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Full Length Research Paper

Zinc availability of two wheat cultivars in soil amended with organic and inorganic Zn sources

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The nutrients and organic matter in organic amendments provide a valuable resource to agriculture, forestry and remediation of degraded lands. The objective of this research was to investigate the effects of two wheat cultivars (cv. Backcross and Alvand) on zinc (Zn) uptake in a loamy soil amended with organic and inorganic Zn sources. A factorial experiment using randomized complete blocks was used in three replications. A Zn enriched cow manure (800 mg Zn kg^{-1}) was applied to the soil at three rates of 25 (V_1), 50 (V_2), and 100 Mg ha^{-1} (V_3). To compare the effects of organic and inorganic sources, similar rates of Zn as zinc sulphate ($ZnSO_4$) were also applied (Zn_1, Zn_2 and Zn_3, respectively). An untreated soil sample was considered as control soil (V_0). In general, cultivation of wheat plant (cv. Backcross) resulted in a lower Zn uptake relative to the Alvand cultivar. However, the plants Zn concentration of both cultivars depended on the rate and type of the applied manure (organic or inorganic sources). Both cultivars showed that plants grown in soil treated with $ZnSO_4$ accumulated significantly greater Zn in their root tissue compared to those grown in soil treated with cow manure. A significant increase in the shoot, spike and root Zn concentration was observed as the loading rate of cow manure increased. The results of this experiment point to the fact that the source of fertilizer, type of the plant and the loading rate of Zn are important factors in determining Zn phytoavailability.

Key words: Heavy metal, cow manure, $ZnSO_4$, phytoavailability, seed yield.

INTRODUCTION

The application of organic amendments to agricultural land has become a common practice over the past several decades. Recycling of organic amendments to agricultural land is generally considered to be the most practicable environmental option because this practice is inexpensive, logical and easy to carry out (Jamali et al., 2006). Since organic amendments contain plant nutrients and organic matter, it may be used to supplement or replace commercial (inorganic) fertilizers for crop production (Cogger et al., 2001). The beneficial effects of using organic amendments in agriculture have been proven by numerous researchers (Edmeades, 2003; Gutierrez-Miceli et al., 2007; Reeves, 1997). It has also been shown that organic amendments application improves the physical, chemical and biological properties of soil. In addition, nutrients in organic amendments increase plant biomass and yield (Singh and Agrawal, 2007). Seyedashrafi et al. (2011) reported that applying 25, 50 and 100 Mg ha^{-1} zinc (Zn)-enriched vermicompost to the soil increased the plant height and 1000- grain weight of the barley plant. Pedreno et al. (1996) found that tomato yield was clearly favoured by sewage sludge fertilization. However, Reed et al. (1991) reported that sludge and nitrogen fertilizer applications as the source of applied nitrogen (N) did not affect the grain yield of the corn.

The characterisation of organic amendment metals is an important requirement for application of these components to farmland, because there is a risk of toxic elements accumulating in the soil (Alvarez et al., 2002). Metal transfer from organic amendment to soil and subsequently to plants, pose potential health risks because they can enter the food chain and the environment. Adding organic amendments to the soils causes a significant increase of heavy metal concentrations, but many

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Table 1. Selected physico-chemical properties of unamended soil.

Parameter	Unit	Unamended soil
pH	-	7.7
EC	dS m^{-1}	2.1
Sand	%	40
Silt	%	40
Clay	%	20
Organic carbon	%	0.3
Total P	%	0.02
$CaCO_3$	%	8
DTPA-extractable Zn	mg kg^{-1}	Nd*
CEC	cmol kg^{-1}	9.3

*Nd, Not detectable; EC, electrical conductivity; $CaCO_3$, calcium carbonate; DTPA, diethylenetriaminepentaacetic acid; CEC, cation exchange capacity; P, phosphorus.

Table 2. Selected properties of the applied cow manure.

