 DOI: 10.31276/VJSTE.64(3).90-96

Effects of bentonite and zeolite minerals on mobility of lead in paddy soil in Chi Dao commune, Van Lam district, Hung Yen province, Vietnam

Tu Ngoc Nguyen*, Huy Quang Trinh, Cong Huy Vo

Vietnam National University of Agriculture

Received 25 October 2021; accepted 28 November 2021

Abstract:

Used lead-acid battery recycling activities in Minh Khai handicraft village, Chi Dao commune, Van Lam district, Hung Yen province, Vietnam has markedly increased the lead (Pb) content in paddy soil. Reducing the mobility of lead and lead accumulation in rice plants/plain rice are major priorities to reduce the impacts of lead in paddy soil. Application of the minerals zeolite (4A and Faujasite) and bentonite (natural and modified) to lead-contaminated soil has been carried out in lab scale for three years. The results showed the efficiencies in reducing accumulated lead in rice were 58 and 56% after adding the artificial additives zeolite 4A and zeolite Faujasite, respectively. These results were better than those of modified bentonite and natural bentonite, which were only 44 and 24%, respectively. The control efficiency of Pb accumulated in rice plants between the supplemented samples of zeolite Faujasite, zeolite 4A, modified bentonite, and natural bentonite were 69, 56, 42, and 40%, respectively, compared with the control samples. The addition of minerals to the soils has also resulted in decreases of the growth and yield of the experimental rice plants compared with the control samples. In this research, 0.1 to 0.2% of zeolite Faujasite showed the best results in terms of reducing Pb content in soil as well as low effect on plant growth. This research opens up on-site pollution control solutions for lead-contaminated agricultural soils.

Keywords: **heavy metals, lead immobilizing, minerals, rice uptake.**

Classification number: **5.3**

Introduction

Lead content in natural soil ranges from 10 to 50 ppm [1]. Due to biogeochemical cycling changes and imbalances from manmade activities such as use of fertilizer [2, 3], manure [4], sludge disposals [5], or polluted irrigation water [6, 7] result in the accumulation of lead in soil and create risks to human health and ecology [8]. Lead in soil may be in a soluble form, or found as lead inorganic compounds PbS, $PbSO_4$, $PbSO_4$. PbO, α-PbO [9], or be associated with organic compounds such as amino acids, fulvic acids, and humic acids [10]. The mobility of lead in soil is largely controlled by pH [11, 12], the presence of organic matter [13], and clay mineral content [14]. Lead phytoavailability and toxicity are dependent on their speciation.

Zeolite is the general name for aluminosilicate minerals called tectosilicates, which have three-dimensional frameworks [15]. Zeolite has high cation exchange capacity and selective absorption, so it is widely used in environmental treatment especially for heavy metal absorption in contaminated soils [16-19]. Chemical stabilization of heavy metals by adding artificial additives has been evaluated as one of the most cost effective in situ remediation techniques for metal contaminated sites [16, 20]. Chemical stabilization may lead to a decrease in extractable metal content in soil [21] and metal phytoavailability in plants [16, 22].

Used lead-acid battery recycling activities in Minh Khai handicraft village, Chi Dao commune, Van Lam district, Hung Yen province, Vietnam discharges copious amounts of acidic wastewater and causes soil and water pollution. Some studies reported that Pb concentration in soils in the handicraft village exceeded the allowable value [23, 24] and causes major health issues in the local community [25, 26]. Therefore the agricultural soil surrounding the handicraft village is not safe enough for cultivation.

This study was implemented to evaluate and determine a suitable in situ remediation for Pb-contaminated sites by adding artificial minerals into soils to immobilize lead and decrease its phytoavailability in rice plants. Some effects of additives on the rice growth (such as plant height, number of panicles, length, and weight of plain rice) in this study were also determined.

