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Ability of some crops for phytoremediation of nickel and zinc heavy metals from contaminated soils

Hamdollah Eskandari[1], Ashraf Alizadeh Amraie[2]

1 Associate Professor, Department of Agriculture, Payame Noor University, Tehran, Iran
2 Instructor, Department of Agriculture, Payame Noor University, Tehran, Iran

Original Article

Abstract

The present study was aimed at comparing the ability of three crop plants for phytoremediation of zinc (Zn) and nickel (Zn) from soils. A factorial (3×2×3) experiment based on RCBD was used to compare the treatments, and was repeated three times. The first factor was crop type (wheat, clover and rapeseed), the second factor was heavy metal types (zinc (Zn) and nickel (Ni)) and the third factor was heavy metal concentration in soil (0.0, 50 and 100 mg.kg^{-1}). With regard to plant type and heavy metal, the highest uptake was recorded in wheat for nickel (Ni) uptake. The lowest uptake of heavy metal was seen in clover crop and nickel (Ni) heavy metal. The highest Ni uptake was observed in wheat at the concentration of 100mg.kg^{-1}. Nickel (Ni) was more absorbed in its higher concentration where the uptake of nickel (Ni) at the concentration of 100.0mg.kg^{-1} was 182% more than 50.0 mg.kg^{-1}. Generally, the results of this experiment showed that it is possible to use phytoremediation as a suitable means for eliminating the excess concentration of zinc (Zn) and nickel (Ni). In this case, wheat was the superior crop and its mechanisms for removal of heavy metal require further investigation.
KEYWORDS: bioaccumulation, heavy metal pollution, toxic effect

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Introduction

Heavy metals are indestructible materials which have a great impact on environmental pollution. They also damage biological and physiological systems of organisms.[1] Heavy metals, which are defined as metals and metalloid with a density of over five g.cm^{-3} [2], are among the most important factors which pollute farming systems. Although small quantities of some heavy metals are essential for normal metabolism, but large amounts of heavy metals are toxic for humans. The toxic effects of high levels of heavy metals in plants can also be seen. Bioaccumulation, the increase in the concentration of a chemical material in an organism compared with its accumulation in the environment, is one of the specific characteristics which has a significant role in the incidence of toxic effects of heavy metals.[3] Heavy metals which are biologically indestructible and irresolvable, remain indefinitely in the environment and ultimately affect soil quality and human health. Thus, the elimination, or at least reduction of heavy metal from farming soils is closely associated with human health.[4]

Some heavy metals are not required by plants and have no biological function. However, some other heavy metals, including zinc (Zn), are essential for normal plant growth and their low availability leads to the reduction of nitrogen metabolism and protein synthesis, internode length and, finally, plant growth.[3] However, zinc (Zn) has a toxic effect when it is absorbed by plants in high concentration which negatively affects physiological and biochemical processes of plant, thereby leading to reduction in plant growth and yield[2]. Nickel (Ni) improves the structure of some plant enzymes[5] and its low concentrations is essential for plant growth and

Corresponding Author:
Hamdollah Eskandari
Email: ehamdollah@gmail.com

sustainability of agroecosystems. However, high concentration of nickel (Ni) has harmful effects (such as cancer, lung problems and skin sensitivity) on human health.[1] As a result, excess amount of zinc (Zn) and nickel (Ni) should be eliminated from the environment.

Different chemical, physical and biological agents have been introduced for the removal of heavy metals from farming soils. However, some of these methods such as soil washing, are costly [6] and some others such as the use of some chemical materials, have negative effects on the biological activity of soil.[7] Chemical and hydroxide precipitation are extensively used for remediation of heavy metal. However, in these methods of heavy metal removal, pH condition of the environment needs to be accurately adjusted to the range of 9-11[8] which limits the growth of numerous crop plants. Although reverse osmosis is a method capable of removing heavy metals from aquatic environments, high consumption of power is the major drawback of this technique.[9]

The phytoremediation technology is an eco-friendly and cost-effective way for removing heavy metals from farming soils.[10] In a research, the ability of three plants of *Arabis arenosa* L., *Amaranthus retroflexus* L. and *Agropyron repens* L. was compared for zinc (Zn) remediation and it was observed that *Agropyron* was the superior plant for this goal.[11] It should be noted that high levels of tolerance to heavy metals does not suggest the suitability of a plant for phytoremediation of heavy metals. For instance, it has been reported that although ornamental cabbage tolerated high amount of nickel (Ni), it was suitable for low to medium levels of pollutions.[5] Parnian *et al.*, (2012), worked on nickel (Ni) phytoremediation by *Ceratophyllum demersum* L. from a hydroponic growing condition, and reported that the highest phytoremediation efficiency (50%) was obtained under the concentration of 1mg.lit^{-1}, suggesting the possibility of nickel (Ni) phytoremediation by this plant.[12]