Characteristic	Unit	Cow manure	U.S. EPA Regulation
pH	-	8.6	-
EC	dS m^{-1}	17	-
Organic carbon	%	35	-
N	%	1.5	-
Pb	mg kg^{-1}	2.7	-
Zn*	mg kg^{-1}	155.9	2800
Ni	mg kg^{-1}	1.5	420
Cd	mg kg^{-1}	0.4	39
Cr	mg kg^{-1}	17.5	3000

*Before enrichment. EC, electrical conductivity; N, nitrogen; Pb, lead; Zn, zinc; Ni, nickel; Cd, cadmium; Cr, chromate.

reports have shown that metals added as inorganic salts are more phyto-available compared to the organic forms of metals e.g. through organic wastes applications (Baghaie et al., 2011; Hettiarachchi et al., 2003; Li et al., 2001; Seyedashrafy et al., 2011). Organic matter and sesquioxides of biosolids increase the sorption capacity of the soil, which reduces metal availability (Hettiarachchi et al., 2003; Hooda et al., 1993). Organic and inorganic fractions of residuals can immobilize heavy metals in soil. The knowledge on the relative contribution of organic and inorganic phases of organic amendments on heavy metal sorption is therefore of great importance for land application of these amendments (Basta et al., 2005). Baghaie et al. (2011) reported that adding 10% (w/w) cow manure or sewage sludge to the soil caused a significant increasing on the Pb sorption capacity of the soil. Seyedashrafi et al. (2011) reported that the soil diethyllenetriaminepentaacetic acid (DTPA)-extractable Zn in soil treated with vermicompost was significantly lower than those treated with the $ZnSO_4$ salt. They concluded that land application of vermicompost increased the sorption capacity of the soil, thus, decreased the soil DTPA-extractable Zn.

About 50% of the soils used for cereal production in the world contain low levels of plant-available Zn, which reduces not only grain yield, but also nutritional quality (Kinaci and Kinaci, 2005). Applying organic amendments in the soils not only provides nutrients to crops, but also improves soil physico-chemical properties and may affect metal bioavailability. However, metal availability is a chemical function found in soil. Plant may change soil metal availability directly and indirectly by different mechanisms such as exudation of complexing agents and respiration roots, which accounts for pH changes, etc. (Hammer and Keller, 2002; Lin et al., 2004; Baghaie et al. 2010). Accordingly, this research was conducted to evaluate Zn availability of two wheat cultivars (cv. Alvand and Backcross) in a loamy soil amended with organic (Zn-enriched cow manure) and inorganic ($ZnSO_4$) Zn sources. The influence of various Zn sources and loading rates on the grain yield and grain Zn uptake in wheat cultivars in organic and inorganic amended soil was also investigated.

MATERIALS AND METHODS

Experimental design

The field experiment was conducted at Arak University Research Farm, central Iran (34° 05′ 21" N, 49° 42′ 36" E), during 2009 to 2010 cropping seasons. The experimental soil of the plot was a loamy, mixed, mesic, Typic Haploxerepts and had a nearly neutral pH, low organic carbon content, and low available Zn concentration (Table 1). The mean annual temperature and rainfall were 13.8°C and 324.3 mm, respectively. Four soil cores (0 to 20 cm depth) were taken from each plot and were mixed to make a composite sample. Soil samples were air-dried, sieved (2 mm), and prepared for chemical analysis. Some of the physico-chemical properties of the soil are presented in Table 1.

The eight-month decomposed cow manure with a low level of heavy metal (Pb and Cd) concentration was selected from Arak Province, center of Iran. The cow manure was enriched with $ZnSO_4$ to 800 mg Zn kg^{-1} and incubated for two weeks. Selected properties of the cow manure are shown in Table 2. The concentration of the metals in the cow manure was less than their tolerable standard values (U.S. Environmental protection agency, 1993). Three rates of Zn (12, 24 and 48 g Zn $plot^{-1}$) in the form of cow manure and $ZnSO_4$ were used in the soil. Accordingly, three loading rates of Zn-enriched cow manure including 25, 50 and 100 Mg ha^{-1} (V_1, V_2 and V_3, respectively) and three rates of $ZnSO_4$ including 49.5, 99 and 198.1 kg ha^{-1} (Zn_1, Zn_2 and Zn_3, respectively) were used. In addition, an untreated soil was considered as the control soil (V_0). All of the treatments were replicated three times. After adding the cow manure, the soil moisture was kept at 80% water holding capacity during the incubation for two weeks.