Materials and methods

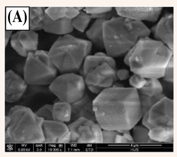
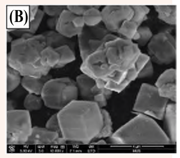
Materials

Zeolite minerals: In this study, minerals of zeolite 4A and zeolite Faujasite were synthesized from silica particles of rice straw. The hydrothermal crystallization method was used to synthetize zeolite minerals and the products, shown in Table 1, were characterized using x-ray powder diffraction (XRD)

*Corresponding author: Email: nguyenngoctu@vnua.edu.vn

and observed by scanning electron microscope (SEM).

Table 1. Properties of zeolite minerals.

No.	Element	Zeolite 4A	Zeolite Faujasite
1	Chemical formula	$Na_{12}Al_{12}Si_{12}O_{48}.27H_2O$	$Na_2Al_2Si_{2.5}O_9 6H_2O$
2	Mineral compositions	Na_2O; Al_2O ; SiO_2	Na_2O; Al_2O_3; SiO_2
3	Crystalline size, µm	2.5	4
4	CEC, meq 100 g^{-1}	341	432
5	Pb absorption efficiency, %	82.67	96.56
6	SEM captured off **(A)** zeolite 4A and **(B)** zeolite Faujasite		

Natural bentonite and modified bentonite minerals: The natural bentonite in this research was collected from the Tam Bo bentonite mines, Di Linh district, Lam Dong province, Vietnam. The mineral was compounded by high Montmorillonite content (about 64%) while the remains were Kaolinite (9.5%), Illite (6.0%), Quartz (5.0%), Feldspar (3.5%), Goethite (3.0%), Canxit (little), and other minerals. Chemical compositions of the natural bentonite were mainly composed of SiO_2 (50.5%), Al_2O_3 (17.67%), and Fe_2O_3 (7.0%). The mineral had a CEC of 19.5 meq 100 g^{-1} and the basal spacing of 15.49 Å.

Al-pillared bentonite was created by activating the natural bentonite with polyoxymetal cations of Al solution. The activated mineral had CEC of 58.6 meq 100 g^{-1} and the basal spacing of 16.81 Å.

Contaminated-Pb soil samples: Soil samples used in the research were collected from the 0-20 cm surface layers of 10 small scale paddy fields surrounding the used lead-acid battery recycling facilities in Minh Khai handicraft village, Chi Dao commune, Van Lam district, Hung Yen province, Vietnam (Fig. 1).

Fig. 1. Soil sampling locations.

Rice plants: Greenhouse pot experiments were conducted at the Vietnam National University of Agriculture (VNUA) and used to evaluate the effects of zeolite and bentonite minerals on the immobility of lead in soil and the growth and grain yield of rice plants. The Bac Thom No.7 resistance leaf blight variety was used in the pot experiments. Rice plants of age 10-13 days after sowing were planted in the experimental pots. Three rice plants with the same height were planted in each experimental pot.

Rice grain samples: The rice grains were used in this research to determine the effectivity of lead cumulative control after adding mineral additives to the soil. These rice grains were collected from the experimental pots.

Methods

Soil analysis: Soil samples were examined by the PIXE method (particle-induced x-ray emission) to determine its chemical composition. Other physio-chemical properties of the soil samples such as pH, electro-conductivity (EC), texture, and organic matter (OM) content were also determined.

Plant-available Pb analysis: Pb phytoavailability was extracted from soil by the diethylenetriamine pentaacetic acid (DTPA) method at a pH of 7.3. Each 10 g portion of air-dried soil was passed through a 2.0-mm sieve to which 20 ml DTPA extractant was added. The suspensions were shaken at 175 rpm for 2 h. The experiments were terminated by filtration of the suspension by a cellulose acetate filter, then determining the soluble ion of Pb using ICP-OES (PE 7300 V-ICP, Perkin Elmer).

