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Assessment Cropping System on Monitoring Cadmium Concentration in Topsoil and Seed Wheat

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ABSTRACT. Soil pollution with heavy metals such as cadmium leads to accumulation of these elements in plant tissues and causes the loss of quality and quantity of agricultural products and ultimately will threaten humans and animals health. This research aimed to assess the effects of cropping system and different growth stage on soil cadmium concentration and wheat grain. It was carried out as a split plot in time experiment based randomized complete block design with three replications at 2014-2015. The main factor included two cropping systems (wheat-rice, fallow-wheat) and the sub factor included growth stages (tillering, flowering, and maturity). The results showed effect of cropping systems and different growth stage on concentration of total cadmium and absorbable cadmium was significant at 1% probability level. Rice-wheat cropping system, due to high consumption of non-standard phosphate fertilizers (containing cadmium) and higher phosphorus concentrations (10.90 mg.kg^{-1}), as well as more residues of crop residue (according to the cropping system), had more total cadmium (1.71 mg.kg^{-1}) and soil absorbable cadmium (10.39 ppb) than of fallow-wheat cropping system. The difference in grain cadmium concentration in two cropping systems was significant at 1% level according to T-test and this trait in rice-wheat cropping system with an average of 0.31 mg.kg^{-1} was more than of fallow-wheat planting system (0.27 mg.kg^{-1}) which is higher than World Health Organization standards. In general, with regard to more accumulation of cadmium in soil and grain yield of rice-wheat system, management of phosphate fertilizer based on soil test, instructions of water and soil institution and crop residue management are necessary.

Keywords: Cropping System, Cadmium, Monitoring, Rice, Wheat.

INTRODUCTION

Soil pollution with heavy metals leads to accumulation of these elements in plant tissues and reduces the quality and quantity of agricultural products and threatens humans and animals health (Liu *et al.,* 2010). Heavy metals are a group of metals with a density greater than 5g.cm^{-3}, which are the most important environmental pollutants (Ji *et al.,* 2014). The toxicity of these metals nowadays has become an increasing specific problem to food ecology and the environment (Benavides *et al.,* 2005). The level of phosphate fertilizer consumption is one of the main sources of soil contamination (Amini, 2005). Studies have shown that wheat especially durum cultivar is able to absorb cadmium more than other grains (rye, barley, oats) (Jansson, 2002). In Khuzestan Province wheat is cultivated in more than 400000 hectares and due to low availability of soil nutrients (such as phosphorus) chemical fertilizers such as triple superphosphate have been used in this area for agricultural production for more than 4 decades (Khan Mirzaei *et al.,* 2012). Agricultural practices such as the use of phosphate fertilizers, sewage, sludge, waste and farming system are the factors that affect the rate of cadmium and its uptake from soil by plants. In Europe, the permitted limit of this element in wheat grain is equal to 0.2 mg.kg^{-1} seed. Food and Agriculture Organization (FAO) and the World Health Organization (WHO) have determined the daily permitted limit of cadmium in human body as 70 micrograms (FAO/WHO, 1984). Valizade *et al.* (2012) reported that fertilizers imported into Iran are contaminated with cadmium and have low quality for agriculture. Moreover, some reports show that in some paddy-fields the rate of cadmium in rice is more than the permitted limit (Zazoli *et al.,* 2006). About 75% of cadmium in the human food chain comes through grain and vegetables. Due to the mentioned problems, American Food and Drug Administration announced that the permitted level of cadmium to be absorbed in human body is 75 mg daily and the organization in Europe announced about 20 to 30 or 40% reduction for this element (CODEX Alimentrarius Commission, 1999).

