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Bioaccumulation of Trace Elements by Different Plant Species Grown on Potentially Contaminated Soils of NWFP, Pakistan

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Abstract: This study was conducted in summer and winter seasons of the years 2000 and 2001 to assess the bioaccumulation of trace elements by different plant species grown on potentially contaminated soils of NWFP, Pakistan. A total of 40 effluent irrigated plant samples were collected from Amangarh Industrial Area and Pirsabak, Nowshehra (NWFP). For comparison four tubewell irrigated plant samples were also collected as background samples. The highest values of 75.0, 137.9, 982.0, 286.9, 8.3, 15.0, 73.0, 72.0 mg kg^{-1} were observed in effluents irrigated plant tissue and 34.2, 18.6, 120.9, 34.0, 2.6, 4.2, 16.0 and 20.0 mg kg^{-1} in tube well irrigated plant tissue for Zn, Cu, Fe, Mn, Cd, Cr, Ni and Pb, respectively. The values observed in this study were also compared with the toxic and excessive levels. The comparison showed that 90, 28, 43, 98 and 30% of samples contained toxic or excessive levels of Cu, Cd, Cr, Ni and Pb, respectively. The concentrations of these elements in effluent irrigated plants were higher than those in tubewell irrigated plants and also higher than those generally reported in the literature.

Key words: Industrial pollution, metal toxicity, contaminated soils

INTRODUCTION

Trace elements are defined as those elements occurring in trace concentrations (micro gram per gram or parts per million) in biological materials[1-3]. Seven trace elements B, Cl, Cu, Fe, Mn, Mo and Zn were designated as micronutrients because they have been determined to be essential for plants based on the criteria of essentiality established by Arnon and Stout[4]. Although it has recently been established that Ni is essential to higher plants[5,6]. The trace elements considered as micronutrients have specific and physiological functions in plant metabolism[7] while Cd, Cr and Pb has not yet shown any specific functions in plant growth.

Plants can accumulate trace elements, especially heavy metals, in or on their tissues due to their great ability to adapt to variable chemical properties of the environment. Thus plants are intermediate reservoirs through which trace elements from soils and partly from waters and air, move to man and animals. Plants may be passive receptors of trace elements (fallout interception or root but they also exert control over uptake or rejection of some elements by appropriate physiological reactions[8]. Fargasova and Svetkova[9] conducted a study in which young mustard (*Sinapis alba* L.) plants were used to evaluate the effect of Cd in combination with Cu, Zn, Pb and Fe on root prolongation and metal accumulation in the roots. They reported that all metal-metal combination significantly inhibited root growth compared to the control sample as well as to both metals alone. Similarly, Uslo *et al.*[10] investigated the comparative growth and Cd (II), Pb (II)and Cu (II)ions bioaccumulation properties of *Rhizopus arrhizus* as a function of initial pH, temperature and initial metal ion concentrations. Results indicated that microbial growth and metal ion uptake of *R. arrhizus* were significantly affected by initial metal ion concentrations.

Trace elements entering plant tissues are active in metabolic processes, but also can be stored as inactive compounds in cells and on the membranes. In each case, however, they may interfere with and upset the chemical composition of plants without causing visible injury[11].

In view of the fact that the number of sources of pollution and demand for food are increasing, the challenge of having adequate knowledge on trace elements toxicities is intensified. This study was conducted to determine the concentrations of trace elements (Zn, Cu, Fe, Mn, Cd, Cr, Ni and Pb) in different plant species grown on potentially contaminated soils of Amangarh Industrial Area and Pirsabak, Nowshehra, in NWFP.

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MATERIALS AND METHODS

The plant samples including bottle gourd (*Cucurbita maxima*), brinjal (*Solanum melongena*), coriander (*Corriandrum sativum*), hot pepper (*Capsicum frutescens*), maize (*Zea mays*), okra (*Abelmoschus esculentus*), spinach (*Spinacia oleracea*), spong gourd (*Luffa acutaugula*), radish (*Raphanous sativus*), turnip (*Brassica napus*) and wheat (*Triticum aestivum*), were collected from 11 different sites in which 10 sites, irrigated with effluents and possibly contaminated by the industrial effluents were selected from Amangarh Industrial Area and Pir Sabak, Nowshehra (NWFP), while the 11th site with in the area irrigated with tubewell water was considered as background sample. The samples were collected both in summer and winter seasons of the years 2000 and 2001. A total of 40 effluent irrigated and 4 tubewell irrigated (background) plant samples were collected and then washed with distil water, oven dried at 70°C and crushed by Willy Mill. The grinded samples were digested, using wet digestion method[12] and analyzed for trace elements (Zn, Cu, Fe, Mn, Cd, Cr, Ni and Pb) by atomic absorption spectrophotometer (Perkin Elmer, Model No. 2380).