Determination of Pb content in rice plant and grain: Pb content in rice plants and grains was determined by using aqua regia (3:1 HCl/HNO_3). Briefly, 50 mg of dried sample was drilled and digested in 50 ml of the aqua regia solution. The solution was then gently shaken and filtered by a cellulose acetate filter. The soluble ion of Pb was determined using ICP-OES (PE 7300 V-ICP, Perkin Elmer).

Greenhouse pot experimental design method: After assessing the composition and properties of the soil, the soil samples were mixed together and then NPK fertilizer was added with an amount of 25 kg per 360 m^2 (corresponding 1.1 g per experimental pot). This soil was then filled into the experimental pots (30 cm diameter x 20 cm height). The experiment was conducted over three seasons. Four types of minerals (natural and modified bentonite, zeolite 4A, and zeolite Faujasite) with six treatments (5 levels of additives from 0.1 to 0.5% and the control) were replicated three times in one season resulting in 72 pots (4x6x3) in total (Table 2). The weight of both soil and added mineral was 5 kg in total. The Bac Thom No.7 resistance leaf blight variety was used in the pot experiment, which was submerged in 5 cm of water over the entire growth period. Three seedlings 13 days in age were planted in each pot. NPK 17-12-5 fertilizer with a dosage of 1.1 g per pot was supplemented three times during the experiment beginning at basal fertilizing (before experiment operation), then the first application of fertilizer (10 days after plantation), and second application addition fertilizer (49 days after plantation) (Table 3).

Table 2. Lab-scale experimental design.

Element	Control	Level 1	Level 2	Level 3	Level 4	Level 5
Ration (w/w)	0%	0.1%	0.2%	0.3%	0.4%	0.5%
Mineral amount, g	0	5	10	15	20	25
Soil amount, g	5,000	4,995	4,990	4,985	4,980	4,975
Total, g	5,000	5,000	5,000	5,000	5,000	5,000

Table 3. Growth stages of rice plant and evaluated elements.

No	Stages	Time, day	Element
1	Seeding	13	Pb total, extractable Pb in soil, pH_{KCl}
2	Transplanting	26	- Extractable Pb in soils - pH_{KCl}
3	Tillering	36	
4	Panicle formation	49	
5	Flowering	61	
6	Harvest	109	- pH_{KCl}, extractable Pb in soil, Pb content in rice plant and polished rice, height of rice plant, number of panicles, length of rice grain and weight of 1000 grains.

Results and discussion

Compositions and properties of soil samples

The results show that soil pH_{KCl} values ranged from 3.4 to 5.2 with an average of 4.1. The soil in the study area is acidic. Although the sampling locations were within a narrow area, the variations in pH_{KCl} value were relatively large. This can be explained by external effects such as the use of wastewater containing high H^+ ions discharged from the village for irrigation. The low pH_{KCl} values in soil may lead to increase in the risk of pollution by mobilizing heavy metals and thus increasing its bioavailability for plants [27] (Table 4).

The OM contents of soil samples ranged from 1.33 to 2.44%. According to the Ministry of Natural Resources and Environment (2015) [28], the soil samples from this area were from the low-to-medium organic matter content groups (from 2.60-3.36%). Soil texture analysis showed that the proportion of clay ranged from 3.7 to 8.0%, limon from 50.0 to 63.1%, and sand from 32.1 to 46.3%. The average CEC value was about 12.8 meq $100g^{-1}$. These low CEC and organic matter values contribute to conditions that make the exchange of Pb content in the soil high. Total Pb content in the 10 soil samples ranged from 403.8 to 1766 mg kg^{-1} with an average of 999±322.28 mg kg^{-1}.

Table 4. Soil compositions and properties in the study.

