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ORIGINAL PAPER

Growth characteristics and response of wheat to cadmium, nickel and magnesium sorption affected by zeolite in soil polluted with armaments

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ABSTRACT

The presence of large heavy metal concentrations in soil polluted with chemical weapons causes serious operational restrictions against cultivation of agricultural crops like wheat. To solve this problem, the usage of zeolite has been proposed as one of the most efficient practical approaches. The main objective of this research is the investigation of the influence of natural Iranian zeolite on sorption of cadmium (Cd^{2+}) and nickel (Ni^{2+}) and the investigation of growth characteristics of wheat in soil polluted with chemical weapons. The experiments were carried out in factorial arrangement in a randomized complete design with three replications during 2015-2016 crop season. Treatments with four levels of zeolite included: a_1) 0%; a_2) 0.5%; a_3) 1.5%; and a_4) 2.5% of soil weight and two soil samples, one obtained from out of the war zone (without contamination) (b_1) and other was from contaminated soil to weapons (b_2). Results showed that the polluted soil led to a significant enhancement in amount of Cd^{2+} and Ni^{2+} in shoots and roots of wheat. In addition, the findings revealed that the application of zeolite caused a significant reduction in Cd^{2+} and Ni^{2+} concentrations in shoots and roots and significantly increased dry matter, chlorophyll index and magnesium (Mg^{2+}) concentration in wheat. In general, results showed that zeolite released nutrients and stabilized heavy metals in polluted soil and the negative effect of soil polluted by toxic heavy metals was reduced in the plant, which lead to decontamination of soil and increase in safety of environment.

Keywords: Chlorophyll; Nickel; Root; Wheat; Zeolite

Introduction

The extensive growth of the human population has caused serious environmental pollution through production of huge amounts of wastewater.[1] This pollution can be defined as discharge of large quantities of hazardous materials and energies into the water and soil resources which endanger human health.[2] In general, war is considered as one of the most important factors polluting the environment on a large scale. Recently, the United Nations has declared its worries about the negative impacts of war on the environment and human health.[3] In the war between Iran and Iraq, around 16,000 km^3 of Iran was destroyed by Iraqi bombs, and over 1,100 km of the border of Iran and Iraq was polluted by 16 million tons of bombs.[4] According to previous researches on the war between Iraq and Iran, approximately 4.2 million hectares have been contaminated with chemicals and non-chemical weapons.[1] Heavy metals are non-biodegradable and can be stable in soils for a long time and bringing about different diseases. The application of modifiers causes immobilization and stabilization of heavy metals in soil through different mechanisms, such as adsorption, acid-base reactions, oxidation reaction and cationic-cation complexation.

Cadmium (Cd^{2+}) is one of the most toxic heavy metals that can provide diseases renal lesions, lung insufficiency, bone lesions and hypertensions, even at low concentrations.[2] The maximum permissible limit for Cd^{2+}

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concentration in agricultural soil is 1–3 mg/kg.[5] Another toxic heavy metal that is ubiquitous in polluted soil is nickel (Ni^{2+}). The presence of nickel in soil and water resources leads to some human diseases like dermatitis, nausea, chronic asthma and coughing.[6] Therefore, 5–40 mg/kg Ni^{2+} concentration was selected as maximum permissible limit in soils.[1] Up to now, different materials have been proposed for metal fixation in soils, but clay minerals have showed perfect efficiency due to their cost-effectiveness, environmentally-friendly nature and their high cation exchange capacity.[7]