There is the possibility of contamination of. soils of agro-ecosystems in industrial regions with heavy metals. However, to prevent the reduction of farmer's income, purification of soils from heavy metals should be done with crop plants. Since there is no sufficient information on the ability of wheat, rapeseed and clover for remediation of zinc (Zn) and nickel (Ni), the current experiment was aimed to compare the ability of these crop plants for phytoremediation of zinc (Zn) and nickel (Ni) from soils so as to reduce the toxic concentrations of these two heavy metals from agro-ecosystems. ZnO powder has been reported previously.[4, 8]

In this process, some parameters affect the process efficiency and energy consumption including the initial solution pH (pH_0), the initial concentration of pollutant (C_0), the dose of nano-sized catalyst (D_{SC}), the ultrasound irradiation frequency (Fr_{SC}), the ultrasound irradiation power (P_{SC}), and the treatment time (t_{SC}). The efficiency of the process may be increased by the optimization of these factors.[13]

The aim of this study is to evaluate the efficiency of DR% and EPM for a solution of DB71during the SC process using synthesized nano-sized ZnO, followed by the optimization of the SC process in order to maximize DR% and to minimize the EPM with regard to the effective operational factors using GA based on the RQRM and the ANN models.

Materials and Methods

A three-factor factorial experiment (3×2×3) was conducted in Payame Noor university of Khuzestan to compare the efficiency of three crop plants for the removal of zinc (Zn) and nickel (Ni) from soil. The first factor was crop type which included wheat (*Triticum aesticum* L. var Chamran, as a crop from the cereal family and the most important grain crop), clover (*Trifolium resupinarum* L. var Aleshteri, as a forage crop from leguminous family) and rapeseed (*Brassica napus* L. var Cobra, as an important oil crop which is normally used in rotation programs). The second factor comprised heavy metals of zinc (Zn) and nickel (Ni) and the third factor was the concentration of heavy metals in soil including 0.0, 50 and 100 mg kg^{-1}. The experiment was designed as RCBD and repeated three times.

For the preparation of contaminated soil, samples supplied from the soils of farm regions (some physical and chemical properties of experimental soil were presented in Table 1) using scientific sampling methods, were contaminated with zinc (Zn) nitrate and nickel

(Ni) nitrate. Since zinc (Zn) and nickel (Ni) nitrates were solid materials, they were directly added to the soil up to the amount of 0.0, 50 and 100 mg kg^{-1} soil. Afterwards, the experimental plots (with 30 cm depth and diameter) were filled by the same amount (10 kg) of contaminated soil.

Seeds of wheat, clover and rapeseed were cultivated in plots according to 400, 700 and 110 plant m^{-2}, respectively. In order to prevent the possibility of leaching of heavy metal from soil, drainage water from plots was reused for irrigation.

Four weeks after planting, all plant parts (including root and shoot) of the three crops were harvested and oven dried at the temperature of 75°C for 72 hours. All samples were milled and, then, the concentration of zinc (Zn) and nickel (Ni) were determined by Perkin-Elmer atomic absorption spectrometer, using dry ash method.[14]

The analysis of variance of the data was done using MSTATC statistical software. Means were compared with Duncan's multiple range test at the statistical probability of P≤0.01.

Table 1. Some physical and chemical properties of experimental soil.

Soil texture	Percentage of soil particles			Nickel (Ni) (ppm)	Zinc (Zn) (ppm)	pH	EC (ds/cm)
	Sand	Silt	Clay				
Clay-Loam	27	35	38	0.14	0.65	7.97	1.4

Results and Discussion

Triple interaction effect of plant type× heavy metal× concentration was insignificant on the total content of heavy metals in plant tissues (Table 1). However, the interaction of plant type× heavy metal, plant type × concentration and heavy metal × concentration were significant at P≤0.01 (Table 2).

Table2. Analysis of variance for the effect of plant type, type and concentration of heavy metal on phytoremediation of zinc (Zn) and nickel(Ni) from soil

Source of Variance	Degree of Freedom	Mean square of metal content
Replication	2	1800.07^{ns}
Plant type (P)	2	26312.24^{**}
Heavy metal (H)	1	2874.74^{ns}
P×H	2	21793.57^{**}
Concentration (C)	2	192023.46^{**}
P×C	4	11898.80^{**}
H×C	2	21858.91^{**}
P×H×C	4	5555.07^{ns}
Error	34	2360.86
CV (%)		29.2

**: significant at P≤0.01 probability level; ns: not significant

Wheat and nickel had the best treatment in terms of plant type and heavy metal (Figure 1). The lowest heavy metal uptake was observed in clover crop and nickel (Ni) heavy metal. Therefore, when nickel (Ni) is in high concentration, wheat is a better crop for rotation than clover and rapeseed. There was no significant difference between clover and rapeseed in terms of nickel (Ni) uptake (Figure 1). However, clover was a powerful crop for the uptake of excess concentrations of zinc (Zn), where zinc (Zn) content in clover tissue was higher than in wheat and rapeseed. It can therefore be concluded that wheat and clover are suitable for phytoremediation of nickel (Ni) and zinc (Zn) from farming soils, respectively (Figure 1). It has been reported that canola (*Brassica napus*) was the superior crop for the removal of excess amount of nickel (Ni) from the soil of agricultural systems.[15] However, this result is not consistent with the findings of the present research, since in this research, wheat was more efficient for Ni phytoremediation.

