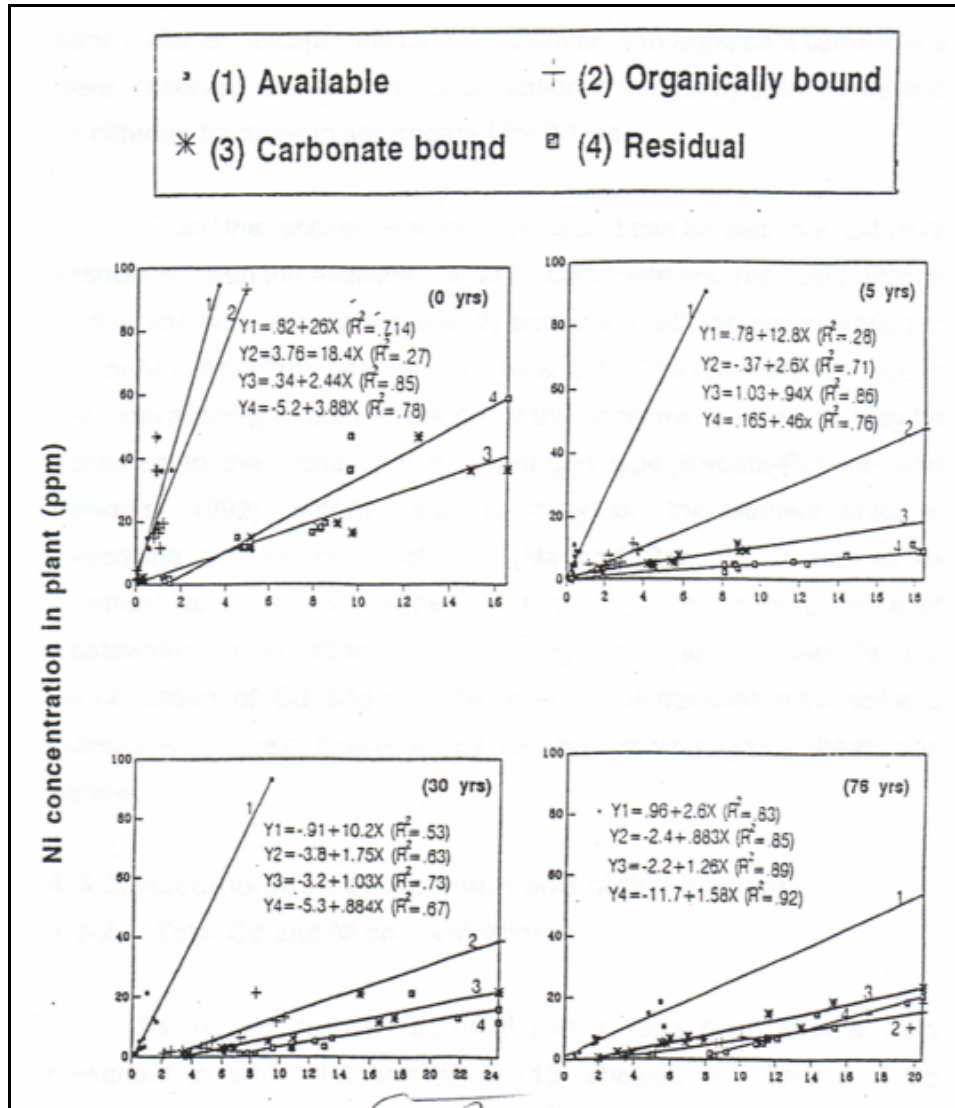


Figure (3) Influence of nickel fractions in soil irrigated with wastewater for different years (0, 5, 30 and 76 yrs) and treated with various concentrations of Ni^{2+} on its accumulation in faba bean shoots.

