Environ Monit Assess (2010) 160:83–89
DOI 10.1007/s10661-008-0659-x

Effect of fertilizer application on soil heavy metal concentration

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Received: 13 May 2008 / Accepted: 5 November 2008 / Published online: 5 December 2008

Abstract A large amount of chemicals is annually applied at the agricultural soils as fertilizers and pesticides. Such applications may result in the increase of heavy metals particularly Cd, Pb, and As. The objective of this study was to investigate the variability of chemical applications on Cd, Pb, and As concentrations of wheat-cultivated soils. Consequently, a study area was designed and was divided into four subareas (A, B, C, and D). The soil sampling was carried out in 40 points of cultivated durum wheat during the 2006–2007 periods. The samples were taken to the laboratory to measure their heavy metal concentration, soil texture, pH, electrical conductivity, cationic exchange capacity, organic matter, and carbonate contents. The result indicated that Cd, Pb, and As concentrations were increased in the cultivated soils due to fertilizer application. Although the statistical analysis indicates that these heavy metals increased significantly (P value < 0.05), the lead and arsenic concentrations were increased dramatically compared to Cd concentration. This can be related to overapplication of fertilizers as well as the pesticides that are used to replant plant pests, herbs, and rats.

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Keywords Arsenic · Cadmium · Fertilizers · Heavy metal · Lead · Wheat

Introduction

Land disposal of municipal and industrial wastes, automobile emissions, mining activity, and applications of fertilizers and pesticides for agriculture have contributed to a continuous accumulation of heavy metals in soils (Nouri et al. 2008; Tu et al. 2000; Selene et al. 2003). The background concentration of heavy metals in soil depends on the geological characteristics of soils. However, normal agricultural practices generally cause accumulation of these elements. Heavy metals can also accumulate in the soil due to application of liquid and soil manure (or their derivates, compost, or sludge) or inorganic fertilizers. These practices are important sources of heavy metals (Martin et al. 2006).

Long-term simultaneous application of fertilizer and manure on the commercial farm showed higher metal accumulation in the soil and plants than those of cooperative farm (Parkpian et al. 2003). Long-term use of excessive chemical fertilizers and organic manures in the bare vegetable field and the greenhouse vegetable field contributed to the accumulation of heavy metals in the soils (Huang and Jin 2008). The presence of cadmium in some fertilizers at high concentrations is of most concern due to the toxicity of this metal and its ability to accumulate in soils and its bioaccumulation in plants and animals (Alloway 1990; Brigden et al. 2002). Lime and superphosphate fertilizer contain not only major elements necessary for plant nutrition and growth but also trace metal impurities such as Cd. These metals can accumulate in the soil, be taken up by plants, and passed on in the food chain to animals and humans (Taylor and Percival 2001). Fertilizer applications may be able to influence Cd speciation and complexation which affects the Cd movement to plant roots as well as Cd uptake (Wa˚ngstrand et al. 2007).

High fertilizer applications and acid atmospheric deposition, combined with insufficient liming, may also cause a decrease in pH and thus increase heavy metal availability, aggravating the problem of deteriorating food quality, metal leaching, and impacts on soil organisms (De Vries et al. 2002). Also, the use of animal feed crops grown on soil with elevated cadmium concentrations may result in high levels of cadmium in beef and poultry (especially in the liver and kidneys). Wheat accumulates more Cd than the other commonly grown cereals (Wa˚ngstrand et al. 2007).

In this study, the concentration of three heavy metals (Cd, Pb, and As) were investigated in the agricultural soils of Mahidasht before fertilizer applications and after harvesting. Due to high wheat economic value, farmers usually apply large amounts of fertilizers and overirrigate their farms to achieve maximum yields (Ju et al. 2007).

Based on interview with farmers and the information available at agricultural centers, the application of fertilizers in this area is more than land requirements, which can result in high concentration of heavy metal in the soil. Alloway (1990) declared that soil pollution by heavy metal resulting from phosphate fertilizer application has been a cause for concern in some countries. Wa˚ngstrand et al. (2007) declared that nitrogen fertilizers may increase Cd concentrations in plants, even if the fertilizers do not contain significant levels of Cd. In addition, Alloway (1995) concluded that phosphate fertilizer application in agricultural lands can cause increased levels of Cd, As, Cr, and Pb in soil and dramatically decreased soil pH that cause desorption of heavy metals from the soil matrix.

Pb is one of the heavy metals which were investigated in this survey. Atmospheric deposition, manures, and sludges are the most important sources of lead in the agricultural soils (Nicholson et al. 2003).

The objective of this study was to evaluate Cd, Pb, and As concentrations in the wheat agricultural soils of Kermanshah Mahidasht region before fertilization and after harvesting in the 2006–2007 crop season and also to investigate the influence of fertilization on these heavy metals.