Zeolite is a hydrous aluminosilicate clay mineral with a primary structural unit based on the presence of either aluminum or silicon in the center of a tetrahedron with four oxygen atoms around it. The negative charges are produced by isomorphic substitution of Si^{4+} with Al^{3+}. The cation exchange capacity (CEC) of zeolite is 100–300 Cmol/kg and has high affinity for adsorption of cations.[8] Natural zeolites, especially clinoptilite, are highly abundant in different parts of Iran. Mahabadi et al. reported that most of Iranian zeolite is clinoptilite and in Gilan Province, north of Iran, it has high ability to fix Cd^{2+}.[9] They believed that the high CEC and alkalinity of zeolite causes Cd^{2+} fixation. Findings of the study by Shi et al. showed that zeolite could adsorb considerable amounts of Cd^{2+} and Pb^{2+} and change them to unavailable forms in plants.[10] Many studies have been done in the country and the world due to the high amount of nutrient elements in zeolite structure and superiority of this mineral fertilizer. But, no research has been performed on the effect of zeolite on Cd^{2+} and Ni^{2+} sorption in soil polluted with weapons. Therefore, the main objective of this study was the investigation of the role of natural zeolite on Cd^{2+} and Ni^{2+} sorption and wheat growth characteristics in polluted soil.

Materials and Methods

This study was carried out to find the role of various zeolite dosages, including 0% (a_1), 0.5% (a_2), 1.5% (a_3), and 2.5% (a_4) of the soil weight on Cd^{2+} and Ni^{2+} sorption by wheat plants and their growth characteristics in non-polluted (b_1) and polluted soil (b_2) treatments. This experiment was performed in a completely randomized design with three replications for each pot in a research field of the Islamic Azad University of Ahvaz during the 2015-2016 crop season. The study area was the southern Dehloran (between Sharhani and Zabidat in Iraq), which had a wide range of contaminating war weapons as a result of the war between Iraq and Iran. In this regard, 50 soil samples polluted by weapons were gathered from the south of Dehloran city at 30 cm depth and the other 50 samples were collected from the non-polluted areas, which were 1 km away from the polluted area with similar area characteristics. Afterward, the samples were air dried, sieved in a 2-mm steel sieve to separate the big particles, and ultimately their physical and chemical characteristics were determined. These are reported in Table 1. Electrical conductivity (EC) and pH of soil were measured in a 1:10 solid/solution ratio using EC meter and pH meter, respectively. Soil texture was also determined using hydrometric method and cation exchange capacity (CEC) was measured through the substitution of sodium (Na^+) with ammonia (NH_4^+) in zeolite structure. Organic carbon determined via Walkley Black method and the calcium carbonate contents measured by titration method.[11,12] In addition, potassium was measured using flame photometer, but absorbable phosphorous and nitrogen were determined using spectrophotometer and *Kjeldahl* methods. Finally, the concentrations of $Ni^{2+}$and Cd^{2+} were measured using digestion method with atomic absorption spectroscopy (AAS, Analytikjenavario 6, Germany).[13]

Zeolite was purchased from Afarand Tuska, Co., Iran. Then, it was washed with distilled water, air dried and passed through a 1-mm sieve. Afterward, the mineralogical features of zeolite were determined using X-ray diffraction

(XRD), which showed that over 75% of zeolite is pure clinoptilite. The polluted and non-polluted soil samples were mixed with various amounts of zeolite and put in 40 cm high×20 cm diameter pots. Ten wheat seeds were put in each pot at a depth of 3 cm and, after germination, thinned to five plants per pot. The pots were irrigated once a week and moisture content was kept at FC. During the cultivation period, no fertilizers, herbicides and pesticides were entered into the soil due to the large quantity of nitrogen and phosphorous substances resulting from chemical weapons application. For investigation of dry matter of roots and shoots, after 75 days the pots were placed in a basin full of water for 12 h. Thereafter, the pots were torn and the roots were cleaned by water flow by using 0.5-mm mesh sieve, manually. Then, the roots and shoots of each pot were dried to constant weight in an oven at 75 ºC for 72 h, separately. To find the Cd and Ni concentrations, the samples were digested in the concentrated HNO_3 and 30% H_2O_2 and their concentrations were measured with atomic absorption spectroscopy (AAS, Analytikjenavario 6, and Germany). Measurement of chlorophyll in the booting stage was performed by using chlorophyll meter model Spectrum SPAD502 company.

Analysis of variance (ANOVA) was performed by SAS software and the cutting method was used for mean comparison of interaction at a significance level of 5%.

