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Interactive Effects of Cadmium and Zinc Application on Their Uptake by Rice Under Waterlogged and Non-waterlogged Conditions

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Abstract
In order to investigate the effect of Cd and Zn on uptake, concentration and the translocation factor of the Cd and Zn in the rice plant, a factorial experiment was conducted with four factors including two rice cultivars of Vandana and Hashemi, two waterlogged and non-waterlogged conditions and three levels of Zn and Cd (0, 5 and 10 mg kg^{-1} soil). The experiment was carried out in a randomized complete blocks design with three replications in the greenhouse conditions. According to the results, by changing water regime from waterlogged to non-waterlogged condition, the Zn concentration of root and shoot and the Cd concentration of root were decreased in Vandana cultivar but Cd concentration of shoot was increased and exceeded from the critical level. Zn application caused an increase in Zn and Cd content of shoot, but caused a decrease in Cd concentration of shoot and root. Cd application caused an increase at the first concentration and then decreased the Zn concentration of shoot and root. With increasing the level of Cd, the Cd concentration of shoot and root and the Zn concentration of root increased at the first concentration of Cd and then at decreased at the second level. By application of Cd in each Zn level, the translocation factor of Zn and Cd were decreased.

Keywords: Cadmium; Rice; Waterlogged; Zinc

Introduction

Rice (*Oryza sativa* L.) is the most important agricultural product after wheat in the world and 90 % of it is produced and used in Asia. The recent droughts have changed cultivation system of this plant from waterlogged to non-waterlogged condition. The rice yield is decreased with changing the moisture regime to the non-waterlogged condition and for this reason, plant breeders have made the rice cultivars resistant to non-waterlogged conditions and have called them upland rice. These cultivars are developed in non-waterlogged conditions and have a suitable yield (Fageria 2009).

Cadmium (Cd) is one of the most poisonous pollutants in the soil and its accumulation in plants and soils has increased concerns about this element (Alloway 1995). Some toxic effects of Cd in humans are lungs chemical inflammation, destroying kidneys and appearing tumors (Hazelton and Murphy 2007). Perhaps the main reason of Cd presence in soils of Iran is over using of phosphate fertilizers polluted to this element (Afyuni*et al*. 2007). Cd is absorbed easily by the plant roots and its poisonous ability on the plants is 2 to 20 times greater than other heavy metals depending on the plant species (Savaghebi*et al*. 2002). Zazoli*et al*. (2006) reported that the average concentration of Cd in the Tarom cultivar of rice in Mazandaran province, north of Iran, is 0.41 mg/kg based on the grain dry weight. Therefore, the average concentration of Cd in this Iranian cultivar is more than the critical level (0.2 mg/kg grains) for the rice plant (Kabata-Pendias and Pendias 2001). Also it has been reported that rice has strong capability for Cd uptake from the polluted soils with low concentration of Cd in comparison with Indian mustard and corn (Ishikawa *et al*. 2006). The normal range of Cd concentration in the plant is 0.05-0.2 mg kg^{-1} and its poisonous range is 5-30 mg/kg (Kabata-Pendias and Pendias 2001). Uptake and translocation of Cd in rice depends strongly on the cultivar (Liu *et al*. 2003). The factors affecting the Cd absorption are classified into two groups of soil and plant. Soil factors are pH, total soil cadmium concentration, temperature, moisture content, soil compaction, aeration, waterlogging, application of phosphoric fertilizers and plant factors are type of cultivar, plant tissue, stage of plant growth and interaction of metals in the cellular membrane (McLaughlin *et al*. 1999).

Zn is a necessary for several biochemical processes such as cytochrome synthesis and nucleotide, chlorophyll production, enzyme activation and cell membrane evolution and participate as an integral part of important enzymes like superoxide dismutase (Marschner 1995). Long time and continuous cultivation of rice and application of nitrogen and phosphorus fertilizers without other nutrients including Zn, has caused the deficiency of this element in the soil. Zn insufficiency not only decrease seed yield, but also lowers the seed quality (Fageria 2009). Zn deficiency at high pH conditions, high concentration of bicarbonate in the calcareous soils, low redox potential in the paddy soils, over using of phosphorus fertilizers and light-texture soils is more common (Gao *et al*. 2006).