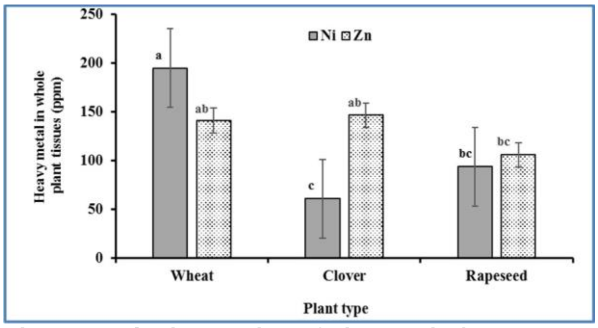

Figure 1. The interaction of plant and element type on the uptake of heavy metals.

The highest heavy metal uptake was observed in wheat at the concentration of 100mg.kg^{-1} (Figure 2). When the soil was not contaminated, (control treatment) all three crops had no significant difference in heavy metal uptake. However, they demonstrated increase in uptake with an increase in the concentration of heavy metal. When the concentration of heavy metal increased from 50.0 to 100.0 mg.kg^{-1}, clover and rapeseed did not show higher heavy metal uptake, which suggests their unsuitability for phytoremediation under high concentration of heavy metals. However, wheat had significant higher heavy metal accumulation in the concentration of 100.0 mg.kg^{-1} (Figure 2), demonstrating the ability of this crop for phytoremediation of high concentration of zinc (Zn) and nickel (Ni).

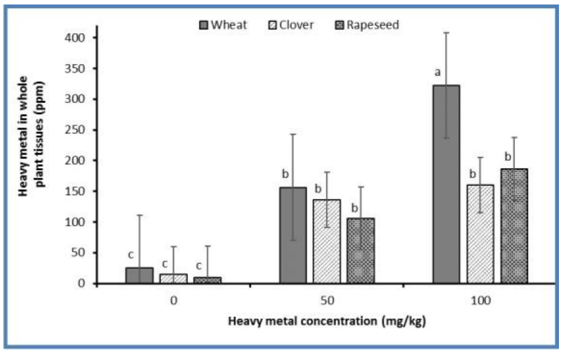

Figure 2. The interaction of plant type and element concentration in soil on the uptake of heavy metals.

The results revealed that nickel (Ni) was more absorbed in higher concentration where the uptake of nickel (Ni) at the concentration of 100.0 mg.kg^{-1} was 182% more than 50.0 mg.kg^{-1} (Figure 3). These results are in agreement with the findings in *Brassica* species where the relative Ni concentration parts increased with increasing Ni levels in soil.[16] In canola, it has also been reported that increase in the concentration of Ni resulted in more solubility of nickel (Ni) in the soil, and thus the absorption of this heavy metal by the plant was facilitated.[17] The difference between 50.0 and 100.0 mg.kg^{-1} was not significant for zinc (Zn) accumulation in plant tissues, suggesting that nickel (Ni) was better absorbed in higher concentrations than zinc (Zn).

Apart from zinc (Zn) in the concentration of 50 mg kg^{-1}, bioaccumulation factor of wheat was higher than clover and rapeseed (Table 3). Bioaccumulation factor of wheat was 72% and 53% more than that of clover and rapeseed, respectively. However, clover was stronger for collection of zinc from the soil under condition of lower concentration. Phytoremediation may be a suitable method for removing excess concentration of heavy metals in contaminated soils. Uptake index is a suitable criterion for determining the ability of crop for phytoremediation of heavy metals.[18] This index is related to crop biomass. Thus, higher biomass can lead to more heavy metal uptake. It has been reported that crops with high biomass are able to uptake more heavy metals from soils when compared with crops having low biomass[19] which is consistent with the finding of the current research. Wheat, which showed more nickel (Ni) accumulation, produces higher biomass compared with clover and rapeseed. Insignificant difference between wheat and clover in terms of zinc (Zn) uptake (Figure 1) showed that high accumulation of heavy metals is not always connected with biomass production. However, the findings suggested the efficiency of phytoremediation of heavy metals which is compatible with the findings of some other researches.[12,20]