Seeds of wheat cultivars (cv, Alvand and Backcross) were drill-seeded on October 25, 2009 by hand at a seeding rate of 500 plants m^{-2}. The plots were irrigated using well water with pH range of 7.4 to 7.8 and electrical conductivity (EC) nearly 1.5 dS m^{-1}. On July 6th, 2010, after harvesting the plants, the roots, shoots, and spikes were sampled separately. The plants were oven-dried at 65°C to a constant weight for 72 h and the dry matter weight was recorded. Thereafter, plant samples were combusted overnight at 480°C.

Table 3. Influence of various Zn sources, different loading rates and wheat cultivars on soil pH.

Treatment	Alvand	Backcross
V_0	7.7[a*]	7.7[a]
Zn_1	7.4[b]	7.7[a]
Zn_2	7.5[b]	7.7[a]
Zn_3	7.5[b]	7.7[a]
V_1	7.4[b]	7.8[a]
V_2	7.4[b]	7.8[a]
V_3	7.5[b]	7.8[a]

V_1, V_2 and V_3; Zn enriched cow manure at doses of 25, 50 and 100 Mg ha^{-1}; Zn_1 Zn_2 and Zn_3, similar Zn content of Zn-enriched cow manure (V_1 V_2 and V_3, respectively) supplied from $ZnSO_4$; V_0, control soil. *Means followed by the same letter are not significantly different (p= 0.05). Zn, zinc.

Experimental analysis

Plant analysis

After the plant samples were combusted overnight at 480°C, the ash was treated with HNO_3, heated to near dryness, and then the samples dissolved in 3 M HC1 with heating. Zn concentration in the extracted solutions was measured using atomic absorption spectrophotometry (AAS) (Perkin Elmer model 3030).

Soil analysis

Total Zn in soil and cow manure was extracted using tri-acid mixture (HNO_3:H_2SO_4:$HClO_4$ 5:1:1) and then determined on AAS (Allen et al., 1986). The DTPA-extractable Zn was extracted using 0.005 M DTPA, 0.1 TEA, and 0.01 M $CaCl_2$, adjusted to pH 7.3 (Lindsay et al., 1978). Soil pH was measured with a digital pH meter (Model 691, Metrohm AG Herisau Switzerland) and EC was measured with an EC meter (Model Ohm-644, Metrohm AG Herisau Switzerland). Organic matter content was determined by the Walkley and Black method (Nelson and Sommers, 1982). Soil texture was determined according to a method presented by Gee and Bauder (1986). Total soil phosphorus (P) was determined by a colorimetric method (Olsen and Sommers, 1982). Cation exchange capacity (CEC) was measured using the Rhoades' (1982) method.

Translocation factor (TF)

The ability of plants to transport heavy metals from roots to shoots was measured by calculating translocation factor (TF) as displayed in Equation 1 (Singh et al., 2007):

$$TF = H_s / H_r \qquad (1)$$

where, H_s and H_r are heavy metal concentrations in shoot and root, respectively. The grain Zn uptake was calculated as displayed in Equation 2:

$$\text{Zn uptake} = \text{Grain yield} \times \text{Zn concentration} \qquad (2)$$

Quality control

The accuracy of Zn analysis was controlled by analyzing certified standards of National Institute of Standards and Technology (NIST) and including blanks in digestion batches. The results were found to be within ±4% of the certified value. Quality control measures were taken to assess the contamination and reliability of data. The coefficient of variation of replicate analysis was determined for precision. Variations were found to be less than 10%.

Statistical analysis

The experimental design of the experiment was randomized complete blocks with factorial arrangement with three replications. Data were analyzed by the analysis of variance (ANOVA) procedure from statistical analysis software (SAS) 8.1 (SAS Institute, 1999). Differences between means were evaluated using the least significant difference (LSD). The 0.05 probability value was used to determine significant difference.

RESULTS AND DISCUSSION

Organic amendment effects on soil properties

The interaction of soil pH and wheat cultivars was significant (p = 0.05), as cultivation of Alvand relative to Backcross cultivar decreased the soil pH by nearly 0.2 units (Table 3). This may be related to the root exudate that changes the availability of the metals. Cultivation of Backcross cultivar did not show any significant effect on soil pH compared to the control soil. Zn sources and different loading rates of Zn had no significant effect on soil pH. This was in agreement with the research of Karami et al. (2009) that adding organic amendment to the soil had no significant effect on soil pH under wheat cultivation. The stability in pH in our research may be related to the buffer capacity of the soil used.

