Chapter 49
The Performance of Sunflower, Turnip and Forage Corn in Uptaking Some Essential Elements and Cadmium Under Wastewater Irrigation

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Abstract The objective of the present study was to investigate the potential of some plants to uptake and accumulate some essential elements and cadmium in soils under wastewater irrigation. The study was performed in the farmer's field in 2005 at Varamin region located in the south of Tehran, Iran. The soil at the studied site belongs to Shahr-e-Ray Series and soil taxa "*Fluventic Camborthids*". The sunflower, turnip and forage corn were selected for the investigation. The wastewater was used for irrigation purpose. The experiment was laid out in a randomized block design (RBD), and treatments were triplicated. The sunflower, turnip and forage corn plants were harvested in 2005, and the plants were separated into roots and aboveground material. The results showed the highest concentration of nitrogen, phosphorus, zinc, copper and cadmium was 6.05%, 1.27%, and 97.27, 22.84 and 0.54 mg kg^{-1} in sunflower, respectively, and the most accumulations of nitrogen, phosphorus, zinc and copper were in grain and cadmium in the leaf. The concentration of potassium and nitrate was 5.79 and 8.26% in turnip, respectively, and the high accumulation of potassium and nitrate was in leaf. The highest concentration of iron and manganese was 349.56 and 144.78 mg kg^{-1}, respectively, in forage corn. The results suggest that the lands irrigated with wastewater with excessive amount of essential elements and cadmium can support sunflower cultivation through uptake of sufficient quantities by selected crops.

Keywords Elemental concentration • Forage corn • Soil remediation • Sunflower • Wastewater

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49.1 Introduction

The nutrient availability changes continuously due to the application of macro- and micronutrients and other trace elements through the application of fertilizers, biosolids, irrigation with wastewater or indirect sources (car exhausts, rainfall and atmospheric deposition from several sources, etc.). Soils, as filters of toxic chemicals, may adsorb and retain heavy metals from wastewater. However, when the capacity of soils to retain toxic metals is reduced due to continuous loading of pollutants or changes in pH, soils can release heavy metals into groundwater or soil solution available for plant uptake. The effects of wastewater irrigation on the availability of some micronutrients and heavy metals in calcareous soil in the south of Mosul, Iraq, showed that the concentration of Fe, Zn, Mn and Cu as micronutrients and Pb, Ni and Cd as heavy metal increased (Meani et al. 1993). Microbial decomposition of organics in wastewater can also release heavy metals into soil solution. But, because of their low solubility and limited uptake by plants, heavy metals tend to accumulate in surface soil and become part of the soil matrix (McGrath et al. 1994). With repeated wastewater applications, heavy metals can accumulate in soil to toxic concentrations for plant growth. The long-term effects of irrigation with wastewater in the south of Tehran, Iran, showed that the available concentration of organic carbon (OC), P, K, Zn, Cu, Cd, Pb and Ni was more than those in control soils (Molahoseini 2001) without significant decrease of wheat and forage corn yield. This practice can lead to reduce the amount of nitrogen, phosphorus and potassium required for crops to less than 75% of the recommended doze determined through soil tests in the laboratory (Molahoseini 2003, 2005).

The results of heavy metal contents of crops in the south of Tehran, Iran, showed that the maximum accumulative concentration of these metals occurs in the order of leaf > tuber > root > stem > fruit > seed. The greatest uptake was found in turnip, lettuce, radish (leaf), sugar beet (leaf) and spinach, while the least was in rice and wheat (grain) and beetroot (Shariati et al. 1998). Phytoremediation is one of the environmental friendly technologies that use plants to clean up soil from heavy metal and trace element contamination.

The uptake and accumulation of pollutants vary from plant to plant and also from species to species within a genus (Singh et al. 2003). Another agronomic principle, which has been neglected in phytoremediation research, is crop rotation. Because of the proliferation of weeds, predators and diseases, which can cause significant yield reduction, crops, including those used for soil remediation, must be rotated. In general, crops are rotated less frequently today than 30 years ago. From crop science, it can be extrapolated that short-term (2–3 years) monoculture (the use of the same species in consecutive seasons) may be acceptable for metal phytoremediation.