Results and discussion

Soil and zeolite characteristics

Some chemical characteristics of soil and zeolite used in the experiments are shown in Tables 1 and 2. Soil pH is one of the greatest factors to control heavy metal bioavailability in soil. The pH of polluted soil is more acidic than non-polluted soil and this result can be due to an increase in the availability of heavy metals in the soil, which increases the possibility of plants using these elements. The residual materials of applied weapons, depending on their nature, change soil pH conditions. The reason for acidity of polluted soil could be the presence of different substances like trinitrotoluene, 2.4.DNT and 2.6.DNT. The EC was higher in

Table 1. Some chemical properties of non- polluted (control) and polluted soils

Sample	pH	EC	K_{AV}	N	P	Ni	Cd	OC	CEC	$CaCO_3$	Clay	Sand
		ds/m	mg/kg	%	mg/kg	mg/kg	mg/kg	%	Cmol/kg	%	%	%
Polluted soil	6.63	4.83	539.7	0.163	47.4	132.4	15.4	0.69	13.64	7.16	29	41
Non-polluted soil	7.56	3.15	142.6	0.058	4.58	25.78	4.76	0.17	9.52	13.52	22	41

Table 2. Some chemical properties of zeolite used in experiment

Parameter	Unite	Value
pH	-	8.45
EC	dSm^{-1}	0.097
CEC	$Cmolkg^{-1}$	170
SiO_2	%	66.5
Al_2O_3	%	11.81
Fe_2O_3	%	1.3
TiO_2	%	0.21
CaO	%	3.11
MgO	%	0.72
Na_2O	%	1.2
K_2O	%	3.12
P_2O_5	%	0.01
LOI	%	10.06

treatment of polluted soil (4.83 dS/m) as compered to non-polluted soil treatment (3.15 dS/m). Furthermore, Cd^{2+} and Ni^{2+} concentrations in polluted soil were higher than non-polluted soil treatments, which cannot be attributed to the parent material.[24] Therefore, the high difference between Cd^{2+} and Ni^{2+} concentrations in polluted and non-polluted soil treatments would be derived from the application of chemical weapons and armaments. In addition, according to results in Table 2, the pH of zeolite is 8.45 and its CEC is 170 Cmol/kg, which increases the CEC of soil and leads to more cation sorption.

Effect of soil and zeolite treatments on Cd^{2+}concentration in roots

Based on Table 3, zeolite treatments have significant effect on Cd^{2+} concentration in roots ($p < 0.01$). According to mean comparison (Fig. 1), increasing zeolite in non-polluted soil does not lead to a significant effect on Cd^{2+} concentration in roots, but in the polluted soils it significantly decreased concentrations of Cd^{2+} in roots. The maximum root Cd^{2+} concentration (31.76 mg/kg) in polluted soil was observed in a_1b_2 treatment and the lowest amount of Cd^{2+} in roots was obtained by using a_4b_2 treatment. Results revealed that the application of a_4b_2, as compared with a_1b_2, caused 20.53 mg/kg decrease in Cd^{2+} root concentration. Indeed, by adding each quantity of 0.5% zeolite, the amount of Cd^{2+} in wheat root decreased by 3.51 mg/kg unit. Shi et al. reported that zeolite could significantly decrease the amount of Pb^{2+} and Cd^{2+} sorption by plants.[10] Mahmoudabadi et al. stated that addition of zeolite to non-polluted soil led to increasing nodule dry matter and decreasing Cd^{2+}, K^{+}, Cu^{2+} and Mn^{2+} concentrations in plant biomass.[14] Moreover, Cd^{2+} of root concentrations in a_1b_2 was 30.75 mg/kg higher than in a_1b_1 treatment, due to the application of chemical weapons.