The EC of the Zn enriched cow manure was 17 dS m^{-1} (Table 2). Baghaie et al. (2011) reported an EC of 17 dS m^{-1} for cow manure in their research. However, the EC of the cow manure depends on many factors such as the raw materials in the food chain of the animal. The soil EC of control soil in this research was below the definition reported for saline soil (Aitken et al., 1984). The soil EC increased with increasing the loading rate of Zn enriched cow manure (Table 4). The wheat cultivars did not have significant effect on soil EC. Greater increase of soil EC in organic relative to inorganic amended soil was due to the high level of soluble salts in the cow manure. Increased soil EC may result in some detrimental effects on plants and microorganisms. Increasing the loading rate of Zn sources from 49.5 to 198.1 kg ha^{-1} (Zn_1 to Zn_3) as $ZnSo_4$ significantly increased the soil EC by 0.6 units. However, adding cow manure in the rate of 25 to 100 Mg ha^{-1} increased the soil EC by 1.4 units (Table 4).

A high correlation relationship (R^2 = 0.9) was observed between the soil CEC and soil organic carbon. Increasing the loading rates of Zn enriched cow manure (V_1, V_2 and V_3) increased the CEC by 1.2, 1.8 and 2.6 units (Table 5) with increasing soil organic carbon by 0.3, 0.5 and 0.9% compared to the control soil, respectively (Table 6).

Table 4. Influence of various Zn sources, different loading rates and wheat cultivars on soil EC.

Treatment	Alvand	Backcross
V_0	2.1g*	2.1g
Zn_1	2.3f	2.3f
Zn_2	2.6e	2.6e
Zn_3	2.9d	2.9d
V_1	3.2c	3.1c
V_2	3.9b	3.8b
V_3	4.6a	4.5a

V_1, V_2 and V_3; Zn enriched cow manure at doses of 25, 50 and 100 Mg ha^{-1}; Zn_1 Zn_2 and Zn_3, similar Zn content of Zn-enriched cow manure (V_1, V_2 and V_3, respectively) supplied from $ZnSO_4$; V_0, control soil. *Means followed by the same letter are not significantly different (p= 0.05). EC, electrical conductivity; Zn, zinc.

Table 5. Influence of various Zn sources, different loading rates and wheat cultivars on soil CEC (cmol kg^{-1}).

Treatment	Alvand	Backcross
V_0	9.3d*	9.3d
Zn_1	9.3d	9.3d
Zn_2	9.3d	9.3d
Zn_3	9.3d	9.3d
V_1	10.5c	10.5c
V_2	11.1b	11.1b
V_3	11.9a	11.9a

V_1, V_2 and V_3; Zn enriched cow manure at doses of 25, 50 and 100 Mg ha^{-1}; Zn_1 Zn_2 and Zn_3, similar Zn content of Zn-enriched cow manure (V_1, V_2 and V_3, respectively) supplied from $ZnSO_4$; V_0, control soil. *Means followed by the same letter are not significantly different (p= 0.05). Zn, zinc.

Table 6. Influence of various Zn sources, different loading rates and wheat cultivars on soil organic carbon (%).

Treatment	Alvand	Backcross
V_0	0.5d*	0.5d
Zn_1	0.5d	0.5d
Zn_2	0.5d	0.5d
Zn_3	0.5d	0.5d
V_1	0.8c	0.8c
V_2	1.0b	1.0b
V_3	1.4a	1.4a

V_1, V_2 and V_3; Zn enriched cow manure at doses of 25, 50 and 100 Mg ha^{-1}; Zn_1 Zn_2 and Zn_3, similar Zn content of Zn-enriched cow manure (V_1, V_2 and V_3, respectively) supplied from $ZnSO_4$; V_0, control soil. *Means followed by the same letter are not significantly different (p= 0.05). Zn, zinc.

Increasing the CEC of soil amended with cow manure increased the adsorption capacity of the soil, thereby changing the solubility of the metal (Basta et al., 2005).

Table 7. Influence of various Zn sources, different loading rates and wheat cultivars on soil nitrogen (%).