Cd and Zn are similar chemically (Kirkham 2006) and therefore, interact negatively in the soil (Gupta and Potalia 1990; Savaghebi*et al*. 2002; Zhu *et al*. 2003; Chaab and Savaghebi 2010). However, some synergetic relations have been reported (Nan *et al*. 2002; Lakzian*et al*. 2009; Behtash*et al*. 2010, Moustakas*et al*. 2011). Zhu *et al*. (2003) reported that Cd adding decreased the Zn concentration of root and shoot in wheat significantly. Based on Zhao *et al*. (2005), Cd concentration in the wheat shoot and root increased by the application of Zn up to 200 μmol/L, but decreased at the high rates of Zn, because increasing Zn in stem limits Cd translocation from stems to seed (Oliver *et al*. 1997). Mohammad and Moheman (2010) reported this phenomenon in potato. In addition to soil, plant and the Zn:Cd ratio, phosphorus is regarded as an important factor in Cd and Zn interaction and Zn deficiency.Phosphorus is a dominant factor in the Cd uptake. Akay and Koleli (2007) reported that, increasing Cd content in the field conditions decreased Zn availability but it had no effect on the barley seed yield. Zn application increased Zn concentration in the seeds and leaves, but the increase was not significant. Furthermore, increasing the Zn level, increased Cd concentration in barley (synergetic effect) at first but then the antagonist effect was observed. In marigold, the negative effect of Zn on Cd concentration at 5 mg Zn/kg was significant. By increasing the Cd level, Zn concentration of leaves was decreased, but it was increased in petals. Also the DTPA extractable Cd and Zn of the soil were significantly correlated with Cd and Zn concentrations in the leaves and petal. The reason for decreasing Cd concentration in leaves by Zn application was expressed as the competition between these ions on translocation and absorption (Moustakas*et al*. 2011).

The objective of this study was to investigate the effect of Zn and Cd in two cultivars of rice (Hashemi and Vandana), on the concentration and uptake of these elements in shoots and roots in two waterlogged and non-waterlogged conditions.

Materials and Methods

In order to carry out this research, a clay loam soil with low available Zn and Cd was taken from the depth of 0 to 25 cm and a combined sample was prepared. After transferring to soil preparation room, the soil was air dried and passed from a 2mm sieve. Soil texture by the hydrometer method (Gee and Bauder 1986), pH in the 1:1 suspension of soil and distilled water (Richards 1969), electrical conductivity (EC) in the 1:1 suspension extract of soil and distilled water (Gupta 2000), organic carbon by the method of Walkaly and Black (Nelson and Sommers 1982), carbonate calcium equivalent (CCE) by the method of neutralizing with hydrochloric acid (Richards 1969), available sodium and potassium by the ammonium acetate method (Jones 2001), available P by the method of Olsen (Olsen *et al*. 1954), available Fe, Mn, Cu, Zn and Cd extracting with the 0.005 M DTPA solution (Lindsay and Norvell 1978) were determined. The experiment was performed as factorial on the basis of randomized complete blocks design with three replications in the greenhouse of the Soil Science Department of the University of Tabriz, Iran in 2010. The factors were two cultivars of rice (Hashemi and Vandana), two moisture regimes (waterlogged and non-waterlogged), three levels of Zn (0, 5 and 10 mg/kg of soil) and three levels of Cd (0, 5 and 10 mg/kg of soil). Each pot (equal to 3kg soil) was treated with three levels of Cd from cadmium nitrate source (Merck Co. Germany)and three cycles of drying and wetting up to field capacity (33 kPa) were applied. Then the amounts of Zn from zinc nitrate source (Merck Co.) with other required nutrients (P, N and Fe) were added to the soil according to the soil analysis. The pots were placed in waterlogged and alternatively in FC (non-waterlogged) conditions for two weeks to reach the relative equilibrium. Then, 10 seeds from Hashemi (the waterlogged cultivar) and Vandana (the non-waterlogged cultivar) were planted in each pot and after one week, they were thinned to three plants. During the growth period, the plants were irrigated with distilled water. After 90 days, plants were cut and washed with distilled water and dried in an oven with at 70 ^{0}C. In order to measure Zn and Cd in the samples, the method of wet digestion was used (Waling *et al*. 1989) and the concentration of Zn and Cd were measured in the extracts by atomic absorption system, Shimadzu, (AA-6300). Data analysis was performed with the MSTATC software and the means were compared by the Duncan's multiple range tests at the 5% probability level. The diagrams were drawn by the Excel software.