The more is crop residues after the harvest, the more cadmium will be absorbed in the next cultivation (Saadat *et al.,* 2012). Each year more than 2.5 million chemical fertilizers are used in Iran. Among chemical fertilizers more than one million tons and 750,000 tons are related to the consumption of nitrogen and phosphate fertilizers, respectively. Therefore, with regard to the amount of cadmium in phosphate fertilizers, it can be said that every year about 75 tons of cadmium enter into agricultural lands. Cadmium in phosphate fertilizers used in Iran ranges from 10 to 170 milligrams per kilogram depending on fertilizer use and the type of its factory (fertilizer grade) (Nazari *et al.*, 2006). Crop rotation is another important factor affecting the solubility of cadmium in soil. Rotation changing soil acidity and increases absorption of cadmium in soil. Soil acidity in flooding conditions (e.g. paddy fields soil) is nearly neutral and rodax potential is about 200 mV, so the solubility of cadmium as cadmium sulfide reduces. In non-flooding conditions (for example, after the absorption of water in rice fields) the access to cadmium increases by reducing the soil acidity and increasing rodax potential (Vali Zade *et al.,* 2012). In order to determine the concentration of zinc and cadmium in the soil of rice paddies in Isfahan, Fars and Khuzestan provinces, Pirzade *et al.* (2012) showed in connection with cadmium content that entered to the food basket of individuals through the consumption of rice that in 12% of Isfahan samples cadmium concentration was more than the recommended rate by the World Health Organization. Most soils under rice cultivation in Isfahan, Fars and Khuzestan have lime tissues and large quantities of phosphate fertilizer have been added to the soil during the past years. Given that phosphate fertilizers often contain high concentrations of cadmium, they have increased soil cadmium concentration. On the other hand, flooding the soil and its lime tissue both play an important role in reducing the usability of zinc and increasing cadmium extraction (Dobermann and Fairhurst, 2000). The average concentration of cadmium in rice grain in 11% of samples produced in these regions was more than the permitted limit of cadmium in grain (0.1 $mg.kg^{-1}$). It could be attributed to the high use of sewage sludge, compost and also excessive consumption of phosphate fertilizer (CODEX Alimentrarius Commission, 1999). Amini *et al.* (2005) reported that the annual average cadmium input to agricultural land in Isfahan Province was 1.2 to 3.5 $g.ha^{-1}$ per year due to the use of animal manure, 1.4 to 15 $g.ha^{-1}$ per year due to the use of phosphate fertilizers and 0.12 to 1.35 $g.ha^{-1}$ per year through sewage sludge. The maximum permissible concentration of total cadmium is different in agricultural soils of various countries and equals to 0.8, 1.6, 3, 1 to 3, and 5 $mg.kg^{-1}$ in Switzerland, America, the United Kingdom and Germany, Poland, and Australia respectively (Karimian and Moafpouryan, 1999). In the past two years (since 2013) the quality control of phosphate fertilizers has been raised by the Soil and Water Research Institute, and it has become mandatory and in all imported phosphate fertilizers and domestically produced zinc sulfate, the concentration of these pollutants is controlled and the maximum permissible limit of cadmium is determined to be 25 $mg.kg^{-1}$. Shavoor area in the center of the Khuzestan province (South-West of Iran) is one of the areas where two cropping systems of rice-wheat and fallow-wheat are common and initial assessments indicate high consumption of phosphate fertilizers there. Given the consumption of phosphate fertilizers with impermissible concentrations of cadmium for several decades and the soil contamination during this period of time it is necessary to examine farming soil. Therefore, with regard to the importance of cadmium concentration in wheat as the main food of Iranian people and Khuzestan's first grade in producing wheat. This research was conducted to investigate the relationship between cropping systems (rice-wheat and fallow-wheat) and different stages of growth including tillering, flowering, and maturity on cadmium content of topsoil and wheat seeds.

MATERIALS AND METHODS

A. Field and Treatment Information

This research was conducted in Shavoor Research Station to monitoring cadmium concentration in soil and plant in two main cropping systems in Khuzestan Province (at south west of Iran) via a split plot in time experiment based on randomized complete block design with three replications during 2014-2015. The main factor included two cropping systems (wheat-rice, fallow-wheat) and the sub factor included different growth stages (tillering, flowering, and maturity). Shavoor Research Station is located in 70 km north of Ahvaz at longitude 48° 27?33?E and latitude 32"37 '0 °N in Khuzestan (South west of Iran). The average annual rainfall, temperature, and evaporation in the region is 240 mm, 22°C and 3000 mm, respectively. Soil properties of the land under test are listed in Table 1.

Table 1: Soil properties of experiment site (depth: 0-30cm).