Materials and method

Site study

The study was conducted in Mahidasht, which is one of the active zones of agricultural practices in the Kermanshah province. Mahidasht is located on the northeast of Kermanshah city on an alluvial plain at 34–45° 34′ N, 46–15° 47′ E with a flat agricultural land of about 35,000 ha and 1,400 m above sea level. The soil texture varied from sandy clay loam to sandy clay. Annual average precipitation was 288 mm for the period 2003 to 2005. The main crops grown are wheat, maize, canola, and vegetables. Mahidasht is one of the most important areas for producing durum wheat. The study was performed in durum wheat cultivars. Winter wheat growing season starts at October and ends up on June. Two-time application of fertilizer is necessary for crops, one basal before sowing and the other in the middle of the growth stages.

Sampling strategy

Studied area was divided into four subareas (A, B, C, and D) as shown in Fig. 1. Forty composite randomized samples (9, 10, 10, and 11 samples from A, B, C, and D subareas, respectively) were taken from these subareas, before fertilization and after harvesting in late September 2006 and early August 2007 from 0- to 30-cm depth of the soil. Also, the type of fertilizers applied in soil was determined by asking the farmers and agricultural service center; on other fertilizers, analysis was done for heavy metals concentration evaluation. Soil samples were separated into two subsamples after sieving to <2 mm. One of which was used to determine soil parameters including pH, electri-

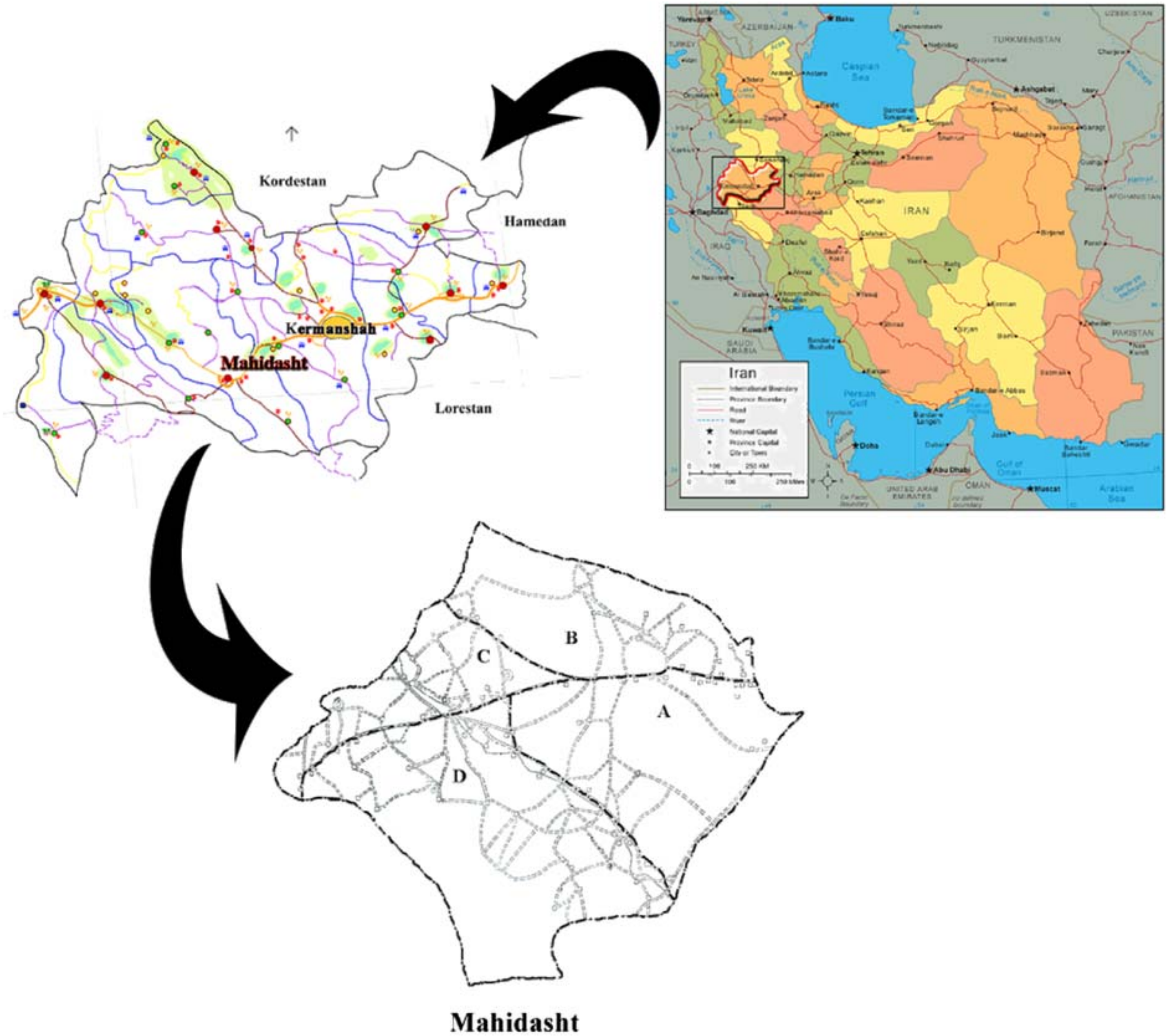

Fig. 1 The study area map (*A*, *B*, *C*, and *D* subareas)