However, for longer-term applications, as most metal phytoextraction projects are anticipated, it is unlikely that successful metal clean up can be achieved with only one remediative species used exclusively in monoculture. Plant rotation is even more important when multiple crops per year are projected (Lasat et al. 2000). In general terms, the macronutrient and micronutrient concentrations for the three crops were lower than that showed by Plank et al. (1995). The normal range of nitrogen (N), phosphorus (P), potassium (K), Iron (Fe), Manganese (Mn), Zinc (Zn) and copper (Cu) was reported in the range of 3–5, 0.3–0.5 and 3–5% and 100–200, 50–100, 50–70 and 10–20 ppm in sunflower; 3–5.5, 0.35–0.8 and 3–5% and 80–370, 30–100, 20–70 and 3–10 ppm in turnip; and 3–3.5, 0.25–.045 and 2–2.5% and 30–200, 15–300, 15–60 and 3–15 ppm in forage corn, respectively (Plank et al.1995). The normal range of cadmium (Cd) was 0.2–0.8 ppm in all of the plants (Ross 1996), and normal range of nitrate (NO_3) ion was less than 0.45% (Maynard 1978).

The long-term effects of soils under wastewater irrigation in the south of Tehran, Iran, cause to increase the available concentration of OC, P, K, Zn, Cu, Cd, Pb and Ni more than control soils. This study was carried out to evaluate plant potential of sunflower, turnip and forage corn to uptake and accumulate some essential elements and cadmium in soils under wastewater irrigation located south of Tehran.

49.2 Materials and Methods

49.2.1 Study Site

The average annual rainfall in the study area is about 173 mm; therefore, it is situated in the arid zone (Table 49.1). Field experiment was conducted by irrigating the plots with wastewater. The experiment was conducted in the south of Tehran, Iran

Table 49.1 Climate data of the area of study

	Temperature °C		Precipitation	Relative humidity (%)		
Months	Av. maximum	Av. minimum	Total (mm)	03 GMT	09 GMT	Average
January	8	−1.4	31.6	75	53	64
February	20	0.2	33.8	66	41	53
March	16	4.7	35.2	60	35	47
April	21	9.5	22.2	55	30	42
May	28	15.4	15.2	42	21	31
June	33	19.7	2.6	32	16	24
July	36	22.7	1.8	32	17	24
August	35	22.0	1.8	30	16	23
September	31	17.9	1.3	31	18	24
October	25	12.1	7.9	44	26	35
November	16	5.5	24.3	61	35	48
December	10	0.6	25.8	70	45	57
Total			173.2			

Station name: Tehran-Mehrabad
Latitude 35 4; longitude 51 19; elevation 1,191 m
Year of record: 1975–2003
Climatic type: Xerothermomediterranean

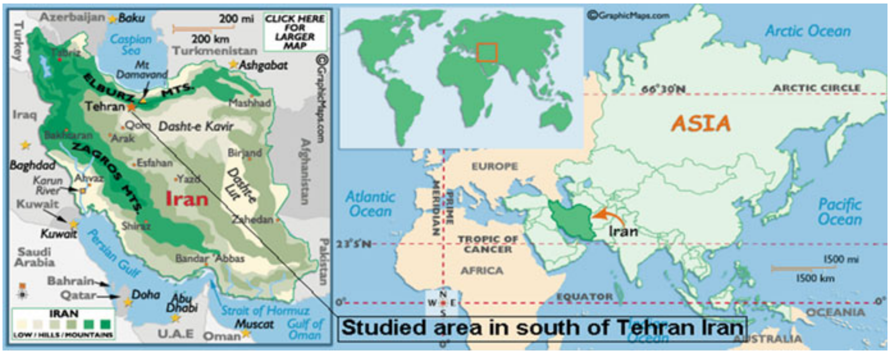

Fig. 49.1 Site location map

Fig. 49.2 View of experimental plots showing different crops

(Fig. 49.1). The general view of experiment is shown in Fig. 49.2. The soil at the study site belongs to Shahr-e-Ray Series (total area of Shahr-e-Ray Series is 3,290 ha). The soil profile displayed a cambic horizon in the upper 1 m from soil surface and has been located in River Alluvial Plain (Table 49.2). The soil taxa at soil family level based on USDA soil taxonomy is "Fine Mixed, Thermic, Fluventic Camborthids" (Iravani, 2000). The basic soil characteristics (0–30 cm) are given in Table 49.3. The studied site is slightly alkaline in reaction and silty clay loam in texture.