Results and Discussion

Some of the physical and chemical characteristics of the soil used in the experiment are presented in Table 1. This neutral soil is non-saline but is calcareous, with a relative fine texture, low organic material content, low available phosphorus, iron and zinc but with sufficient potassium, manganese and copper.

Table 1. Selected physical and chemical characteristics of the experimental soil

Texture class	Sand	Clay	CCE	SOM	N	pH	EC	Na	K	P	Fe	Mn	Cu	Zn	Cd
	(%)					(1:1)	($dS\ m^{-1}$)	($mg\ kg^{-1}$)							
Clay loam	38.5	39	15.2	1.01	0.02	7	0.47	325.7	556.4	8.7	3.98	7.01	2.2	0.52	0.04

a) Cadmium concentration in shoots

Table 2 and Figure 1 show that the Cd concentrationin shoots was increased by changing the waterlogged condition to non-waterlogged in two cultivars. But this increase in the Hashemicultivar, passed the critical level. There was a significant difference between the two cultivars in both water regimes and Hashemi had the higher Cd concentration. Similar results have been reported by Dong *et al*. (2007). In the waterlogged condition, more dissolution of Fe component decreased Cd toxicity through the effect on photosynthesis (Kabata-Pendias and Pendias 2001). By increasing the Zn level in Hashemi, Cd concentration of the shoot did not change significantly, but then decreased. Similar results have been reported by Jiao *et al*. (2004), Oliver *et al*. (1997), Choudhary*et al*. (1994) in wheat and by Moustakas*et al*. (2011) in marigold. In the Vandana cultivar, by increasing the Zn level, Cd concentration in shoots was decreased at first and then increased, although it was not reached to the rate of control. The reason for decreasing the Cd concentration in Vandana in relation to the control was the increase in shoot dry weight that led to decrease in Cd concentration by the dilution effect (Marschner 1995). Also by increasing the soil Zn level in the non-waterlogged condition, Cd concentration of shoots did not change significantly at first, but in the waterlogged conditions it was decreased first and then increased. Application of Zn decreased Cd concentration. At any Zn level, Cd concentration in the non-waterlogged condition was greater than the waterlogged condition which should be considered when changing the water regime. This result is in concordance with the findings of Gupta and Potalia (1990) but it has some discrepancy with Chaoui*et al*. (1997), Hassan *et al*. (2005), Zhao *et al*. (2005), Liu *et al*. (2007) and Behtash*et al*. (2010). According to their reports, application of Zn increased Cd concentration in the plant shoot. By increasing Cd level at any Zn level, the Cd concentration of shoots was increased. However, by increasing Zn, the rate of increase became slower (Figure 2). Probably at higher concentrations of Cd in the root zone, Zn uptake may increase (Lakzian*et al*. 2009).

Table 2. Concentrations of Cd and Zn in the shoot and root of rice at different Cd and Zn levels and two water regimes