Parameters	Soil sample No.									
	S_{01}	S_{02}	S_{03}	S_{04}	S_{05}	S_{06}	S_{07}	S_{08}	S_{09}	S_{10}
pH_{KCl}	3.40 (±0.01)	3.59 (±0.01)	3.41 (±0.01)	3.90 (±0.01)	4.14 (±0.01)	3.92 (±0.01)	4.65 (±0.02)	4.59 (±0.01)	3.69 (±0.01)	5.20 (±0.03)
OM (%)	2.44 (±0.02)	2.24 (±0.02)	2.39 (±0.05)	2.09 (±0.02)	1.89 (±0.02)	2.90 (±0.05)	2.04 (±0.02)	2.12 (±0.02)	2.60 (±0.05)	1.33 (±0.04)
EC (µS cm^{-1})	305.3 (±5.51)	339.3 (±9.71)	234.3 (±17.6)	163.3 (±2.46)	178.7 (±11.3)	165.2 (±4.07)	129.5 (±4.90)	156.2 (±4.16)	163.5 (±4.15)	92.6 (±2.20)
CEC meq $100g^{-1}$	13.0 (± 3.7)	15.4 (± 1.9)	12.2 (±4.6)	11.4 (± 3.1)	11.6 (± 4.7)	13.2 (± 1.5)	12.7 (±0.8)	11.9 (±3.4)	13.5 (± 2.4)	12.8 (± 4.6)
Pb, mg kg^{-1}	1,116	921	1,014	1,090	1,766	972	816	827	1,064	404
Cu, mg kg^{-1}	218.3	208.3	184.2	240.0	297.0	178.4	189.5	189.3	209.8	183.5
Zn, mg kg^{-1}	219.5	228.7	271.7	289.7	264.5	263.0	202.7	200.1	220.3	174.3
Ni, mg kg^{-1}	44.09	38.98	46.20	46.99	39.72	40.61	47.18	40.05	39.99	44.37

Effects of minerals on plant-available Pb in soil and Pb-uptake by rice plant

Effects on plant-available Pb content in soils: Analysis results after three consecutive experiments showed that there was a signification decrease in the concentration of Pb extracted by the *DTPA* solution when the four types of adsorbents at different levels were added. The average mobile Pb content in the control sample was 53.94 mg kg^{-1}. After the experiment (over 3 crops, 109 days for summer-autumn crop or 137 days for winter-spring crop), the average content over 3 crops of mobile Pb was about 32.26 mg kg^{-1} achieving an efficiency of about 40.14% reduction in soluble Pb content in the soil (Fig. 2). One-way ANOVA analysis showed that the difference in Pb content values between the control and mineral added samples was significant ($p<0.05$).

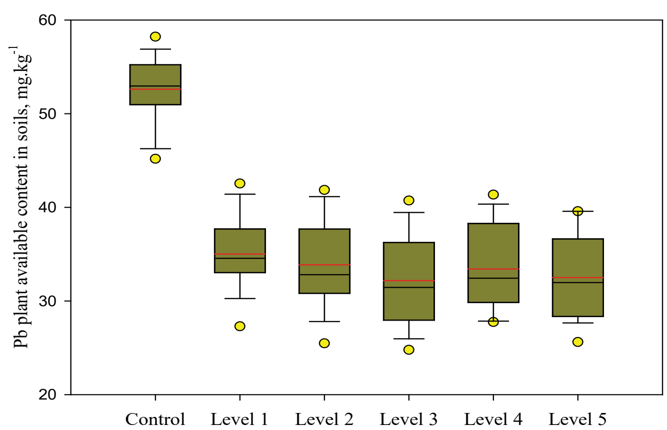


Fig. 2. Plant-available Pb content in soils in relation to minerals added. Amount of added minerals, level 1: 0.1%; level 2: 0.2%, level 3: 0.3%, level 4: 0.4%; level 5: 0.5%. The above Pb contents were calculated by the average value of 4 minerals within 3 crops.

Although the immobility of Pb in soil by two minerals of zeolite and bentonite was relatively good during the whole experiment, there was a significant difference between the growth stages of the rice plants. The effect of minerals on Pb mobility was shown immediately after two growth stages of sowing (day 13) and transplanting (day 26). In the subsequent stages, the degree of reduction in mobile Pb content was lower. The impact of minerals reached an equilibrium state after the first two growth stages of the rice plants (Fig. 3).