Table 1 Heavy metal concentration in consumed fertilizer ($n = 3$)

Fertilizer	Cd	Pb	As
	Mean ± SD	Mean ± SD	Mean ± SD
$ZnSO_4$	8.62 ± 0.20	18.16 ± 0.2	3.20 ± 0.10
$(NH_4)_2SO_4$	0.02 ± 0.03	4.20 ± 0.3	1.18 ± 0.10
$K(SO4)_2$	0.04 ± 0.02	4.28 ± 0.3	0.24 ± 0.03
KNO_3	1.12 ± 0.10	3.32 ± 0.2	1.88 ± 0.10
TSP	6.74 ± 0.40	5 ± 0.5	0.24 ± 0.03
Mix	10.42 ± 0.60	1.42 ± 0.1	2.42 ± 0.10

Table 2 Cadmium concentration in soil samples

Subarea	Number	Cadmium			
		Before cultivation		After harvesting	
		Range	Mean ± SD	Mean ± SD	Range
A	9	1.15–1.50	1.34 ± 0.10	1.55 ± 0.09	1.40–1.68
B	10	1.33–1.55	1.45 ± 0.06	1.60 ± 0.08	1.45–1.73
C	10	1.23–1.55	1.42 ± 0.10	1.52 ± 0.10	1.40–1.73
D	11	1.30–1.43	1.36 ± 0.04	1.59 ± 0.08	1.45–1.73
Total	40	1.15–1.55	1.39 ± 0.09	1.57 ± 0.09	1.40–1.73

Table 3 Lead concentration in soil samples

Subarea	Number	Lead			
		Before cultivation		After harvesting	
		Range	Mean ± SD	Mean ± SD	Range
A	9	1.80–6.05	3.59 ± 1.30	8.76 ± 1.7	6.83–12.85
B	10	1.60–5.08	3.6 ± 1.20	5.93 ± 1.3	3.35–7.95
C	10	2.80–5.03	4 ± 0.77	5.84 ± 1.7	2.75–8.60
D	11	2.75–6.05	3.51 ± 0.97	7.84 ± 2.8	3.70–12.85
Total	40	1.60–6.05	3.68 ± 1.07	7.07 ± 2.3	2.75–12.85

Table 4 Arsenic concentrations in soil samples

Subarea	Number	Arsenic			
		Before cultivation		After harvesting	
		Range	Mean ± SD	Mean ± SD	Range
A	9	2.05–7.30	4.14 ± 1.8	12.10 ± 2.4	9.10–15.33
B	10	1.85–9.85	4.88 ± 2.2	14.22 ± 2.8	10.20–18.98
C	10	1.58–9.85	4.53 ± 2.5	11.48 ± 3.4	5.89–15.15
D	11	2.15–11.55	3.86 ± 2.6	12.79 ± 4.9	9.25–26.40
Total	40	1.58–11.55	4.34 ± 2.3	12.66 ± 3.6	5.89–26.40

Table 5 Comparison of heavy metal concentrations in the subarea soil before fertilization and after harvesting

	Paired differences					*t*	*df*	*P* value (two-tailed)	Remark
	Mean	SD	SEM	95%Confidence interval of the difference					
				Lower	Upper				
Cd_B–Cd_A	−0.17	0.09	0.01	−0.2	−0.14	−11.24	39	0.000	Sig
Pb_B–Pb_A	−3.3	2.25	0.35	−4.1	−2.66	−9.51	39	0.000	Sig
As_B–As_A	−8.3	3.57	0.56	−9.4	−7.17	−14.72	39	0.000	Sig

B before, *A* after

cal conductivity (EC), organic matter (OM), soil texture, cationic exchange capacity (CEC), and $CaCO_3$ percent and the other was air-dried for analysis of heavy metals (Cd, Pb, and As). The soil pH and EC were measured by a glass electrode in a 1:2.5 soil–water suspension.