EC($ds.m^{-1}$)	pH	P_b ($g.cm^3$)	OC (%)	P	K	Fe	Cu	Mn	Zn
				(p.p.m)					
2.8	7.8	1.35	0.7	10.9	239	9.6	1.3	8.5	0.6

B. Traits Measurement

Method of measuring seed cadmium concentration. In order to measure the concentration of heavy metals first the plant grains were washed three times with distilled water in order to remove dirt and dust and pollution and then the samples were dried in the oven at 75°C and for 72 hours and then they were crushed into powder in the mortar. Then the powder samples were poured in paper bags and were kept in refrigerator at 4°C until the measurement. Then, in order to determine cadmium concentration, the plant samples were digested via wet digestion (70% nitric acid, Per chloric acid, and sulfuric acid).

After the extraction and reaching the desired volume, the prepared samples were measured using graphic furnace (Model: Perkin Elmer 600) (Soltanpoor, 1991).

Method of measuring cadmium DTPA concentration. As the aim was to measure the concentrations of cadmium and this element usually accumulates in surface layers of soil, the sampling depth was considered to be 0-30 cm with three replications. Soil samples were taken in three phases (midtillering, flowering and maturity) with three replications. The soil samples were crushed after being air-dried and then passed through a 2-mm sieve. Then extractable metals were extracted with DTPA. For extraction operation with DTPA, 60 ml DTPA solution was added to 30 g of air-dried soil and it was shaken for 15 minutes and after filtering through Whatman paper No.42, the amount of cadmium was measured with graphic furnace (Model: Perkin Elmer 600) (Soltanpoor, 1991).

Method of measuring soil total cadmium concentration by nitric acid fourth molar. To do this 60 ml of 4 M nitric acid was added to 9.6 g of air-dried soil and the mixture was heated for 12 hours at 70°C. Then it was centrifuged for 15 minutes and was filtered by Whatman paper No.42 and the concentration of cadmium and the produced extract was meas-ured by atomic absorption spectrophotometer (Model: Perkin Elmer 3010) (Sposito *et al.,* 1982).

C. Statistical Analysis

Descriptive statistics such as mean, variance, maximum, kurtosis, skewness and standard error of the measured traits were calculated by Minitab software (Ver.14). Analysis of variance and mean comparisons by Duncan test at 5% probability level were done through SAS software (Ver.8). The amount of cadmium in wheat seed in two cultivation systems (rice- wheat and fallow-wheat) were compared via T-Test using Minitab software (Ver.14) at 1% level.

RESULTS AND DISCUSSION

A. Total Cadmium

According to Table 2, the ANOVA results showed that the effect of cropping systems on total cadmium was significant at 1% level, but the effect of growth stages on total cadmium was not significant. The soil of rice-wheat cropping system had higher amounts of total cadmium (1.71 $mg.kg^{-1}$) in comparison with fallow-wheat cropping system (1.37 $mg.kg^{-1}$) (Table 3). Higher concentration of cadmium in lands under the cultivation of rice-wheat in comparison to the lands with fallow-wheat cultivation system is due to more application of phosphate fertilizers according to the soil test in such conditions (10.90 $mg.kg^{-1}$) (Table 1), while in rice cultivation conditions with regard to high level of groundwater (Gooshe and Ghalebi, 2012) and availability of oxidation conditions due to flooding conditions, the concentration of cadmium solution in rice farming soil has increased and because of antagonistic relationship between cadmium and zinc and consumption of phosphate fertilizers the possibility of accumulation of high concentrations of cadmium in rice plant increases (Tsukahara *et al.,* 2003). In rice cultivation conditions, the rate of soluble cadmium reduces because of the formation of cadmium sulfide, but after the rice harvest and development of oxidation conditions in soil, the solubility and availability of absorbable cadmium concentration for the next cultivation (wheat) increases drastically (Pavilikova *et al.,* 2007).

Table 2: ANOVA result of measured traits.

S.O.V	df	Total Cadmium ($mg.kg^{-1}$)	Cadmium DTPA (ppb)
Replication	2	0.0105^{*}	3.622^{**}
Cropping system	1	0.520^{**}	9.634^{**}
Error a	2	0.0055	0.1142
Growth Stage	2	0.0426^{ns}	1.0669^{ns}
Cropping system* Growth stage	2	0.00001^{ns}	0.0005^{ns}
Replication* Growth stage	4	0.0020^{ns}	0.1191^{ns}
Error b	4	0.0016	0.0668
CV (%)	-	12.32	11.22

^{ns}, * and **: no significant, Significant at 5% and 1% of Probability level, Respectively.