It is worth emphasizing that the selected site was previously used for wheat cultivation, where wheat was harvested in July. The site was properly prepared for the experiment. The sunflower, turnip and forage corn were planted to investigate the ability of the different parts of plants to accumulate some elements. The cultivars

Table 49.2 Soil profile description related to Shahr-e-Ray Series

Depth (cm)	Horizon	Texture	Sand (%)	Silt (%)	Clay (%)	Sp	ECe (dS m^{-1})	pH	OC (%)	Av. P (ppm)	Av. K (ppm)	$CaCO_3$ (%)
0–20	Ap	SiCl	14	52	34	49	1.6	7.9	0.6	11.7	340	18
20–60	B1	SiC	13	45	42	43	0.9	8.2	0.3	3.2	380	19
60–100	B21	SiC	11	46	43	48	1.3	8.1	0.2			15
100–150	B22	SiC	14	43	43	47	1.2	8.1	0.2			15

Depth (cm)	Horizon	SAR (mmoles L^{-1})$^{0.5}$	CEC (cmol^{+} kg^{-1})	ESP
0–20	Ap	3.0	12	3
20–60	B1	2.0	15	2
60–100	B21	2.8	18	2
100–150	B22	2.5	17	2

SP saturation percentage, *ESP* exchangeable sodium percentage, *CEC* cation-exchange capacity, *SiCl* silty clay loam, *SiC* silty clay

Table 49.3 Soil characteristics (0–30 cm) of the experimental site

Soil characteristics	Units	Quantity
Organic carbon	%	1.26
EC	dS m^{-1}	1.5
SAR	(mmoles L^{-1})$^{0.5}$	3
ESP	%	3
CEC	cmol^{+} kg^{-1}	12
Gypsum	%	0
Total N	%	0.013
Available P	mg kg^{-1}	72
Available K	mg kg^{-1}	287
Fe	mg kg^{-1}	21.6
Mn	mg kg^{-1}	9.1
Zn	mg kg^{-1}	10.0
Cu	mg kg^{-1}	7.5
pH (soil extract)	Slightly alkaline	7.5
Sand (2–0.05 mm)	%	14
Silt (0.05–0.002 mm)	%	49
Clay (<0.002 mm)	%	37
Textural class	Silty clay loam	–

of sunflower, turnip and forage corn were Hyson33, Native and Single Cross 704, respectively. The wastewater irrigation scheduling was with the interval of 6 days, and 10 cm (4 in.) water was applied per irrigation. The fertilizer was applied based on soil testing. The experiment was conducted during 2005 and 2006, using randomized block design, with three replications in a net plot size of 30 m^2.

49.2.2 Plant Sampling and Analysis

In the autumn of 2005, three plant samples per plot were collected. Each sample was a composite of two plants taken in the centre of the experimental plot. Each sample was separated into roots, aboveground materials (shoots, leaves, etc.) and grains, dried at 75°C in an oven, and then weighed, grounded, homogenized and a representative subsample analysed.

The samples were analysed for N using Kjeldahl apparatus; Olsen P was determined colorimetrically, and K was determined by using flame emission spectroscopy. The cadmium and trace elements (Cd, Cu, Fe, Mn and Zn) were extracted using DTPA (diethylenetriamine pentaacetic acid (DTPA)) and determined by atomic absorption spectrophotometer. In all cases, standard procedures described by Sparks et al. (1996) were used.

49.2.3 Statistical Analysis

All data were subjected to analysis of variance (ANOVA), and when significant differences ($p<0.05$) were detected, Duncan's test was performed to allow separation of means.

49.3 Results and Discussion

49.3.1 Mineral Composition of Plant Components

The analysis of variance of N, P, K, Fe, Mn, Zn, Cu and nitrate ion in grains shows highly significant effect ($p<0.01$), whereas cadmium has shown significant effect ($p<0.05$). The analysis of variance of N, P, K, Fe elements and nitrate ion in leaf and root of the plant treatments had high significant effect ($p<0.01$). The analysis of variance of N, P, K, Zn, Cu and Mn elements and nitrate ion in the stem of the plants had high significant effect ($p<0.01$). The mean mineral composition of roots and aerial biomass (leaf, stem and grain) of each crop are shown in Tables 49.4 (macronutrients) and 49.5 (micronutrients).