Treatment		Shoot								Root							
		Cd (mg kg^{-1})				Zn (mg kg^{-1})				Cd (mg kg^{-1})				Zn (mg kg^{-1})			
$Zn(NO_3)_2$	**$Cd(NO_3)_2$**	Vandana		Hashemi		Vandana		Hashemi		Vandana		Hashemi		Vandana		Hashemi	
(mg kg^{-1})		W	NW	W	NW	W	NW	W	NW	W	NW	W	NW	W	NW	W	NW
0	0	1.2	1.4	1.4	1.7	15.4	14.0	12.1	9.5	3.5	4.9	5.5	3.9	32.1	62.7	50.1	56.6
	5	4.2	4.8	2.7	7.6	12.4	12.3	9.9	11.4	56.3	60.3	89.5	77.8	28.2	26.7	49.4	38.2
	10	6.5	9.2	4.5	9.1	13.3	15.4	9.5	11.9	123.8	75.3	121.6	124.3	49.1	30.1	75.0	28.6
5	0	0.9	1.2	1.5	2.1	20.9	23.5	16.6	17.3	3.2	3.5	3.08	3.3	75.3	50.8	81.2	66.9
	5	1.6	5.7	3.2	6.5	21.4	24.2	20.2	17.5	51.5	51.7	54.8	95.4	97.4	69.7	67.9	105.1
	10	2.6	8.1	5.0	9.3	18.7	20.2	14.8	20.0	102.7	77.1	94.6	105.0	78.4	54.2	90.9	55.1
10	0	1.1	1.6	1.5	2.0	25.1	25.1	22.0	25.9	3.8	2.53	2.89	3.6	87.8	67.8	100.9	58.0
	5	2.4	4.2	4.1	3.9	20.3	23.3	20.3	23.2	59.5	61.7	89.3	60.3	88.2	65.0	125.8	86.3
	10	4.2	7.9	5.5	4.2	23.0	19.0	20.7	26.0	113.5	97.7	85.9	50.5	98.1	56.1	75. 8	99.0
LSD$_{5\%}$		0.82				3.95				0.006				6.76			
A×B		**				ns				**				ns			
A×C		**				**				**				**			
B×C		**				ns				**				**			
A×D		**				ns				**				**			
B×D		**				ns				**				**			
C×D		**				*				**				**			
A×B×C		**				*				**				**			
A×B×D		**				*				**				**			
A×C×D		**				ns				**				**			
B×C×D		**				ns				**				**			
A×B×C×D		**				ns				**				**			

*,**Significant at 5 % and1%probability levels, respectively ; ^{ns}Not significant.

Note: A, B, C and Dare cultivar, moisture regime, zinc and cadmium, respectively. W and NW are waterlogged and non-waterlogged conditions, respectively.

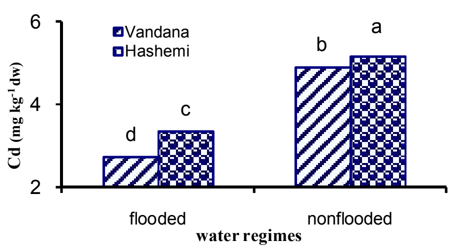

Figure 1. Interactive effect of cultivar and water regime on shoot concentration of Cd

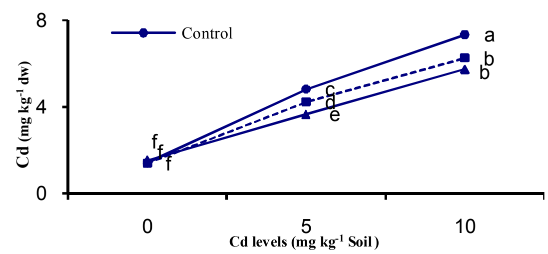

Figure 2. Interactive effect of Cd and Zn levels on shoot concentration of Cd

b) Zn concentration in shoots

According to Table 2, with increasing Zn level, Zn concentration of shoots was increased in the Hashemi cultivar, but it was increased at the first concentration and then remained constant in the Vandana cultivar. Similar results have been reported by Hosseini and Maftun (2005), Gao*et al*. (2006) and Akay and Kolli (2007). Singh and Bollu (1983) reported that surface adsorption of Zn on Fe and Mn oxides in the non-waterlogged condition or oxygenated rice rhizosphere in the waterlogged condition is regarded as an important factor in decreasing the concentration and mobility of Zn. Based on Koleli*et al*. (2004) and Chaab and Savaghebi (2010), increasing Cd in the soils with insufficient Zn has led to decrease Zn concentration in wheat shoots and corn plants but it was opposite at higher Zn levels. Presumably, the increase in phytosiderophores releasing from the plant roots under insufficient Zn has increased the absorption and translocation of Cd to the shoot. This type of finding was in concordance with the results of Moustakas*et al*. (2011). Charati*et al*. (2005) also reported that application of Cd decreased Zn concentration in shoots at any level of Zn. They attributed this phenomenon to the competition for uptake and translocation between Cd and Zn. At the second level of Zn, by increasing Cd, Zn concentration in shoots did not change at first but it was decreased later on (Figure 3).