RESULTS AND DISCUSSION

Zinc: The Zn concentrations ranged from 31.6-75.0 mg kg^{-1} with the mean value of 34.15±4.67 (Table 1). The highest and lowest values were observed in samples of spinach and brinjal, respectively. However, the background plant sample (Okra) contained the maximum value of 34.2 mg kg^{-1}.

According to t-test comparison, the concentrations of Zn in effluent and tube well irrigated plants showed no significant differences (Table 2).

Katyal and Randhawa[13] reported that normal range of Zn in healthy vegetables is 20-100 mg kg^{-1} while Kabata-Pendias and Pendias[11] reported that toxic or excessive levels of Zn in plants is 100-400 mg kg^{-1}. Comparing with normal and toxic range, all the plant samples collected from various sites of NWFP (Amangharh and Pirsabak) were found within sufficiency range rather than toxic one. Wazir[14] reported Zn values from 57.33-131.33 mg kg^{-1} in plant leaves grown on possibly contaminated soils within the proximity of Peshawar city. Kitagishi and Yamane[15] recorded average value of 21 mg kg^{-1} in rice grains grown in contaminated sites of Japan while Diez and Rosopulo[16] observed average value of 36.0 mg kg^{-1} in potato tubers grown in contaminated sites of West Germany. So, the values observed in this study are in agreement with those reported for contaminated sites.

Table 1: Range and average values (mg kg^{-1}) of trace elements in effluent and tubewell irrigated (background) plant samples collected from various sites of NWFP Province

Trace elements	Effluent irrigated plant values (n=40) Range	Mean±SD	Tubewell irrigated plant values (n=4) Range	Mean±SD
Zn	31.6-75.0	34.15±4.67	23.6-34.2	27.00±4.84
Cu	29.2-137.9	49.27±28.22	14.7-18.6	16.72±2.17
Fe	79.8-982.0	191.84±125.6	90.4-120.9	100.22±14.3
Mn	64.0-286.9	19.90±30.94	22.0-34.0	29.40±5.25
Cd	2.8-8.3	3.13±0.99	1.3-2.6	1.78±0.59
Cr	3.9-15.0	5.31±0.97	1.0-4.2	3.15±1.46
Ni	10.0-73.0	26.01±11.17	10.0-16.0	13.00±2.60
Pb	20.5-72.0	25.98±8.92	5.0-20.0	14.00±6.40

SD: Standard Deviation

Table 2 : Statistical difference among trace elements in effluent vs tubewell irrigated (background) plant samples collected from various sites of NWFP Province

Trace elements	t-value
Zn	2.93
Cu	2.23
Fe	1.64
Mn	4.65*
Cd	6.12**
Cr	2.88
Ni	2.97
Pb	7.77**

*, **, Significant at $p<0.05$ and 0.01, respectively

Table 3: Classification of plant samples on the basis of trace elements toxicity

Elements	ΨToxic or excessive levels (mg kg^{-1} DW)	NWFP (n=40) No. of samples	% of samples
Zn	100-400	-	-
Cu	20-100	36	90
Fe	-	-	-
Mn	300-500	-	-
Cd	5-30	11	28
Cr	5-30	17	43
Ni	10-100	39	98
Pb	30-300	12	30

ΨSource: Kabata-Pendias and Pendias[11]

Copper: The concentrations of Cu ranged from 29.2-137.9 mg kg^{-1} with the highest value in sample of spinach and lowest in turnip. The highest value of 18.6 mg kg^{-1} was recorded in spinach collected from background soil.

The Cu concentrations in effluent and tubewell irrigated (background) plants showed no significant differences (Table 2).