49.3.2 Macronutrient Concentrations of Crops

The concentrations of the studied macronutrients N, P, K and NO_3 showed some differences according to the plant treatment and their components. The highest concentrations of N and P were in sunflower grain and K and NO_3 in the turnip leaves

Table 49.4 Macronutrient concentrations (%) in the plants and their components

Components	Crop	Nitrogen	Phosphorus	Potassium	Nitrate
Grains	Sunflower	6.05a	1.27a	1.39a	0.00a
	Turnip	0.00c	0.00c	0.00c	0.00a
	Forage corn	2.57b	0.44b	0.56b	0.00a
Leaves	Sunflower	3.46b	0.35b	5.41a	0.50b
	Turnip	4.98a	0.49a	5.79a	8.26a
	Forage corn	2.27c	0.25c	1.63b	0.05b
Stems	Sunflower	0.98a	0.11a	1.19b	2.27a
	Turnip	0.00b	0.00b	0.00c	0.00b
	Forage corn	0.80a	0.18a	1.91a	0.49b
Roots	Sunflower	0.49c	0.05c	1.92b	0.38b
	Turnip	5.14a	0.61a	5.56a	5.52a
	Forage corn	0.87b	0.12b	1.97b	1.29b

Means with different letter in each column are significantly different between treatments at $p<0.05$ Duncan's test

(Table 49.4). According to Plank et al. (1995), the macronutrient concentrations of N, P and K for leaves of the three crops were lower than normal value, but nitrate concentrations in turnip leaves were more than normal range as stated by Maynard (1978) (normal range 0.45%).

49.3.3 Soil Macronutrient Uptake by Crops

The highest uptakes of N and P were 376.1 and 65.5 kg ha^{-1}, respectively, by sunflower, and for K and nitrate ion were 294.2 and 347.3 kg ha^{-1}, respectively, by turnip (Fig. 49.3).

49.3.4 The Crops Micronutrient and Cadmium Concentration

The concentrations and accumulation of the micronutrients and Cd also showed differences between the plant treatments (Table 49.5). The highest concentration of Fe and Mn was in forage corn root and leaves, respectively. The highest concentration of Zn and Cu was in sunflower grain and Cd was in sunflower leaves. According to Plank et al. (1995), the concentrations of Fe in forage corn and sunflower leaves were more than normal values whereas Mn in forage corn was less than normal values, and in sunflower and turnip leaves was close to the normal values. The Zn was lower than normal range in leaves of the three plants, but the concentration of Cu and Cd was more than normal range in turnip leaves.

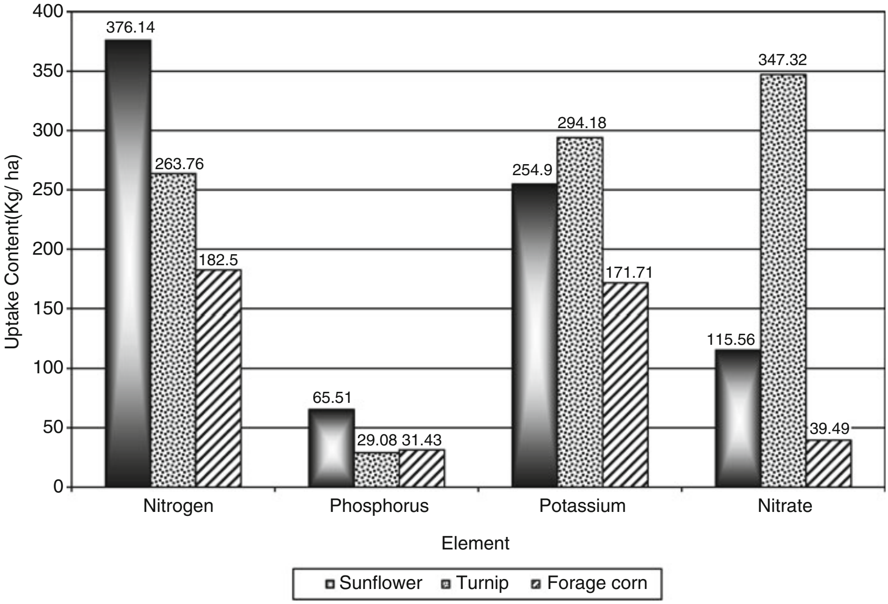

Fig. 49.3 The uptake of N, P, K and nitrate ions by sunflower, turnip and forage corn

Table 49.5 Micronutrient and cadmium concentration (mg kg^{-1}) in the plant components