c) Cd concentration in roots

Based on Table 2, by changing from waterlogged to non-waterlogged condition, Cd concentration of roots was decreased in both cultivars but the amount of decrease was greater in the Vandana cultivar. In the Hashemi cultivar, by increasing Zn levels, Cd concentration of roots was decreased, but in Vandana, it was decreased at first and then increased. Similar results were reported by Jiao *et al*. (2004) and Liu *et al*. (2007). The decrease in Cd concentration may be attributed to the dilution effect. Cd concentration in the roots of Vandana was less than the Hashemi cultivar. In the waterlogged condition, by increasing Zn levels, Cd concentration of root decreased at first and then increased, but it was less than the control level. In the non-waterlogged condition, by increasing Zn levels, Zn concentration of roots decreased (Table 2). Hassan *et al*. (2005) also reported similar results. However, Lakzian*et al*. (2009) and Behtash*et al*. (2010 reported that when Zn concentration is high in the solution, the increase in Zn concentration leads to increase in Cd absorption and thus Cd content increases in the root. Table 2 shows that by increasing the Cd level at any level of Zn, Cd concentration increased in the root. However, this increase was small at higher levels of Zn. Similar results have been expressed by Hassan *et al*. (2005).

d) Zn concentration in roots

Increasing Zn had significant and positive effect on Zn concentration of roots in both water regimes (Table 2). Cd did not have any significant effect on Zn concentration of roots in Vandana while in the Hashemi cultivar, Zn was increased at first and then decreased, but it was not significantly different from the control. Decreasing Zn concentration of root by application of Cd has been reported by Zhu *et al*. (2003). Also, in the waterlogged condition increasing Cd level, increased Zn concentration of roots at first but remained almost stable after that. Under non-waterlogged condition, it was increased at first and then decreased. At the first level of Zn, its concentration decreased at first and then increased, although the concentration was lower than the control (Figure 4). On the other hand, application of Cd at lower rates, not only did not decrease Zn concentration, but also increased it, but it had antagonistic effect on Zn at higher rates.

e) Cadmium content

By changing from waterlogged to non-waterlogged condition, the Cd uptake increased in Vandana, but decreased in the Hashemi cultivar (Table 3 and Figure 5). By increasing Zn levels in Hashemi, the Cd content was not changedsignificantly. Smith and Brennan (1983) also obtained similar results. In the Vandana cultivar, Zn application increased Cd uptake. If soil has enough available Zn, probably Zn usage will not be effective on the Cd uptake (Zhu *et al*.

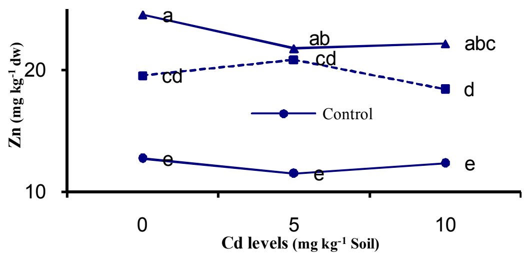

Figure 3. Interactive effect of Cd and Zn levels on shoot concentration of Zn

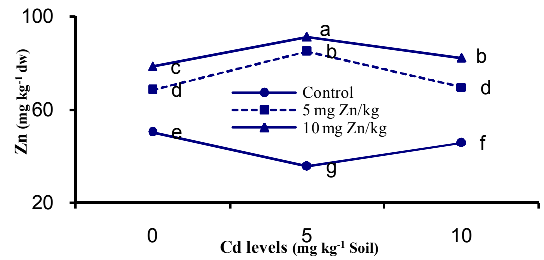

Figure 4. Interactive of Cd and Zn levels on root concentration of Zn

2003). This result may be attributed to the antagonistic relationship of these elements, because they compete with each other in order to adhere to the translocation places in the root. Increasing the Cd concentration at higher Zn concentrations, has also been reported by other researchers (Nan *et al*. 2002; Behtash*et al*. 2010; Chaab and Savabeghi2010; Mohammad and Moheman 2010). In the waterlogged condition, by increasing Cd at any level of Zn, the Cd content was increased, although by increasing the Zn levels, the rate of increase became slower. In the non-waterlogged condition, by increasing Cd at any level of Zn, Cd content was increased at first but then it remained constant at the first and second levels of Zn, but decreased at third level (Table 3).