Treatment	Alvand	Backcross
V_0	0.03d*	0.03d
Zn_1	0.03d	0.03d
Zn_2	0.03d	0.03d
Zn_3	0.03d	0.03d
V_1	0.05c	0.05c
V_2	0.08b	0.08b
V_3	0.10a	0.10a

V_1, V_2 and V_3; Zn enriched cow manure at doses of 25, 50 and 100 Mg ha^{-1}; Zn_1 Zn_2 and Zn_3, similar Zn content of Zn-enriched cow manure (V_1, V_2 and V_3, respectively) supplied from $ZnSO_4$; V_0, control soil. *Means followed by the same letter are not significantly different (p= 0.05). Zn, zinc.

Table 8. Influence of various Zn sources, different loading rates and wheat cultivars on root Zn concentration (mg kg^{-1}).

Treatment	Alvand	Backcross
V_0	22.0i*	20.0j
Zn_1	40.0d	35.0f
Zn_2	45.0c	41.2d
Zn_3	96.0a	94.0b
V_1	25.0h	25.0h
V_2	29.0g	30.0g
V_3	38.0e	35.0f

V_1, V_2 and V_3; Zn enriched cow manure at doses of 25, 50 and 100 Mg ha^{-1}; Zn_1 Zn_2 and Zn_3, similar Zn content of Zn-enriched cow manure (V_1, V_2 and V_3, respectively) supplied from $ZnSO_4$; V_0, control soil. *Means followed by the same letter are not significantly different (p= 0.05). Zn, zinc.

Moreover, Seyedashrafy et al. (2011) reported that adding 25, 50 and 100 Mg ha^{-1} Zn enriched vermicompost caused a significant increasing in the CEC of organic amended soil by 0.9, 1.4 and 2.2% respectively. Soil application of Zn enriched cow manure (V_1, V_2 and V_3) increased the soil nitrogen by 0.02, 0.05, and 0.07% compared to the control soil, respectively (Table 7).

Zn concentration in plant tissues

In general, Zn efficiency in Alvand cultivar was greater than Backcross cultivar. In all treatments, root Zn concentration of Alvand cultivar was greater than Backcross cultivar even in control soil (Table 8). In addition, the root Zn concentration in both wheat cultivars grown in the plots treated with cow manure was lower than that of plants grown in the plots which received $ZnSO_4$. This can be related to the sorption capacity of organic amendment that affected the soil Zn availability and thereby root Zn uptake of the wheat cultivars. However the role of the

Table 9. Influence of various Zn sources, different loading rates and wheat cultivars on shoot Zn concentration (mg kg^{-1}).

Treatment	Alvand	Backcross
V_0	Nd*	Nd
Zn_1	12.0f**	9.0g
Zn_2	20.0c	20.0c
Zn_3	30.0a	25.0b
V_1	9.0g	7.1h
V_2	14.0e	12.2f
V_3	20.0c	16.0d

V_1, V_2 and V_3; Zn enriched cow manure at doses of 25, 50 and 100 Mg ha^{-1}; Zn_1 Zn_2 and Zn_3, similar Zn content of Zn-enriched cow manure (V_1, V_2 and V_3, respectively) supplied from $ZnSO_4$, V_0, control soil, *Nd: not detectable. **Means followed by the same letter are not significantly different (p= 0.05). Zn, zinc.

Table 10. Influence of various Zn sources, different loading rates and wheat cultivars on spike Zn concentration (mg kg^{-1}).

Treatment	Alvand	Backcross
V_0	Nd*	Nd
Zn_1	8f**	6h
Zn_2	13b	11d
Zn_3	11d	9e
V_1	5i	4j
V_2	9e	7g
V_3	16a	12c

V_1, V_2 and V_3; Zn enriched cow manure at doses of 25, 50 and 100 Mg ha^{-1}; Zn_1 Zn_2 and Zn_3, similar Zn content of Zn-enriched cow manure (V_1, V_2 and V_3, respectively) supplied from $ZnSO_4$; V_0, control soil, *Nd: not detectable. **Means followed by the same letter are not significantly different (p= 0.05). Zn, zinc.

Table 11. The influence of various Zn sources and their loading rates on the grain yield of two wheat cultivars (kg ha^{-1}) planted in organic and inorganic amended soil.