Components	Crop	Iron	Manganese	Zinc	Copper	Cadmium
Grain	Sunflower	86.45a	39.27a	97.27a	22.84a	0.28a
	Turnip	0.00c	0.00c	0.00c	0.00c	0.00b
	Forage corn	27.45b	13.22b	29.44b	4.11b	0.06ab
Leaf	Sunflower	578.01a	107.27a	59.69a	20.49a	0.54a
	Turnip	278.22b	110.88a	42.11a	9.67a	0.00a
	Forage corn	349.56b	144.78a	54.89a	8.78a	0.00a
Stem	Sunflower	32.51a	14.53b	18.12a	10.24a	0.06a
	Turnip	0.00a	0.00c	0.00b	0.00c	0.00a
	Forage corn	84.43a	39.78a	16.55a	5.98b	0.00a
Root	Sunflower	1,025.11b	28.53b	24.37b	12.73a	0.00a
	Turnip	339.56c	48.22a	50.00a	10.55a	0.00a
	Forage corn	1,341.0a	50.84a	33.83ab	12.42a	0.00a

Means with different letter in each column are significantly different between treatments at $p<0.05$ Duncan's test

49.3.5 *Soil Micronutrient and Cadmium Uptake by Crops*

The highest uptake of Fe, Cu, Zn and Cd was 2.955, 0.643, 0.2, 0.003 kg ha^{-1} by sunflower, respectively, and Mn was 0.537 kg ha^{-1} by forage corn (Fig. 49.4).

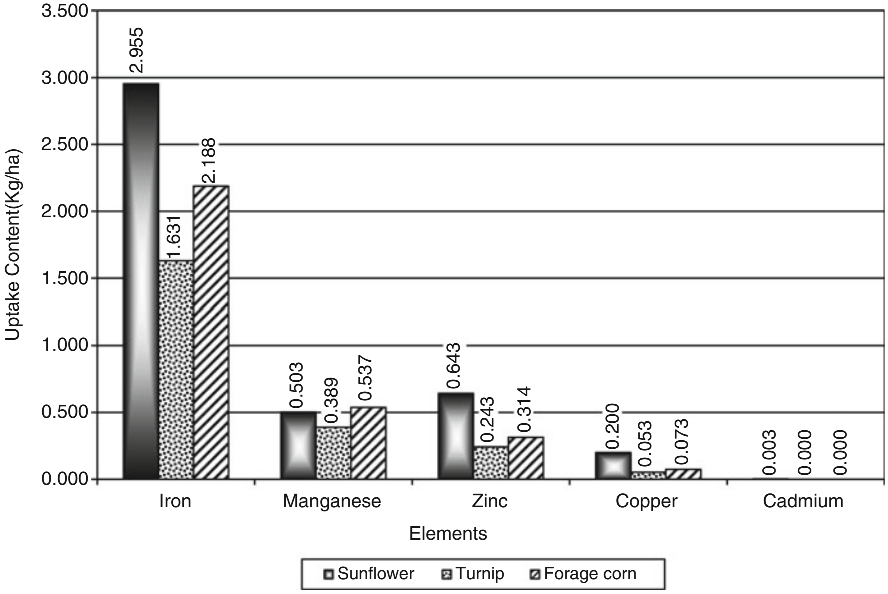

Fig. 49.4 Uptake of Fe, Mn, Zn, Cu and Cd elements by sunflower, turnip and forage corn

The results of this study showed that the plants of sunflower, turnip and forage corn have different potential to concentrate and accumulate essential elements and cadmium from lands under wastewater irrigation. Based on these results, the most concentration and accumulation of N, P, Zn and Cu were in sunflower grain and cadmium in sunflower leaf. The most concentration and accumulation of K and NO_3 were in turnip leaf. Finally, the most concentration and accumulation of Fe was in forage corn root, and Mn was in forage corn leaf. It is therefore concluded that the proper plant rotation and suitable plant selection could decrease pollution of land under wastewater irrigation. Overall, the lands under wastewater irrigation with excessive amount of essential elements and cadmium could recommend sunflower to uptake excessive content of N, P, Zn, Cu and Cd; turnip to uptake excessive content of K and NO_3; forage corn to uptake excessive amount of Fe and Mn without any yield decrease.

49.4 Conclusion

This study was carried out to evaluate the potential of sunflower, turnip and forage corn to uptake and accumulate some essential elements and cadmium in soils under wastewater irrigation in a site located south of Tehran. Based on the results of this experiment, lands under wastewater irrigation with excessive amount of essential elements and cadmium can support cultivation of sunflower to uptake excessive content of nitrogen, phosphorus, zinc, copper and cadmium; turnip to uptake excessive content of potassium and nitrate; and forage corn to uptake excessive content of iron and manganese without any yield decrease.

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