Table 3. Content and translocation factor of Cd and Zn in different Cd and Zn levels in two water regimes

Treatment		Contentin shoot								Translocation factor							
		Cd ($\mu g\ pot^{-1}$)				Zn ($\mu g\ pot^{-1}$)				Cd				Zn			
$Zn(NO_3)_2$	$Cd(NO_3)_2$	Vandana		Hashemi		Vandana		Hashemi		Vandana		Hashemi		Vandana		Hashemi	
($mg\ kg^{-1}$)		W	NW	W	NW	W	NW	W	NW	W	NW	W	NW	W	NW	W	NW
	0	1	3	4	4	14	26	34	21	0.34	0.29	0.25	0.45	0.48	0.22	0.24	0.17
0	5	10	9	13	20	35	24	51	30	0.08	0.08	0.03	0.10	0.45	0.47	0.20	0.30
	10	10	27	20	9	20	46	44	10	0.05	0.12	0.04	0.07	0.27	0.51	0.13	0.39
	0	6	3	10	6	162	55	116	47	0.28	0.34	0.46	0.66	0.28	0.46	0.20	0.26
5	5	17	27	27	23	180	111	146	61	0.03	0.11	0.06	0.07	0.22	0.35	0.30	0.17
	10	17	47	40	9	118	115	127	23	0.03	0.10	0.05	0.09	0.24	0.37	0.16	0.36
	0	10	13	10	3	270	198	167	46	0.31	0.62	0.51	0.54	0.28	0.37	0.22	0.45
10	5	27	33	27	30	245	211	126	169	0.04	0.07	0.04	0.07	0.23	0.36	0.16	0.27
	10	37	37	47	7	199	84	134	47	0.04	0.08	0.08	0.09	0.24	0.34	0.27	0.26
$LSD_{5\%}$		0.01				0.32				0.05				0.05			
A×B		**				**				ns				ns			
A×C		**				**				**				**			
B×C		**				**				ns				**			
A×D		**				**				**				ns			
B×D		**				**				**				*			
C×D		ns				**				ns				**			
A×B×C		**				**				**				**			
A×B×D		**				**				ns				**			
A×C×D		ns				**				**				**			
B×C×D		**				**				ns				**			
A×B×C×D		**				**				**				**			

***,** Significant at 5% and 1% probability level respectively;[ns]Not significant.**

Notes: **A, B, C and Dare cultivar, moisture regime, zinc and cadmium, respectively. W and NW are waterlogged and non-waterlogged conditions, respectively.**