Treatment	Backcross	Alvand
V_0	4934.65h*	5084.43g
Zn_1	5220.17g	5430.29f
Zn_2	5425.32f	5926.88e
Zn_3	4785.09i	5520.11f
V_1	7145.00d	7434.57c
V_2	7364.91c	7645.37b
V_3	7688.56b	7953.63a

V_1, V_2 and V_3; Zn enriched cow manure at doses of 25, 50 and 100 Mg ha^{-1}; Zn_1 Zn_2 and Zn_3, similar Zn content of Zn-enriched cow manure (V_1, V_2 and V_3, respectively) supplied from $ZnSO_4$; V_0, control soil. *Means followed by the same letter are not significantly different (p= 0.05). Zn, zinc.

wheat cultivar on root Zn uptake cannot be ignored.

Increasing the loading rate of Zn as $ZnSO_4$ (Zn_1, Zn_2 and Zn_3) significantly increased the root Zn concentrations of Alvand cultivar by 1.8, 2.0 and 4.36 times (Table 8). For Backcross cultivar, it increased by 1.75, 2.0 and 4.7 times, respectively. On the other hand, applying Zn enriched cow manure (V_1, V_2 and V_3) significantly increased the root Zn concentrations of Alvand cultivar by 1.13, 1.31 and 1.72 times compared to those grown in the control soil, respectively (Table 8). For Backcross cultivar it increased by 1.25, 1.5 and 1.75 times compared to those grown in the control soil, respectively. Similar to this result, other researchers have reported that the metals applied by inorganic salt are more phytoavailable than the equivalent quantity of metal applied by organic amendments (Baghaie et al., 2011; Basta et al., 2005; Hettiarachchi et al., 2003; Li et al., 2001; Seyedashrafy et al., 2011). These results have been interpreted as indicating that organic amendment adds adsorptive phases to soils, which reduce metal availability to plants. The root Zn concentrations in wheat plants were much higher than those in aerial tissues. However, partitioning and distribution of trace elements in different plant tissues depends on the plant species (Sharifi et al., 2010).

Shoot Zn concentration showed significant differences between wheat cultivars (Table 9). Increasing the loading rate of $ZnSO_4$ from 49.5 (Zn_1) to 99 and 198.1 kg ha^{-1} (Zn_2 and Zn_3) significantly increased the shoot Zn concentrations of Alvand cultivar by 1.6 and 2.5 times, while for Backcross cultivar it increased by 2.2 and 2.7, respectively. On the other hand, with increasing the loading rate of Zn-enriched cow manure from 25 to 50 and 100 Mg ha^{-1}, the shoot Zn concentrations of Alvand wheat cultivar significantly increased by 1.5 and 2.2 times, respectively. Similarly, for Backcross cultivar it increased by 1.71 and 2.2, respectively. Similar to the root Zn concentration, the shoot Zn concentration of the plants grown in organic amended soil (V_2 and V_3) was lower than that of plants grown in inorganic amended soil (Zn_2 and Zn_3), respectively (Table 9). Shoot Zn concentration of both cultivars was not detectable by atomic absorption spectrophotometry.

For Alvand and Backcross cultivars, increasing the loading rate of $ZnSO_4$ from 49.5 (Zn_1) to 99 (Zn_2) kg ha^{-1} significantly increased the spike Zn concentration by nearly 1.7 times, respectively (Table 10), but decreased it at the greatest loading rate of Zn (Zn_3). The significant decrease of the grain yield at the greatest loading rate of inorganic Zn sources (Table 11) may be due to the significant decrease of the spike Zn concentration at the Zn_3 treatment compared to Zn_2 treatment. On the other hand, 1.7 times increase in the spike Zn concentration of Zn_2 compared to Zn_1 treatment in Alvand and Backcross cultivars resulted in a significant increase in the grain yield by 496.59 and 205.15 kg ha^{-1}, respectively (Table 11). However, the role of genetic properties of the plants cannot be ignored as the grain yield of the Alvand was greater than Backcross cultivar in all of the organic and

Table 12. The influence of various Zn sources and their loading rates on the grain Zn uptake and translocation factor (TF) of two wheat cultivars planted in organic and inorganic amended soil.