Planks[17] reported that normal range of Cu concentration in plants ranges from 5-20 mg kg^{-1} whereas concentration greater than 20 mg kg^{-1} is considered as toxic. Similarly, Jons *et al.*[18] reported that sufficiency range of Cu in leaves is between 3-7 mg kg^{-1} while the toxicity range begins at 20-30 mg kg^{-1}. Keeping in view these limits, Cu concentration in plant samples is in the toxic range. Wazir[14] observed Cu concentration in the range of 12.13-32.8 mg kg^{-1} in plant samples collected from possible contaminated sites within the proximity of Peshawar. So, the observed values in this study are very high than those reported by Wazir.

Iron: The concentrations of Fe varied between 79.8-982 mg kg^{-1} with the mean value of 191.84±125.59 (Table 1). The highest and lowest values were observed in spinach and wheat samples, respectively. While, the maximum value of 120.9 mg kg^{-1} was recorded in mustard collected from background soil.

The t-test comparison showed no significant differences between the concentration of Fe in effluent and tube well irrigated plants (Table 2).

Jones *et al.*[18] reported sufficiency level of Fe content in leaf that ranged from 50-75 mg kg^{-1}. The results of this study can also be compared with those reported by Ikramullah[19] for wastewater irrigated spinach and lettuce which contained Fe content of 93.46 mg kg^{-1} and 101.5 mg kg^{-1}, respectively.

Manganese: The concentrations of Mn ranged from 64.0-286.9 mg kg^{-1} with the highest value in sample of coriander and lowest in bottle gourd. However, the background plant sample (spinach) contained the maximum value of 34.0 mg kg^{-1}.

According to t-test comparison, the concentrations of Mn in effluent irrigated plants were significantly higher than those in tubewell irrigated (background) plants (Table 2). These variations may be due to industrial effluents used for irrigation and soil organic matter content.

The results of this study can be compared with those reported by Kabata-Pendias and Pendias[11] for plant foodstuffs, which contained variable amount of Mn being the highest in beet roots (36-113 mg kg^{-1}) and the lowest in tree fruits (1.3-1.5 mg kg^{-1}DW). The Mn content shows a remarkable variation for plant species, stage of growth and different organs as well as for different ecosystems. A relatively small variation has been observed in the Mn content of cereal grains, which range from 15-80 mg kg^{-1} (DW) throughout the world.

Cadmium: The concentrations of Cd ranged from 2.8-8.3 mg kg^{-1} with the mean value of 3.13±0.99 (Table 1). The maximum and minimum concentrations were observed in samples of spinach and brinjal, respectively. The maximum value of 2.6 mg kg^{-1} was recorded in spinach collected from background soil.

The Cd concentrations in effluent irrigated plants were significantly higher than those in tubewell irrigated (background) plants (Table 2). This suggests that the effluents from different industries contributed Cd to the plants in irrigation waters and enhanced its accumulation to undesirable level.

Bingham[20] reported that corn and other grass are tolerant to high metal concentrations. Wolnik *et al.*[21] reported that Cd concentration in vegetable crops grown on non-contaminated soil of USA ranged between 0.017 and 0.16 mg kg^{-1} while according to Shacklette[22], Cd concentration in plants ranged from 0.05-1.20 mg kg^{-1}. Kabata-Pendias and Pendias[11] reported that normal level of Cd concentration in mature leaf is 0.05-0.2 mg kg^{-1} while excessive or toxic level is 5-30 mg kg^{-1}. Comparing plant samples with the above mentioned limits we can conclude that 28% of samples have reached at the toxic level (Table 3) while the rest of the samples contained Cd concentration above normal level, which could also exceed to toxic limits, if the water of the same quality is used for a longer period. The results of this study can also be compared with those reported by Ikramullah[19] who observed Cd concentration of 0.36-1.08 mg kg^{-1} in vegetables irrigated by industrial or city effluents.

Chromium: The concentrations of Cr varied between 3.9-15.0 mg kg^{-1} in plant samples with the highest value observed in hot pepper and lowest in wheat sample, while the maximum value of 4.2 mg kg^{-1} was recorded in okra collected from background soil.

The t-test comparison showed that the concentrations of Cr in effluent and tube well irrigated plants differed non significantly (Table 2).

Duke[23] reported Cr concentration in the range of 0.05-8.0 mg kg^{-1} (DW) in the edible parts of vegetables. Glinski and Baren[24] and Cary *et al.*[25] reported 0.2 mg kg^{-1} (DW) Cr in wheat grain while that reported by Welch and Cary[26] was 0.014 mg kg^{-1} (DW).