Table 3. ANOVA results of applied treatment on cadmium, nickel, magnesium, shoot and root dry matte

Source of Variance	df	Cd Shoot	Cd Root	Shoot Ni	Root Ni	Soot dry matter	Root dry matter	Chlorophyll	Mg^{2+} concentration
		Mean of squares							
Zeolite(z)	3	2.30**	152.95**	1.35**	3.764**	260.79**	30.26**	142.73**	0.017**
Soil(s)	1	351.01**	2304.3**	19.81*	220.88**	665.81**	24.24**	645.84**	0.004**
Interaction (z*s)	3	101.42**	144.00**	0.904**	1.98**	33.19**	14.9**	1.84ns	0.001ns
Error	16	0.18	0.26	0.07	0.05	2.6	1.63	14.13	0.00

ns, * and ** are not significant and significant at the P value of 0.05 and 0.01, respectively

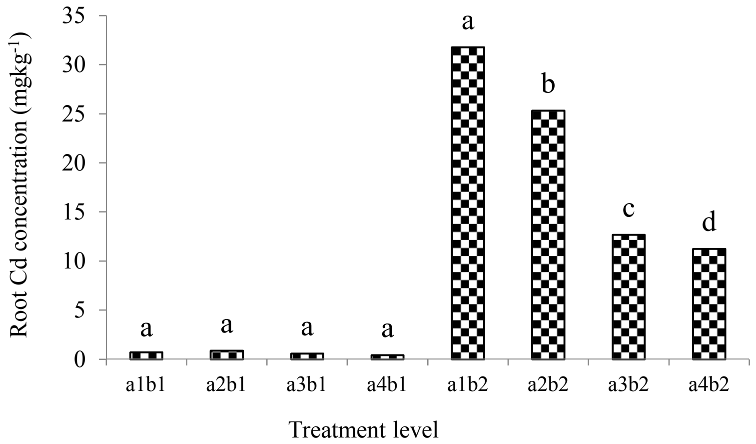

Fig. 1. Effect of soil (b_1: non-polluted and b_2: polluted) and zeolite treatments (a_1: zero, a_2:0.5%, b_3:1.5%, b_4:2.5%) on cadmium concentration of roots.

Effect of soil and zeolite treatments on Cd^{2+} concentration in shoots

The results of mean comparison of different amounts of zeolite on concentration of Cd^{2+} in wheat shoots are shown in Fig. 2. According to the figure, increase of zeolite in polluted soil has a significant effect on Cd^{2+} reduction in shoots, indicating the efficiency of zeolite in decreasing Cd^{2+} in plant shoots. But in non-polluted soil, the differences were not significant. In polluted soil, by using a_4b_2 treatment as compared with a_1b_2, a reduction by 2.27 mg/kg occurred in Cd^{2+} concentration in shoot dry matter. Results showed that the differences between zeolite treatments with control (a_2b_1) were significant, but no significant difference was observed between a_2b_2 and a_3b_2. By using each extra zeolite (quantity of 0.5%) in polluted soil, the amount of Cd^{2+} in wheat shoots decreased by 0.561 mg/kg unit. This phenomenon can be ascribed to the alkalinity and high CEC of zeolite and the high nutrient availability in zeolite that increases wheat shoots dry matter and decreases Cd^{2+} concentration in shoots. Mahmoudabadi et al. reported that the entrance of zeolite to the polluted soil lead to increases nodes dry matter and decreases Cd^{2+} concetration.[14]

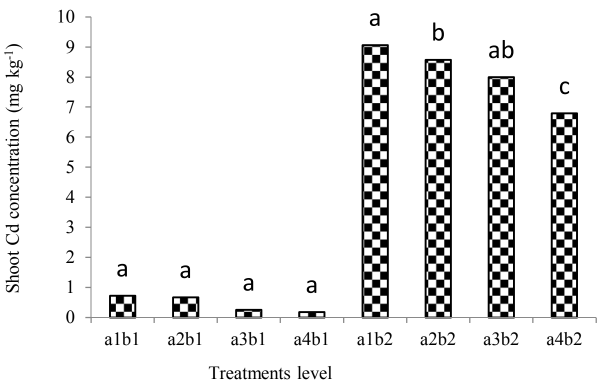

Fig. 2. Effect of soil (b_1: non-polluted and b_2: polluted) and zeolite treatments (a_1: zero, a_2:0.5%, b_3:1.5%, b_4:2.5%) on cadmium concentration of shoots