Effects on Pb content uptake by rice plant: The results from three experimental crops showed a significant difference in Pb content in rice plants depending on the type and level of minerals added to the soil. All of the mineral-supplemented pots showed a lower Pb accumulated content in rice compared to the control pots. The ability of the minerals to control Pb accumulation in rice plants ranged from 24 to 58% compared to the control samples. The efficiency of reducing Pb accumulation in rice plants treated with the minerals zeolite 4A and zeolite Faujasite was 58 and 56%, respectively, which was better than the modified and natural bentonite minerals (44 and 24%, respectively). The largest content of Pb intake in the rice plants reached 78.76 mg kg^{-1} (dry biomass) at the pot with natural bentonite added, meanwhile, the lowest Pb content was only 52.41 mg kg^{-1} with the supplementation of zeolite 4A. In the two experiments that added zeolite Faujasite and modified bentonite, the amount of Pb accumulated in rice was 57.07 mg kg^{-1} and 70.82 mg kg^{-1}, respectively (Fig. 4).

There is a relatively strong correlation between the Pb content accumulation in rice plants and the additional mineral levels as seen from R^2 ranging from 0.66 to 0.94 (n=15). Although the capacity to control Pb content in rice varied between the types of mineral supplementation, the general trend for all four materials was that Pb concentration in rice decreased with the increase of mineral amount added to the soil.

Effects on Pb contents in rice grain: There was a significant difference in the extracted Pb content between the control and mineral-added samples for all four types of adsorbent. The general trend was that the Pb content of rice was much lower than that of the control treatment. The more mineral

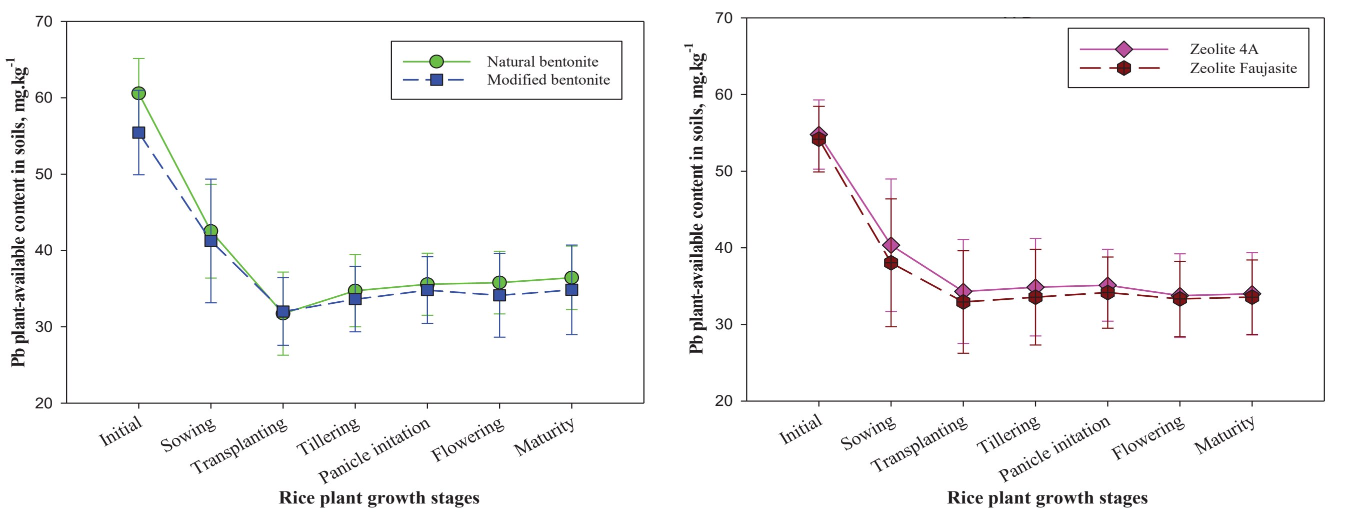


Fig. 3. Ranges of soluble Pb content in soil during growth stages of rice plants.