f) Zn content

By changing the moisture regime from the waterlogged to non-waterlogged condition, Zn content in both cultivars decreased and this decrease was greater in the Hashemi cultivar. Vandana was better in Zn uptake than Hashemi in the non-waterlogged condition (Table 3). This result was is concordance with the reports of Gao *et al*. (2006). A plant can absorb more nutrients that have higher water use efficiency, stronger roots and higher root to shoot ratio (Liu *et al*. 2003) and the Vandana cultivar had these specifications. In the waterlogged condition, increasing Fe and Mn concentrations increased Zn uptake. As Fe^{2+} and Mn^{2+} have more surface adsorption capability in the oxidation forms, as a result compete with Zn to be adsorbed by organic materials, clay or other oxides (Neue*et al*. 1998). Meanwhile, Fe^{2+} prevents the ZnS formation, but at high concentrations, it prevents Zn uptake by plants. Phosphorus availability increases in the waterlogged condition (Neue*et al*. 1998) which decreases Zn absorption and translocation from root to shoot, especially if Zn uptake capability is small. Zn deficiency is related to high bicarbonate concentration in calcareous soils (Neue*et al*. 1998). A lot of factors that determine Zn bioavailability, change after transferring from the waterlogged to non-waterlogged condition. For example, the decrease or increase in the soil pH depends on the initial pH of the soil. In addition, redox potential will be increased and will cause to Fe oxidation, $Fe(OH)_3$ precipitation and surface adsorption of Zn on these oxides. Increasing nitrification may cause the nitrate uptake by the plants instead of ammonium and may increase soil pH. Furthermore, decreasing soil water content may interrupt zinc diffusion to the root and as a result, prediction of bioavailability of zinc with the change in water regime will be difficult (Gao *et al*. 2006). Changing moisture regime from the waterlogged to non-waterlogged condition created favorable conditions for mycorrhizae activity that led to the increase in Zn uptake. Also changing water regime changes N transformation that affects Zn diffusion and uptake (Gao *et al*. 2011). The effect of Zn application on the concentration of Zn in shoots was positive and significant in both cultivars which was in concordance with the results of Fageria (2002). Decreasing the Zn uptake by the plants at the first level of Zn is probably related to the concentration of bicarbonate. High concentrations of bicarbonate (40-15mM) decreases Zn absorption by the roots of rice strongly, specially the translocation factor. The sensitivity of rice cultivars to Zn deficiency in alkaline soils is variable which is related to the different response to bicarbonate concentration. Therefore, rice cultivars efficient in absorbing Zn are mainly tolerant against bicarbonate. In the inefficient cultivars, even at 5-10 mM concentration, it prevents the root growth. Strong positive correlations have been observed between organic acids accumulation in roots and prevention of root growth by high concentrations of bicarbonate (Robson 1993). By increasing Cd level, Zn content of shoot increased at first in both cultivars and both water regimes, and then decreased. Similar results have been reported by Smith and Brennan (1983). By increasing Cd level at each Zn level, Zn content was increased at first and then decreased (Figure 6)

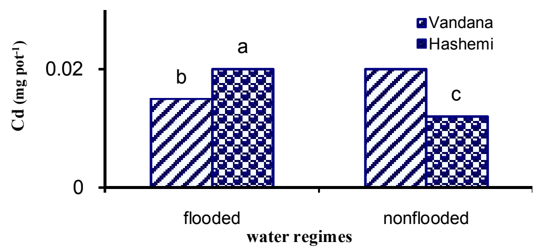

Figure 5. Interactive effect of variety and water regime on shoot content of Cd

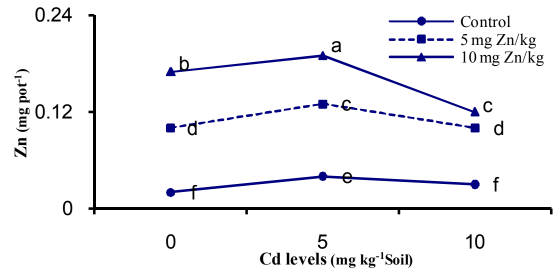

Figure 6. Interactive effect of Cd and Zn levels on shoot content of Zn

f) Zn translocation factor

By increasing the Zn level in the Vandana cultivar, the Zn translocation factor was decreased at first and then no significant change was observed (Table 3). In the Hashemi cultivar, Zn application did not have a significant effect on Zn translocation factor. By increasing Zn in the waterlogged condition, Zn translocation factor was decreased first and then remained constant. In the non-waterlogged condition, Zn consumption did not have any significant effect on Zn translocation factor. Our results showed that, only Zn application in the soil does not guarantee to increase its translocation to the shoots. Therefore, by using Zn as seed enrichment and foliar application, we can overcome the Zn deficiency. By increasing Cd level in the waterlogged condition, Zn translocation factor did not change significantly at first but decreased later. In the non-waterlogged condition, application of Cd did not have significant effect on Zn translocation factor at first and then increased. The Cd effect on Zn translocation factor at the second level of Zn was not significant. At the third level of Zn, Cd decreased Zn translocation factor at first and then remained constant. At the first level of Zn with using cadmium, it was increased at first and then remained almost unchanged (Figure 7).