The majority of heavy metals, unlike other biological contaminants, are non-biodegradable and can accumulate in the soil, which is a threat to life of human beings.[15] Furthermore, the results observed that a larger amount of Cd^{2+} is stored in plant roots and a smaller amount of Cd^{2+} is transferred to plant shoots. Findings of Simon et al. showed that concentration of Cd^{2+}, Cu^{2+}, Zn^{2+}, and Ni^{2+} in plants growing in polluted soil decreased with addition of zeolite.[16]

Effect of soil and zeolite treatments on Ni^{2+} concentration in roots

Results of ANOVA showed that the effect of soil and zeolite treatments on Ni^{2+} concentrations in roots were significant (Table 3). According to the figure 2, the maximum reduction in Ni^{2+} concentration in roots (0.6 mg/kg) in non-polluted soil was obtained by using a_4b_1. However, the application of other treatments had a not significant effect on Ni^{2+} reduction in wheat roots. Furthermore, in polluted soil treatments, a significant difference was observed in Ni^{2+} reduction in roots by using different amounts of zeolite. In fact, application of a_4b_2 treatment, compared with a_1b_2, led to 3.16 mg/kg decrease in Ni^{2+} concentration. The maximum amount of Ni^{2+} sorption in polluted soil (8.56 mg/kg) was obtained in control (a_1b_2), which reveals that the application of toxins in chemical weapons led to the enhancement of heavy metal concentrations like Ni^{2+} and Cd^{2+}, that caused plant toxicity. Moreover, using zeolite treatments decreased Ni^{2+}concentration in plant roots where the highest amount of zeolite was the most effective treatment in Ni^{2+} reduction due to the high CEC and alkalinity of zeolite.

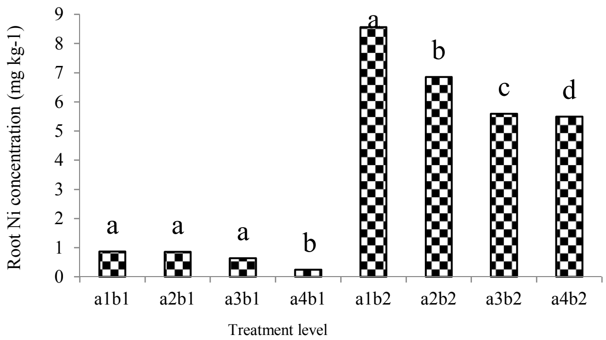

Fig. 3. Effect of soil (b_1: non-polluted and b_2: polluted) and zeolite treatments (a_1: zero, a_2:0.5%, b_3:1.5%, b_4:2.5%) on nickel concentration of roots

Fathi and Chorom, in a similar research, reported that zeolite can absorb heavy metals through an ion exchange process due to their high CEC.[17] In addition, the Ni^{2+}concentration of root in *polluted* soil was 7.72 mg/kg higher than non-polluted soil, which can be attributed to the abundance of Ni^{2+} in polluted soil due to the application of chemical weapons. Saadat and Baranimotlagh stated that zeolite could decrease Cd^{2+} concentration in maize roots.[18]

Effect of soil and zeolite treatments on the Ni^{2+} concentration in shoots

Results of mean comparison (Fig. 4) show that in non-polluted soil, zeolite treatments have no significant effect on Ni^{2+} concentration in wheat shoots. But, in polluted soil, a significant reduction was observed in Ni^{2+} concentration by using different amounts of zeolite. Results show that a_4b_2 treatment, compared with a_1b_2, could decrease Ni^{2+} concentration in shoots by 1.82 mg/kg, which can be attributed to high CEC of zeolite that does not let toxic elements enter into the plant body. Furthermore, the maximum and minimum Ni^{2+} sorption were 2.77 and 0.95 mg/kg, which were obtained by control and 2.5% zeolite treatments, respectively. In addition, by adding each 0.5% of zeolite, around 0.455 mg/kg Ni^{2+} in wheat shoots was observed. Results of a study by Kumpiene et al. revealed that zeolite has great ability to fix heavy metals in soils polluted with chemical weapons.[19]