Organic matter was determined by carbon total determination, which was done by dry combustion after ignition at 1,050°C and discounting the carbon contained in carbonates (organic material = organic carbon × 1.721). Soil texture was determined by hydrometric method (Houba et al. 1995). Metal contents (Cd, Pb, and As) were extracted by acid digestion method (HNO_3, HCl, and H_2O_2; Soon and Abboud 1993; Gupta 2000). Heavy metals (Cd, Pb, and As) in soil and fertilizer extracts were measured by inductively coupled plasma (MTX Varian mod, USA).

Statistical analysis

Comparison of the heavy metal content before fertilization and after harvesting was done with *t* test analysis in SPSS software ver 11.5.

Results

Soil texture in subregion A was silty clay and clay loam. In subregion B, it was silty clay and clay. In subregion C, it was silty clay and clay loam but in subregion D it was clay loamy and clay. The soil texture in all of the subregions is categorized as heavy and very heavy soils. Therefore, they have high capacity of water and mineral holding. CEC for A, B, C, and D subregions was 24.31, 24.84, 25.72, and 27.6 meq/100 $_{\text{g soil}}$ and mean CEC for all of these subregions was 25.2 ± 4.88. Mean OM content of samples in A, B, C, and D subregions was 1.78%, 1.67%, 1.69%, and 1.74%, respectively; also, mean organic content was 1.72± 0.35 in all of the regions. pH was in the range of 7.5–8.2 with mean value of 7.96 in all subregions. EC of samples was in the range of 2.9–6.8 with mean value of 4.5 mmohs/cm. Calcium carbonate of soil in all subregions was in the range of 21–41.5% TNV.

Table 1 shows heavy metal concentration in the applied fertilizers. Tables 2, 3, and 4 show the Cd, Pb, and As concentrations in soil samples before cultivation and after harvesting. Table 5 shows comparison of heavy metal content variation before fertilization and after harvesting.

Discussion

Fertilizer consumption and heavy metal content

Fertilizer consumption rate was 380, 200, 100, and 20 kg/ha per year for nitrogen, phosphate, and micronutrient fertilizer, respectively. Farmers consume a lot of fertilizer without any evaluation of land requirement by experts.

Maximum concentration of Cd was found in composite fertilizer and triple super phosphate with value of 10.42 and 6.74 mg/kg, respectively. The first one was greater than the CDFA, AAPFCO, Japan, and Canada standard (with value of 4, 10, 8, and 4 mg/kg soil) and the second was more than the CDFA and Canada standards.

Maximum concentration of Pb was found in zinc sulfate fertilizer with the value of 18.16 mg/kg that was in the safe value range.

Maximum concentration of arsenic was found in zinc sulfate fertilizer (3.2 mg/kg) that was nearly two times more than CDFA standard, which was 2 mg/kg for arsenic. These data show that yearly fertilizer application could introduce a large amount of heavy metal with accumulating characteristics to soils.

Heavy metal concentration in soil

Heavy metal concentration in soils before fertilization and after harvesting does not exceed standards. Statistical analysis showed soil heavy metal concentration increases after fertilization with confidence interval of 95% (P value < 0.05).

Cadmium concentration in the studied region was in the range of 1.15–1.55 with mean value of 1.39 ± 0.09 mg/kg soil before fertilization; also, after harvesting, it reached the range of 1.4–1.73 with mean value of 1.57 ± 0.09 mg/kg soil.

Manures, fertilizers, and atmospheric precipitation are the major Cd source that leads to Cd accumulation in agricultural soils (McLaughlin et al. 1999). In addition, Ju et al. (2007) reported that the Cd concentration increases by overusage of manure and phosphate fertilizers. The maximum concentration of Cd was 1.73 mg/kg that was below standards.

In addition, arsenic concentration was in the range of 1.58–11.55 (mean value = 4.34 ± 2.3) before fertilization and after harvesting reached to the range of 26.4 ± 5.89 (mean value = 12.66 ± 3.6); high As concentration may be due to herbicide, pesticide, and fertilizer application (O'Neill 1995).

Lead concentration was in the range of 1.6–6.05 mg/kg soil (mean value = 3.68 ± 1.08 mg/kg) before fertilization and after harvesting reached to the range of 2.75–12.85 (mean value = 7.07 ± 2.3). Pb concentration increased two times after harvesting. The maximum Pb concentration was 12.85 mg/kg that was below all standards. Atmospheric deposition, manure, and sludge application are the most important sources of Pb in agricultural soils (Nicholson et al. 2003).

Conclusion

Farmers use very large amounts of fertilizers to obtain maximum yields for relatively high economic value of the extra yields and difficulties in the accurate management of fertilizer application.

At present, overuse or misuse of fertilizers in agriculture contributes to environmental deterioration from nonpoint source pollution and is therefore of great concern nationally and internationally. Fertilizer application rates in agricultural area have increased dramatically in recent years.

Iran must formulate appropriate agricultural policies at a national level to enhance the extension services and educate farmers to reduce fertilizer application for sustainable development.

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