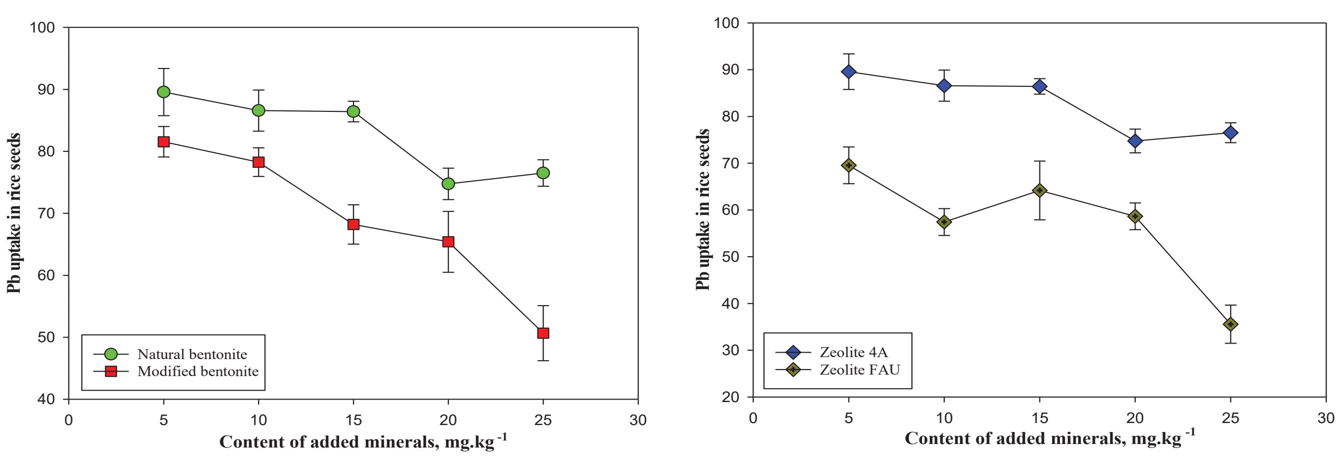


Fig. 4. Pb content accumulated in rice plants with amount of added minerals.

supplementation, the lower the Pb content in rice. The mean impact of controlling Pb content in rice when comparing the supplement levels of zeolite Faujasite, zeolite 4A, modified bentonite, and natural bentonite was 69%, 56%, 42%, and 40%, respectively (Table 5).

Table 5. Intake Pb contents in rice grain.

Type of minerals	Pb contents in rice grain, $\mu g.g^{-1}$					
	Control	*Level 1*	*Level 2*	*Level 3*	*Level 4*	*Level 5*
Natural bentonite	0.81±0.01	0.42±0.02	0.57±0.06	0.65±0.05	0.39±0.03	0.42±0.04
Modified bentonite	0.78±0.05	0.40±0.03	0.54±0.11	0.56±0.09	0.38±0.06	0.38±0.03
Zeolite 4A	0.75±0.07	0.58±0.06	0.37±0.09	0.26±0.08	0.20±0.01	0.24±0.02
Zeolite Faujasite	0.67±0.05	0.35±0.16	0.23±0.04	0.23±0.06	0.12±0.03	0.11±0.03
Std. threshold*	0,2 $\mu g.g^{-1}$					

Amount of added minerals, level 1: 0.1%; level 2: 0.2%, level 3: 0.3%, level 4: 0.4%; level 5: 0.5%; *: QCVN 8-2:2011 of the Ministry of Health.