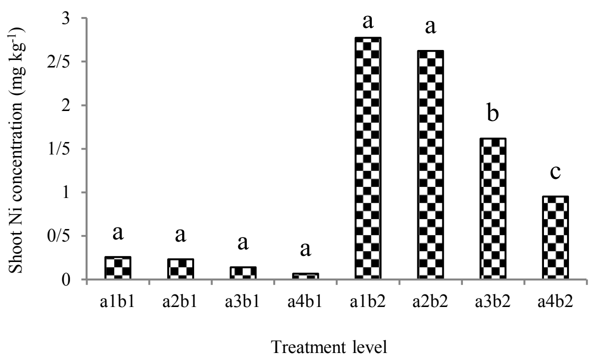

Fig. 4. Effect of soil (b_1: non-polluted and b_2: polluted) and zeolite treatments (a_1: zero, a_2:0.5%, b_3:1.5%, b_4:2.5%) on nickel concentration of shoots

Shoots Ni^{2+} concentration in polluted soil was 2.51 mg/kg higher than in non-polluted soil, which may be due to the application of chemical weapons that discharged large amounts of Ni^{2+} into the soil.

Effect of soil and zeolite treatments on root dry matter

Results of ANOVA indicate the statistically significant effect of soil and zeolite treatments and their interaction effects on roots dry matter ($p < 0.01$) (Table 3). As can be seen from Fig. 5, in non-polluted soil a_4b_1 has significant impact on dry matter, while the differences between a_1b_1, a_2b_1 and a_3b_1 were not insignificant (Fig. 5). Application of a_4b_1 led to increase in roots dry matter by 3.47 g compared with the control (a_1b_1) treatment. It can be concluded that the zeolite has a high amount of nutrient elements that becomes available in physiologically active form in roots. It is reported that the zeolite increases soil CEC and the capacity of nutrient element sorption.[20] Furthermore, it can increase saturated hydraulic conductivity which improves soil porosity, ventilation and root growth.[21]

Results have confirmed that in polluted soil, a significant difference was obtained between effects of 2.5% zeolite and effects of other treatments on root dry matter (Fig. 5). The highest amount of root dry matter was 11.18 g, which was obtained by using a_4b_2 treatment, while the lowest root dry matter (6.24 g) was observed in a_1b_2 treatment. The most probable reason for this phenomenon may be attributed to the fact that zeolite could store nutrient elements and release them to plants and also prevent the sorption of toxic elements. Zeolite can retain some cations in its structure due to its high CEC and improve the plant nutritional conditions.[7] It seems that the effect of zeolite on growth is related to the absorption and maintenance of ammonium and potassium, which leads to water retaining in the soil and preventing rotting of the plant root.[17] The roots dry matter in polluted and non-polluted soil treatments was different. This difference may be derived from the presence of nitrogen and phosphorous substances in polluted soil that entered the soil from chemical weapons' deposits (Table 1).

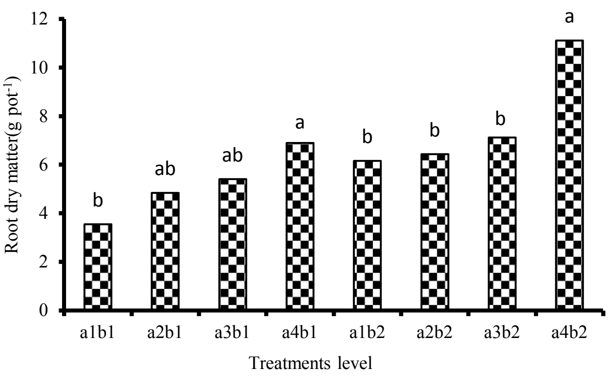

Fig. 5. Effect of soil (b_1: non-polluted and b_2: polluted) and zeolite treatments (a_1: zero, a_2:0.5%, b_3:1.5%, b_4:2.5%) on roots dry matter