The content of total nickel (Ni) was greatly affected by the type of plant species cultivated in the soil. In this case, it has been concluded that the ability for Ni phytoremediation is dependent on the level of nickel (Ni) concentration in soil.[7] When nickel (Ni) is in high concentrations, much time is required for removing its excess amounts from soil. These findings are in line with the finding of this study, where clover and canola showed no significant difference between 50 mg kg^{-1} and 100 mg kg^{-1} for phytoremediation of Ni. Although wheat was the best crop for nickel (Ni) remediation, its ability was considerably lower than that of *Ceratophyllum demersum.*[12] However, *Ceratophyllum demersum* is a suitable plant for phytoremediation of heavy metals in aquatic conditions and cannot be efficiently used in agricultural systems. The ability of the three crop plants for zinc (Zn) removal was not significantly different (Figure 1), suggesting that wheat, clover and rapeseed can be efficiently used for removing zinc from the soil.

Accumulation of zinc (Zn) in plant tissues was not significantly affected when its concentration in soil increased from 50.0 to 100 mg.kg^{-1} (Figure 3). In other words, increase in the amount of zinc (Zn) did not affect its accumulation in plant tissues. This contradict the finding in water duckweed which indicates that by increasing its concentration in the environment, more zinc (Zn) uptake can be observed.[20] This observation may be the cause of pH difference in the two different environments.[21] Positive correlation between the concentration of zinc (Zn) in the soil and its uptake has been reported [18] which is compatible with the findings of this research. Wheat was superior crop for zinc (Zn) phytoremediation and its ability for zinc (Zn) collection is higher than that of *Arabis arenosa*, *Amaranthus retroflexus* and *Agropyron repens.*[11] Zinc (Zn) content of wheat tissues (under the concentration of 100 $mgkg^{-1}$) was 251$mgkg^{-1}$, while *Arabis arenosa*, *Amaranthus retroflexus* and *Agropyron repens* uptake were 99, 90 and 116 $mg\ kg^{-1}$.

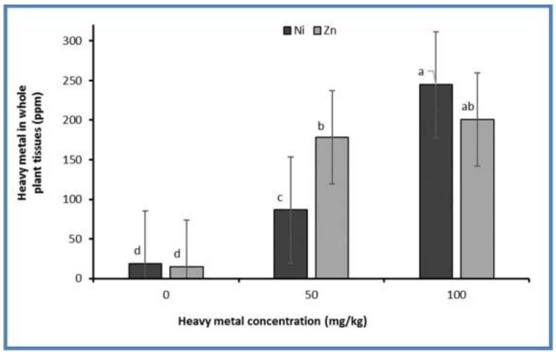

Figure 3. The interaction of element type and concentration in soil on the uptake of heavy metals.

Bioaccumulation factor (BAF) is an appropriate index for illustrating the ability of crops for uptake of heavy metals from the soil[7]. The value of this factor for wheat was significantly higher than that of rapeseed and clover, signifying the superiority of wheat

Table 3. Mean comparison of bioaccumulation factor for zinc (Zn) and nickel (Ni) collecting from the soil by wheat, clover and rapeseed.

Plant type	Zinc (Zn)		Nickel (Ni)	
	50 $mg\ kg^{-1}$	100 $mg\ kg^{-1}$	50 $mg\ kg^{-1}$	100 $mg\ kg^{-1}$
Wheat	3.27a	3.9a	2.99b	2.52a
Clover	0.72c	1.28c	4.7a	1.93b
Rapeseed	102b	2.16b	2.98b	1.55b

for zinc (Zn) and nickel (Ni) phytoremediation. It has been reported that by increasing crop life period, more heavy metals accumulate in crop tissues, resulting in more purification of soil from heavy metals.[12] Although all crops in this experiment were harvested simultaneously, wheat can be a more efficient crop for phytoremediation of nickel (Ni) and zinc (Zn) owing to its longer growth period.

In order to attain a better understanding on The ability of wheat, clover and rapeseed for heavy metals uptake, it is necessary to evaluate phytoremediation in different environmental conditions such as different soil pH and moisture. In addition, albeit wheat was the best crop for zinc (Zn) and nickel remediation from the soil. The accumulations of heavy metals in different parts of wheat, especially the grains, require further documentation in order to determine, if the grain (or other parts for animal nutrition) of wheat can be consumed or not based on the existing standards.

Conclusion

Generally, the findings of this experiment indicated that it is possible to use phytoremediation as a suitable way for removing excess concentration of zinc (Zn) and nickel (Ni). Wheat was the superior crop for nickel (Ni) phytoremediation. All three crops, wheat, clover and rapeseed can be used to reduce excess concentration of zinc (Zn) heavy metal. In terms of utilization, the dry matter produced could be burned for energy.

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