Treatment	Grain Zn uptake (g ha^{-1})		TF	
	Backcross	Alvand	Backcross	Alvand
Zn_1	31.32[i*]	43.44[g]	0.25[h]	0.30[f]
Zn_2	59.67[e]	77.04[c]	0.48[b]	0.44[c]
Zn_3	43.06[g]	60.72[e]	0.26[g]	0.31[f]
V_1	28.55[j]	37.17[h]	0.28[g]	0.36[e]
V_2	51.55[f]	68.80[d]	0.40[d]	0.48[b]
V_3	92.26[b]	127.25[a]	0.45[c]	0.52[a]

V_1, V_2 and V_3; Zn enriched cow manure at doses of 25, 50 and 100 Mg ha^{-1}; Zn_1 Zn_2 and Zn_3, similar Zn content of Zn-enriched cow manure (V_1, V_2 and V_3, respectively) supplied from $ZnSO_4$, *Means followed by the same letter are not significantly different (p= 0.05). Zn, zinc; TF, translocation factor.

inorganic treatments even in the control soil. Unlike the inorganic sources in Alvand and Backcross cultivars, increasing the loading rate of Zn-enriched cow manure from V_2 to V_3 treatment, significantly increased the spike Zn concentration by seven and five units, respectively (Table 10). It may be concluded that applying the greatest loading rate of cow manure in the soil increased the solubility of Zn, thereby increasing spike Zn concentration. However, the role of Zn solubility as affected by soil pH cannot be ignored (Lindsay and Norvell, 1978). The results of the Seyedashrafi et al. (2011) confirmed this clearly. They reported that applying 100 Mg ha^{-1} Zn-enriched vermicompost significantly increased the Zn spike concentration of barley plant relative to the lower rates (25 and 50 Mg ha^{-1}) and applying the 100 Mg ha^{-1} Zn inorganic sources as $ZnSO_4$ showed toxicity effect and thereby, decreasing the grain yield or Zn spike concentration of the barley plant. Bourg and Darmendrail (1992) reported that organic metal complexes in soil solution play an important role in the soil Zn availability to plants.

A significant linear relationship (R^2 = 0.83) was observed between the Zn spike concentration and grain Zn uptake. Considering the relationship between Zn uptake and Zn concentration, it may be concluded that Zn plays an important role on the grain yield of both wheat cultivars. However, the role of other nutrition and the genetic properties of the wheat cultivars cannot be ignored as the greatest grain yield was observed for Alvand cultivars which was planted in soil that received 100 Mg ha^{-1} Zn enriched cow manure (data was not shown). In both cultivars, the greatest grain Zn uptake was observed for the wheat cultivars cultivated in the soil that received 100 Mg ha^{-1} Zn-enriched cow manure (Table 12). However, grain Zn uptake was greater for the Alvand relative to Backcross cultivars. In general, applying organic relative to inorganic Zn sources caused a significant increase in the grain Zn uptake for both cultivars.

Translocation factor of Zn

The ability of plants to translocate heavy metals from roots to shoots was measured by calculating the TF. TF values of more than one suggest that heavy metals are readily transported from root to shoot whereas values less than one signify more accumulation of heavy metals in root. Zn concentration in the aerial parts of the plants cultivated in the control soil (V_0) was less than the detection limit of the atomic absorption spectrophotometry. Regardless of the Zn source for both cultivars, the TF value of Zn was less than one for all treatments (Table 12). This was in agreement with the researches of Seyedashrafi et al. (2011) and Baghaie et al. (2011) that reported the translocation factor below one. Singh and Sinha (2005) reported increased accumulation of Zn in tissues of *Brassica juncea* with increasing rate of tannery sludge from 10 to 100%, although the greatest accumulation of Zn was found in roots (Singh et al., 2005).