Effect of soil and zeolite treatments on wheat shoots dry matter

The effect of soil and zeolite treatments on shoots dry matter is showed in Fig. 6. In non-polluted soil, the application of 2.5% zeolite treatment (a_4b_1) had a significant effect on shoots dry matter. The maximum (16.88 g) and minimum (6.97 g) amount of shoots dry matter was obtained by using a_4b_1 and a_1b_1, respectively. It can be said that zeolite added large amounts of Si^{4+}, K^+, and Mg^{2+} to the plant which increased its shoots dry matter.[20] Zeolite increases soil CEC that leads to the enhancement of nutrient elements retention.[8] Mahmoudabadi et al. reported that the addition of zeolite to the non-polluted soil causes an enhancement of the concentration of nutrient elements like N, P, K^+, Fe^{2+}, Mn^{2+},Cu^{2+}, and Zn^{2+} in plant bio matter, which increased soybean shoots dry matter. The results of mean comparison indicated that in polluted soil, a significant difference was observed for different treatments of zeolite in shoots dry matter. The minimum and maximum amount of shoots dry matter was 34.69 and 12.28 g, which was obtained by using a_4b_2 and a_1b_2, respectively. Khanmohammadi et al. stated that the application of zeolite leads to increase in shoots dry matter of sorghum.[22] The result also showed that shoots dry matter in polluted and non-polluted soil treatments is 12.28 and 7.41 g, respectively. The result of the current study reveled that the presence of nitrogen, phosphorous and potassium in polluted soil (Table 1) leads to increasing of shoots dry matter. Findings of Eshghi et al. have revealed that zeolite can decrease toxic effect of heavy metals and increase roots and shoots dry matter.[23]

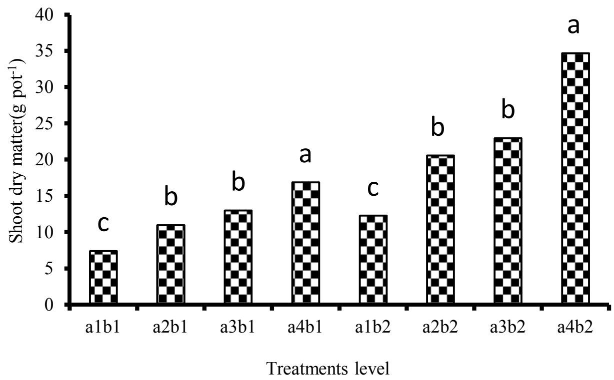

Fig. 6. Effect of soil (b_1: non-polluted and b_2: polluted) and zeolite treatments (a_1: zero, a_2:0.5%, b_3:1.5%, b_4:2.5%) on shoots dry matter

Effect of soil and zeolite treatments on chlorophyll index

Based on table 3, significant differences observed for chlorophyll under different soil and zeolite treatments, but their interaction were not significant on chlorophyll. The result of mean comparison showed that the effect of zeolite treatments on chlorophyll in treatment of 2.5% zeolite (a_4b_1 and a_4b_2), as compared to 0.5% treatments (a_2b_1 and a_2b_2) were significant, but the differences between 1.5% zeolite treatments(a_3b_1 and a_3b_2) and 0.5% treatments (a_2b_1 and a_2b_2) were not significant (Fig.7). The maximum and minimum chlorophyll in polluted and non-polluted soil were observed in treatment of 2.5% zeolite (a_4b_2) and control (a_1b_1) by 50.56 and 29.9, respectively. This can be ascribed to the improvement of availability of nutrient elements to the plant and enhancement of nitrogen and magnesium sorption by using zeolite. In fact, zeolite increases photosynthesis, chlorophyll production and water sorption by plants. High chlorophyll production in polluted soil as compared to non-polluted soil may be attributed to the presence of large amounts of nitrogen, phosphorous and other required elements (Table 1) due to the application of chemical weapons.