Kabata-Pendias and Pendias[11] reported that normal or sufficient level of Cr concentration in mature leaf is 0.1-0.5 mg kg^{-1} while excessive or toxic level is 5-30 mg kg^{-1}. Comparing plant samples with the above mentioned limits, it was found that 50% of samples have potentially toxic level of Cr (Table 3), while the rest of the samples also contained Cr concentration above normal level which could reach to toxic level, if the water of the same quality is used for a longer period.

Nickel: The concentrations of Ni ranged from 10.0-73.0 mg kg^{-1} with the average value of 26.01±11.7 (Table 1). The maximum and minimum values were reported in samples of turnip and okra, respectively.

However, the background plant sample (spinach) contained the maximum value of 16 mg kg^{-1}.

According to t-test comparison, the concentrations of Ni in effluent and tube well irrigated plants differed non-significantly (Table 2).

Tyler[27] and Szentmihalyi *et al.* reported[28] the concentrations of Ni, which ranged from 4.8-6.2 mg kg^{-1} and 3.9-9.0 mg kg^{-1} (DW) in blue berry and grass grown in contaminated sites of Sweden and East Germany, respectively. According to Shacklette[29], the concentration of Ni in vegetables ranged from 0.2-3.7 mg kg^{-1} (DW). Kabata-Pendias and Pendias[11] reported Ni content ranging from 0.1-5 mg kg^{-1} as sufficient and toxic or excessive when ranged from 10-100 mg kg^{-1} in mature leaf tissue. Keeping in view these limits, 98% of samples were found in the toxic range (Table 3), while the remaining samples contained Ni content above normal level. The results of this study are quite high when compared with the values reported by the above investigators.

Lead: The concentrations of Pb ranged from 20.5-72.0 mg kg^{-1} with the highest value in sample of turnip and lowest in okra. The maximum value of 20.0 mg kg^{-1} was recorded in spinach collected from background soil.

The t-test comparison showed that Pb concentrations in effluent irrigated plants was significantly higher than those observed in tubewell irrigated (background) plants (Table 2). Such a high concentration can be related with industrial wastewater used for irrigation and atmospheric fallout from industrial and automobile emissions.

The results of this study can be compared with those reported by Wazir[14] and Khattak *et al.*[30]. According to Wazir[14], the concentration of Pb ranged from 18.66 to 56.00 mg kg^{-1} in plant samples collected from contaminated soils within the vicinity of Peshawar city, while Khattak *et al.*[30] observed Pb values ranging from 12-101 mg kg^{-1} in potato tubers and leaves collected from roadside soils in Abbottabad, Pakistan. Although it is understood that Pb is neither essential for plants nor for animals, however, its excessive concentration in soils and plants could be toxic in terms of food chain organisms.

By comparing the observed values with the reported concentrations of Kabata-Pendias and Pendias[11], most of the plant samples were found at the levels, which could be potentially toxic while only few samples contained these trace elements at the sufficiency, or normal levels. The toxic effects on the plants i.e. appearance of dark green leaves, wilting of older leaves, brown margin of leaves, blackish brown spots on leaves were also noted in the field by visual observations. The contamination of plants can be associated with the use of irrigation water contaminated by the industrial effluents and domestic sewage, atmospheric fallout, contaminated soils and the use of various fertilizers, insecticides and pesticides. The various plant samples also showed different concentrations of trace elements which can be ascribed to the variations in trace elements concentrations in soils, soil properties, plant species and types which have different affinity for the soil elements.

The concentration of trace elements in most of the effluent irrigated samples were higher than those in tube well irrigated samples, which can mainly be ascribed to the industrial wastewater used for irrigation. However, some of the trace elements in tubewell irrigated plant samples (background) were observed at high level which may be due to atmospheric fallout and the use of chemical fertilizers, animal and poultry manure, various agro chemicals, herbicides, pesticides and insecticides. As a matter of fact, it is not easy to find a site, which can be called a background level. Therefore , these so called sites are merely providing comparison between effluents and tubewell irrigated samples.

Trace elements concentration in most of the plant samples was above the permissible levels for human consumption. The regular use of such plants would be highly risky for the human health.

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