According to Duncan test, there was not a significant difference between different growth stages but generally there was a decline in the level of total cadmium since tillering stage to maturity (Table 3). It seems that this is due to lack of variability of soil cadmium concentration over a time interval between planting and harvesting wheat. The interactive effect of cropping systems and growth stages on total cadmium content of soil was not significant (Table 2). Moreover, the highest total cadmium concentration belonged to rice-wheat planting system during tillering stage (1.80 $mg.kg^{-1}$) and the lowest total cadmium concentration belonged to fallow-wheat cropping system (1.29 $mg.kg^{-1}$) (Table 3). Jafarnejadi *et al.* (2011) said that the main source of cadmium in the soil of croplands in Khuzestan was the use of diammonium phosphate fertilizer. Given the history of cultivation and optimal farming management in the area under the study in the present study it seems like that the presence of cadmium originating from the consumption of diammonium phosphate fertilizer greatly contributed to contamination with this element. The mean concentration of total cadmium in the studied soils was 1.54 $mg.kg^{-1}$ (Table 5) which is much more that the permissible limit in many countries and indicates the risk of contamination with cadmium in such areas. It should be noted that the range of variation of total cadmium concentration in non-contaminated soil is determined as $0.1^{-1}mg.kg^{-1}$ (Pais and Jones, 1997). This indicates mismanagement of phosphate fertilizer consumption. The results are consistent with the measured values of soil in central areas of Iran (Isfahan and Fars) (Amini *et al.,* 2005). Moreover, the consumption of micronutrients chemical fertilizers such as zinc sulfate results in the increase of soil cadmium concentration in these areas because these two elements are similar to each other chemically and during the shortage of zinc, cadmium can replace it through the consumption of phosphate fertilizer.

Table 3: Mean comparison of cropping system and growth stage on measured traits.

Treatment	Total Cadmium ($mg.kg^{-1}$)	Cadmium DTPA (ppb)
Cropping system		
Rice-wheat	1.71^{a*}	10.39^{a}
Fallow-wheat	1.37b	8.93b
Growth Stage		
Tillering	1.63a	10.12a
Flowering	1.53a	9.56a
Ripening	1.46a	9.29a

*****Similar letters in each column show non-significant difference at 5% level in Duncan's Multiple Rang Test.

B. DTPA-Cadmium

The ANOVA results showed that that the effects of cropping systems and growth stages on this trait were respectively significant at 1% level and non-significant (Table 2). Comparison of the means showed that higher concentration of absorbable cadmium belonged to rice-wheat cropping system (10.39 ppb) in comparison with fallow-wheat cropping system (8.93 ppb) (Table 3). Crop residues are among the important factors increasing absorbable cadmium in soil so the more are crop residues in soil after the harvest the more will be their effect on the rate of cadmium absorbed by plant (Pavilikova *et al.,* 2007). It should be noticed that the importance and the effect of cropping systems on the concentration of absorbable cadmium by soil are not less than those of the consumption of phosphate fertilizers. For instance, during the research it was found that despite the lower consumption of phosphate fertilizers in the east of Khuzestan (Izeh, Bagh Malek, Ramhormoz) in comparison to the north of it, the concentration of absorbable cadmium in the east of Khuzestan is more than that of northern parts of the province (Jafarnejadi *et al.,* 2012).

This is probably due to the kind of effect of dominant frequency in these areas (rice-wheat rotation) since during the rice cultivation, the soil acidity changes and in such conditions (reducing) the insoluble compounds of cadmium (cadmium sulfide) are generated. In such soils, after the oxidation conditions during the late rice cultivation and wheat cultivation periods the concentration of dissolved cadmium compounds sharply increases (Maejima *et al* ., 2007, Pavilikova, *et al.,* 2007). According to result of Jafarnejadi (2010) in the eastern parts of Khuzestan the effect of cultivation system on concentration of absorbable cadmium was more important than the effect of the rate of consumption of phosphate fertilizer. This was also confirmed in examining the southeastern part of Khuzestan (Behbahan Town) so that despite lower consumption of phosphate fertilizers per area unit, the concentration of absorbable cadmium by soil was greatly more than that of northern parts of Khuzestan because in the above areas the dominant rotation is wheat-maize-wheat and probably the return of cadmium available in maize residues into the soil can have a more important effect than the consumption of phosphate fertilizer.