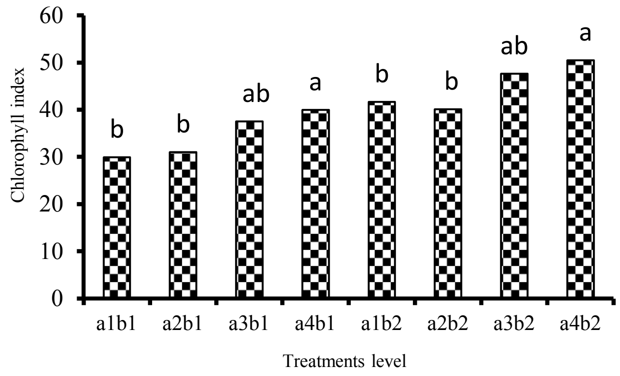

Fig. 7. Effect of soil (b_1: non-polluted and b_2: polluted) and zeolite treatments (a_1: zero, a_2:0.5%, b_3:1.5%, b_4:2.5%)on chlorophyll index

Effect of soil and zeolite treatments on Mg^{2+} concentrations in grain

According to table 3, the effect of soil and zeolite treatments on Mg^{2+} concentrations were significant, but their interaction were not significant. Results of mean comparison showed that in both polluted and non-polluted soil treatments, the 1.5% and 2.5% zeolite treatments as compared to control and 0.5% treatments, had significant effect on Mg^{2+} sorption (Fig. 8). In fact, in both soil treatments, a significant increase was observed in Mg^{2+} concentration of grain by using zeolite. Previous research has confirmed that zeolite is able to release some nutrient elements such as phosphorous, potassium, magnesium, zinc, iron, copper, etc., in the soil and enhance its sorption into plants.[17]

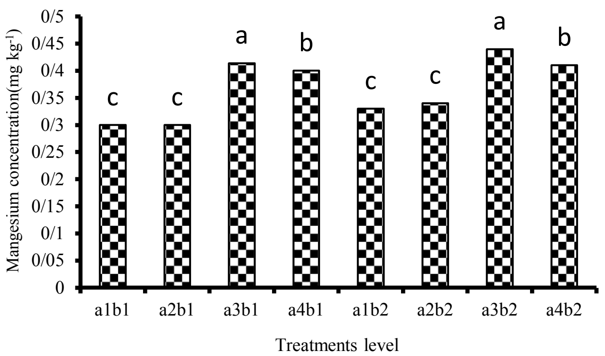

Fig. 8. Effect of soil (b_1: non-polluted and b_2: polluted) and zeolite treatments (a_1: zero, a_2:0.5%, b_3:1.5%, b_4:2.5%)on magnesium concentration

The maximum amounts of Mg^{2+} in grain in polluted and non-polluted soil treatments were 0.446 and 0.414 mg/kg, respectively, which was obtained by using the 1.5% zeolite treatment. Furthermore, in control treatment the concentration of Mg^{2+} sorption in polluted and non-polluted soil was different, which can be attributed to the high amount of Mg^{2+} in polluted soil due to the application of chemical weapons.

Conclusion

Results showed increased Cd^{2+} and Ni^{2+} concentrations in roots and shoots of wheat in soil polluted with chemical weapons. The amounts of Cd^{2+} and Ni^{2+} in roots were higher than in shoots, which indicates that wheat can store larger amounts of heavy metals in its roots and prevent their entrance into the shoots. However, by using zeolite, the Cd^{2+} and Ni^{2+} concentrations in wheat shoots and roots decreases significantly. Furthermore, increasing the amount of applied zeolite leads to a decline in the entrance of Cd^{2+} and Ni^{2+} into wheat shoots and roots, which can be ascribed to the high CEC of zeolite and its alkalinity, that has high cation adsorption capability. Moreover, the results indicate that zeolite can stabilize Cd^{2+} and Ni^{2+} in soil polluted with chemical weapons and it has high ability to stabilize heavy metals. Additionally, the application of zeolite in both polluted and non-polluted soil treatments increases Mg^{2+} concentration and roots and shoots dry matter.

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Conflict of interests

The authors declare no conflict of interest.

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