The TF ranged from 0.25 to 0.52 with the greatest values of 0.57 for Alvand cultivar cultivated in the soil amended with 100 Mg ha^{-1} Zn-enriched cow manure (Table 12). For both cultivars, increasing the loading rate of cow manure significantly increased the TF. It can be concluded that applying enriched cow manure increased the plant growth, thereby increasing the TF value. For both cultivars, at the greatest loading rate of Zn as $ZnSO_4$, the TF value significantly decreased especially for Backcross cultivar. However, the lowest TF was found when 25 Mg ha^{-1} Zn-enriched cow manure was applied to Backcross cultivar. Moreover, the role of the plant genetic on the translocation of heavy metals from root to shoot cannot be ignored. For Alvand and Backcross cultivars, applying the greatest loading rate of Zn organic (V_3) relative to inorganic (Zn_3) sources significant increased the TF factor by 0.21 and 0.19, respectively. Accordingly, at the greatest loading rate of organic amendment, the grain yield (data not shown) and grain Zn uptake of both cultivars was significantly greater than those cultivated in

Table 13. Influence of different loading rates and various Zn sources on soil DTPA-extractable Zn.

Treatment	Alvand	Backcross
V_0	Nd*	Nd
Zn_1	9^{d**}	7^e
Zn_2	13^c	10^d
Zn_3	19^a	16^b
V_1	7^e	5^f
V_2	10^d	7^e
V_3	14^c	10^d

V_1, V_2 and V_3; Zn enriched cow manure at doses of 25, 50 and 100 Mg ha^{-1}; Zn_1 Zn_2 and Zn_3, similar Zn content of Zn enriched cow manure (V_1, V_2 and V_3, respectively) supplied from $ZnSO_4$, V_0, control soil, *Nd: not detectable; **means followed by the same letter are not significantly different (p= 0.05). Zn, zinc; DTPA, diethylenetriaminepentaacetic acid.

Zn_3 treatment (Table 12).

Effect of organic and inorganic Zn sources on the soil DTPA-extractable Zn

For both cultivars, increasing the loading rate of Zn from both organic and inorganic sources significantly increased the soil DTPA-extractable Zn (Table 13). The soil DTPA-extractable Zn was greater for the soil under cultivation for Alvand relative to Backcross cultivars. This may be related to the root exudate that changed the Zn availability via the decreasing of the pH of the soil under the cultivation of Alvand relative to Backcross cultivar (Table 3). For both cultivars at the same loading rate, the DTPA-extractable Zn in the soils treated with $ZnSO_4$ was significantly greater than the cow manure amended soils (Table 13). For Alvand cultivar, applying organic Zn (V_1, V_2 and V_3) significantly decreased the Soil DTPA-extractable Zn by 22.2, 23 and 26.3% compared to the similar rate of Zn inorganic as $ZnSO_4$ (Zn_1, Zn_2 and Zn_3), respectively. For Backcross cultivar, it decreased by 28.5, 30 and 37.5%, respectively. For Alvand cultivar, increasing the loading rate of Zn enriched cow manure from 25 to 50 and 100 Mg ha^{-1} significantly increased the soil DTPA-extractable Zn by 42 and 100%, and for Backcross it increased by 40 and 100%, respectively.

Similar to our results, Li et al. (2001), Hettiarachchi et al. (2003) and Seyedashrafy et al. (2011) showed that the amount of metals required to cause yield reductions are always lesser with salts as compared to organic amendments. The organic residuals generally contain different compounds such as organic materials, iron (Fe), manganese (Mn) and aluminum (Al) oxides, which adsorb heavy metals and could reduce the solubility of metals in the polluted soils (Basta et al., 2005).

Conclusion

The results of the current study revealed that the Zn efficiency was greater for Alvand relative to Backcross cultivar. However, for both cultivars, the Zn-phytoavailability in soils treated with cow manure was significantly lower than those treated with the $ZnSO_4$ salt. Greater decrease of soil DTPA-extractable Zn at the V_3 treatment compared to the Zn_3 treatment indicated that land application of cow manure increased the adsorption capacity of the soil and thus decreased the soil DTPA-extractable Zn. For both cultivars, the soil DTPA-extractable Zn showed a positive correlation with the Zn root concentration and thereby its translocation to the aerial parts. In addition, a significant linear relationship (R^2 = 0.83) was observed between the Zn spike concentration and grain Zn uptake. Except the greatest loading rate of inorganic Zn source, application of Zn from both organic and inorganic sources significantly increased the grain yield of wheat cultivars. This indicates that plant growth in organic amended soil may be affected by the soil organic carbon content and the plant nutrients that are available in cow manure. Therefore, it seems that applying the greatest loading rate of Zn-enriched cow manure may have more significant effects on the plant growth and Zn spike concentration.

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