g) Cd translocation factor

The Hashemi cultivar showed the highest Cd translocation factor. It was also greater under the non-waterlogged condition as compared with the waterlogged condition. By the application of Zn, Cd translocation factor was increased at first, but at the third level of Zn, no significant change was observed. In both cultivars and water regimes, by the application of Cd, its translocation factor was at first decreased and then no significant change was observed. By increasing the Cd level at any level of Zn, Cd translocation factor was at first decreased and then it remained constant (Table 3 and Figure 8). Zn and Cd uptake compete with each other for some reasons. This may be related to the essential role of Zn in preserving plasma membrane of the root cells (Moustakas*et al*. 2011). Zn deficiency damages plasma membrane of root cells and increases membrane penetration that leads to the increase in Cd mobility to the plant through mass flow. Cd is bonded to sulfidrils groups of the membrane protein and then makes the membrane system unstable and results in the disulfide formation that destructs membrane and ionic channels. However, Zn prefers to connect to SH-protein groups of the membrane and protects the phospholipids and proteins against oxidation and the formation of disulphide and also through the protection of sulfidrils group, it synthesize the chlorophyll (Prasad 1995). Another reason is that Zn deficiency increases acid amines, sugars and phenol acids exudation by the root.

Absorption capability of Cd may be increased by chelating with root exudations (Jiao *et al*. 2004). The increase of phytosidrophores releasing from root to the soil due to Zn deficiency, increases root absorption of Cd and its translocation to the shoot and therefore, the symptoms of Cd toxicity is appeared (Oliver *et al*. 1997). Furthermore, the translocation of elements depends on phytochelatin (PC) to some extent. Cd toxicity produces PC complex materials quickly. Zn competes with Cd in order to form complex with PC (Hassan *et al*. 2005). Cd-PC complexes cause the accumulation of Cd in root cells' vacuole and decrease Cd translocation from root to shoot. However, at the presence of Zn, Zn-PC complexes are formed that are able to increase free Cd concentration and as a result increase its translocation (Sarwar*et al*. 2010). Another reason that Zn increases Cd uptake by the plant, is some changes in the special carriers of metal ions in the plasma membrane after increasing Zn level in the plant growth medium. Cd shows also strong tendencyto transfer through these carriers and as a result, its absorption and translocation to shoot increases (Yang *et al*. 2004).

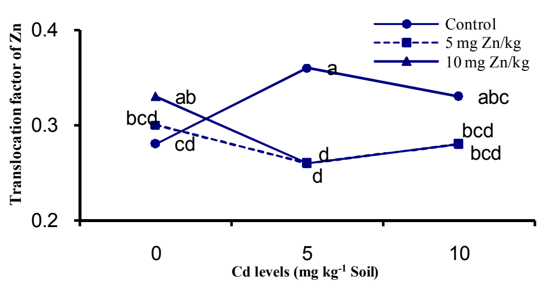

Figure 7. Interative effect of Cd and Zn levels on translocation factor of Zn

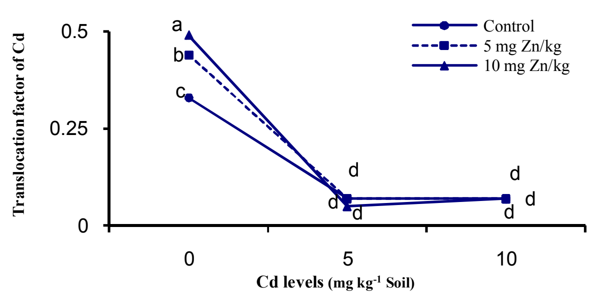

Figure 8. Interative effect of Cd and Zn levels on translocation factor of Cd

Conclusion

Based on our findings, by changing from waterlogged to non-waterlogged condition, root Zn concentration, Zn content in the shoot, and Cd concentration and content of the root in the Vandana cultivar decreased, but Cd concentration and content and Zn concentration in the shoot were increased. Also, by increasing Zn rate, Cd concentration in the shoot and Cd content and concentration in the root were decreased and Cd content and Zn concentration and content of the shoot increased. By application of Cd, the Zn content of the shoot was increased at first and then decreased and Zn concentration was decreased.

Furthermore, Zn concentration of the shoot in two rice cultivars and in both water regimes, were higher than the deficiency limit, but it was below the optimal level. This shows the reduction of Zn uptake in both water regimes. Cadmium concentration of the shoot in Hashemi was higher than the critical level under non-waterlogged conditions.

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