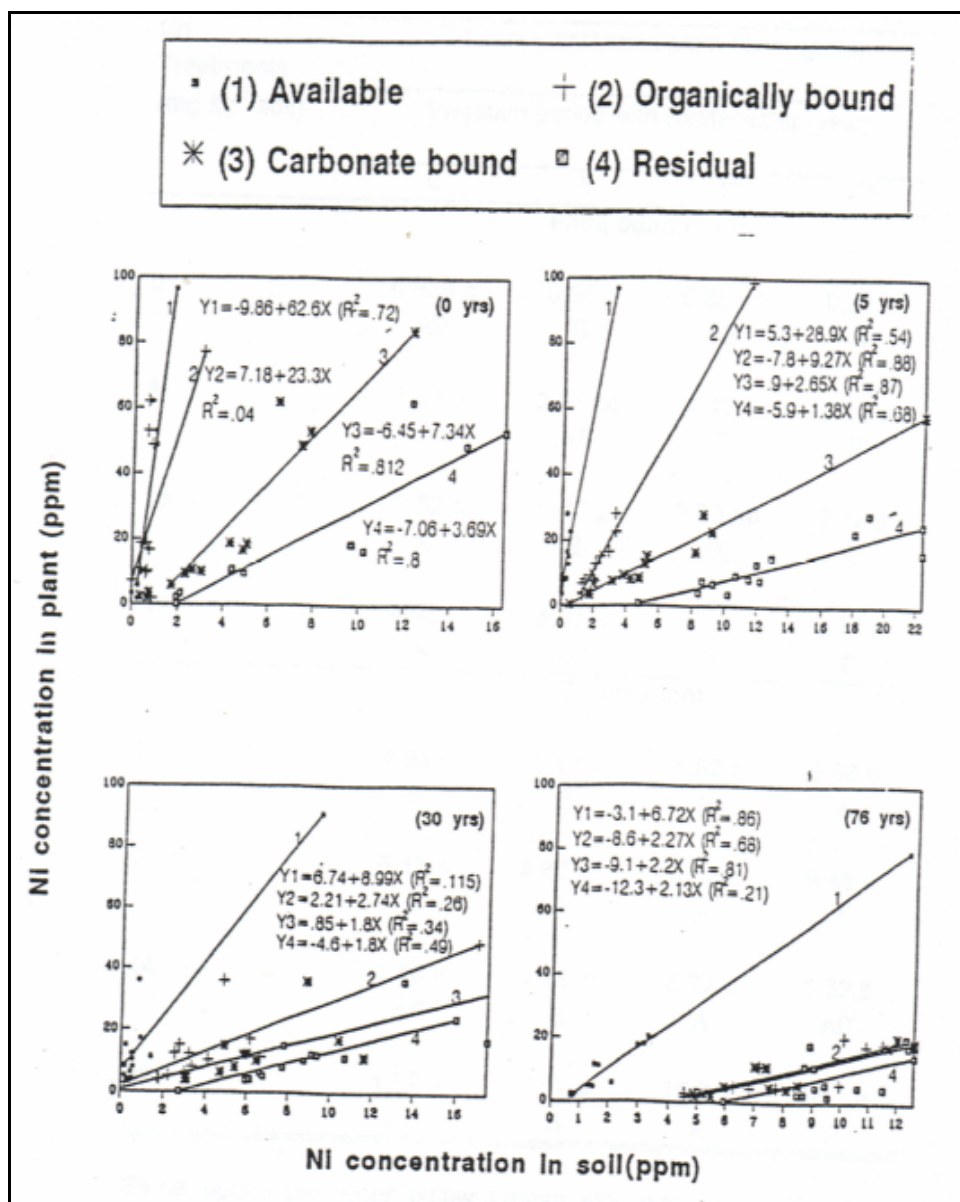


Figure (4) Influence of nickel fractions in soil irrigated with wastewater for different years (0, 5, 30 and 76 yrs) and treated with various concentrations of Ni^{2+} on its accumulation in barley shoots.

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الصور الكيميائية للعناصر الصغرى في التربة المروية بمياه متدنية الجودة وتيسير الكاديوم والنيكل للنبات

محمد أحمد محمود مصطفى¹، عبد اللطيف صالح السباعي¹، سمية أحمد حسنين²
ومصطفى حلمى السيد²

قسم الأراضى كلية الزراعة جامعة عين شمس¹ - معهد بحوث الأراضى والمياه والبيئة ، مركز البحوث الزراعية² - القاهرة - مصر

اجريت تجربة أصص تحت ظروف ملوثة بهدف دراسة الصور الكيميائية المختلفة للعناصر الدقيقة في تربة مروية بمياه منخفضة الجودة (مياه المجارى) لفترات زمنية تتراوح بين صفر، 5، 30، 76 سنة، وكذلك تقييم تيسر الكاديوم والنيكل لنبات الفول والشعير. واستخدم الإستخلاص المتتالى لعناصر الكاديوم والنيكل والرصاص والزنك والنحاس في التربة بإستخدام أربع صور بطريقة McGrath and Cegarra (1992) وهى الصورة الذائبة والمتبادلة والصورة المرتبطة بالمادة العضوية والصورة المرتبطة بالكربونات وأخيرا الصورة المتبقية. أوضحت النتائج أن إعادة استخدام المياه منخفضة الجودة في الري لفترات زمنية مختلفة أدى الى زيادة كل من الصورة الميسرة والمرتبطة بالمادة العضوية والمرتبطة بالكربونات لكل من الزنك والنحاس والنيكل وكذلك الكاديوم في حين كان الرصاص في التربة معظمه مرتبط مع الكربونات، مما يوضح أن العناصر تحت الدراسة تختلف مع بعضها البعض لتحديد الصورة السائدة، أما عنصرى الكاديوم والنيكل غالبا ما توجد في الصورة المتبقية، وفي نفس الوقت الصور الكيميائية لكل من عنصرى الكاديوم والنيكل في التربة كانت لها علاقة ايجابية مع تراكم كل من العنصرين في المجموع الخضرى لنبات الفول والشعير. بالإضافة الى أن استخدام الماء العادم في الري وعلى المدى الطويل يؤدى الى رفع تركيز الكاديوم والنيكل في الصور غير المتبقية non- residual fractions في التربة وبالتالي تيسيرها الى النباتات النامية.