Therefore, the more is the rate of plant residues in soil after the harvest the more will be their effect on the rate of absorbable cadmium in plant (Pavilikova *et al.*, 2007). This shows that the kind of management of the farm in terms of returning plant residues and the type of cultivation plan have significant effects on the concentration of absorbable cadmium. It seems that high levels of underground water in Shavoor region (Gooshe and Ghalebi, 2012) can develop alternative conditions of rehabilitation and oxidation that were described for the rice fields and lead to more accumulation of cadmium in rice-wheat cropping system than in fallow-wheat cultivation system. Like total cadmium, there was no significant difference between different growth stages but there was a decreasing trend in the rate of total cadmium since the early tillering stage to the maturity (Table 3). The interactive effect of cropping systems and different growth stages on absorbable cadmium was not significant (Table 2). The highest concentration of absorbable cadmium belonged to rice-wheat cropping system during tillering stage (10.86 ppb) and the lowest total cadmium concentration in soil belonged to fallow-wheat planting system (8.56 ppb) (Table 4). Descriptive data showed that in the studied lands the mean of absorbable cadmium was equal to 9.66 ppb (Table 5).

Table 4: Interaction effect of Mean comparison of cropping system and growth stage on measured traits.

Treatment		Total Cadmium ($mg.kg^{-1}$)	Cadmium DTPA (ppb)
Rice-wheat	Tillering	1.80^{a*}	10.86^{a*}
	Flowering	1.71^{a}	10.28^{a}
	Ripening	1.63^{a}	10.03^{a}
Fallow-wheat	Tillering	1.46^{b}	9.38^{ab}
	Flowering	1.36^{b}	8.84^{b}
	Ripening	1.29^{b}	8.56^{b}

*****Similar letters in each column show non-significant difference at 5% level in Duncan's Multiple Rang Test.

Table 5: Descriptive statistics of measured traits.

Variable	Total Cadmium ($mg.kg^{-1}$)	Cadmium DTPA (ppb)
Mean	1.54	9.66
Standard deviation	0.190	1.08
Variance	0.036	1.17
Median	1.55	9.33
Max	1.88	11.34
Skewness	0.102	0.073
Kurtosis	-1.280	-1.261

Table 6: T-test result to compare seed cadmium concentration of cropping system.

Treatment	Number of Observation	Mean ($mg.kg^{-1}$)	Standard deviation	t
Rice-wheat	3	0.31	0.01527	5.01^{**}
Fallow-wheat	3	0.27	0.0109	

t-Value = 5.01 P-Value = 0.038, **: Significant at 1% probability level

C. Grain Cadmium

According to the results of Table 6, the difference between the mean concentration of seed cadmium in rice-wheat and fallow-wheat cropping systems was significant at 0.05% probability level (P-Value = 0.038) so that the cadmium concentration in wheat grain in rice-wheat cropping system (0.31 $mg.kg^{-1}$) was more than that of fallow-wheat cropping system (0.27 $mg.kg^{-1}$) which seemed to be due to more accumulation of cadmium in lands under rice-wheat cultivation. Other researchers had also referred to this point (Jafarnejadi *et al.,* 2011, Pavilikova *et al.,* 2007). Moreover, it is necessary to be mentioned that the mean concentration of cadmium in both cropping systems were above the standard level of World Health Organization as much as 2 $mg.kg^{-1}$ (FAO/WHO, 1984).

CONCLUSION

Knowing the factors affecting the solubility and bioavailability of pollutants particularly cadmium in agricultural lands is very essential. The mean concentrations of total cadmium and absorbable cadmium of studied soils were more than the permitted limits in most countries which indicates the risk of contamination with cadmium in such areas.

With regard to concentration of soil phosphorus it seems that the consumption of phosphorus fertilizers during the last three decades has led to the accumulation of cadmium over the permitted limit in soil and grain of cultivated crops in the lands under study. In general, due to some factors such as further consumption of phosphate fertilizers, high level of groundwater in rice cultivating conditions (deficiency of drainage system), complex formation with organic materials, return of rice residues (containing cadmium) into the soil and further salinity of soil in rice planting conditions, the accumulation of cadmium in soil and grain yield more in rice-wheat planting system in comparison with fallow-wheat planting system. Therefore, with regard to the above mentioned points, more management of consumption of phosphate fertilizers especially according to the quality standards of Soil and Water Research Institute and considering crops residues management are considered as important and essential points.

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