The content of Pb accumulated in rice varied considerably (0.11 to 0.65 $\mu g.g^{-1}$) between mineral added levels, and these values were lower than that of the control samples (from 0.67 to 0.81 $\mu g.g^{-1}$). The mean Pb intake by rice among the mineral supplements was significantly different when compared with the control sample ($p<0.05$, $n=9$). The most general trend was that Pb intake in rice decreased in accordance with an increase in added mineral amount. Artificial minerals of the zeolite group have better control on Pb accumulation in rice than minerals of the bentonite group. The content of Pb in different parts of the plant tended to decrease in the order of root > stem > leaf > flower > seed. J. Liu, et al. (2003) [29] showed that the ratio of Pb content in root:stem:leaf of the rice plants was 60:5:1 at the flowering stage and 19.4:2.9:1 at the mature stage. In this study, Pb concentrations in rice plants were 155 to 274 times greater than that in polished rice. This is because the fixation of Pb to the root cell wall is greater than that of other plant parts [30]. The addition of minerals to the soil reduced the Pb accumulation in rice plants and this led to a decrease in the accumulation of Pb in rice grains. Due to the higher CEC of the artificial minerals in the zeolite group (zeolite 4A and Faujasite zeolite are 341 and 432 meq.100 g^{-1}, respectively) compared to the bentonite group (natural bentonite and modified bentonite are 19.5 and 58.6 meq.100 g^{-1}, respectively), a difference in the Pb concentration in the rice grain is understood.

Effects of minerals on rice plant grow

Effects on rice plant's height: At the mature stage, the height of the rice plants in all experimental treatments reached an average value of 67.65 cm. However, the growth heights of these plants varied between different types of added minerals. While the average height of the rice plants in the control sample was 84.25 cm, the maximum growth height in the formula with natural bentonite was only 74.33 cm. The lowest height occurred with the Faujasite zeolite mineral supplement experiment at only 66.64 cm. The average heights of the rice plants in the two treatments supplemented with zeolite 4A and modified bentonite was 73.38 cm and 70.77 cm, respectively (Fig. 5). The research by N. Hung and I. Kosinova 2019 [31] showed that less than 10 mg kg^{-1} Pb content in soil can promote rice growth and increase tillering ability and root length. However, concentrations greater than 10 mg kg^{-1} will inhibit the tillering stage and plant height (R^2=0.8-0.9, $p<0.05$).

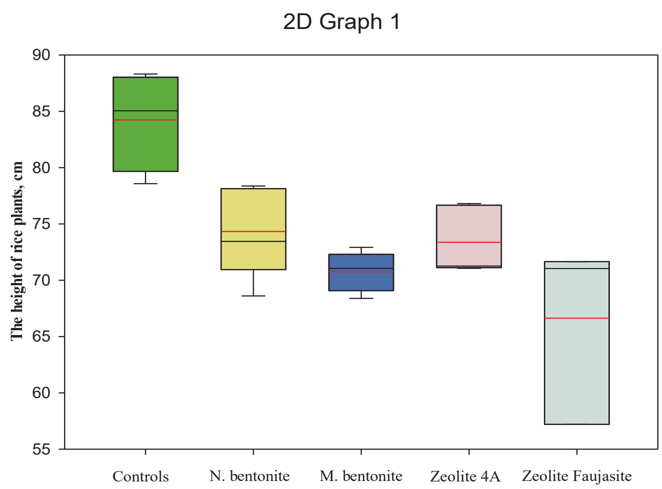


Fig. 5. The height of rice plants in different rate of added minerals.

Effects on the number of rice panicle: The average number of rice panicles obtained in the experiments of adding natural bentonite, modified bentonite, and zeolite 4A was 11.2, 12.4, and 12.8 panicles per crop, respectively. For zeolite Faujasite, the average number of panicles was only 9.0 per crop. Thus, the rice cultivation efficiency of the soil amended with Faujasite zeolite was much lower than that of other minerals. In addition, the average number of rice panicles of the experimental treatments was also 14.17 panicles lower than that of the control samples. These results show that the amount of rice panicles

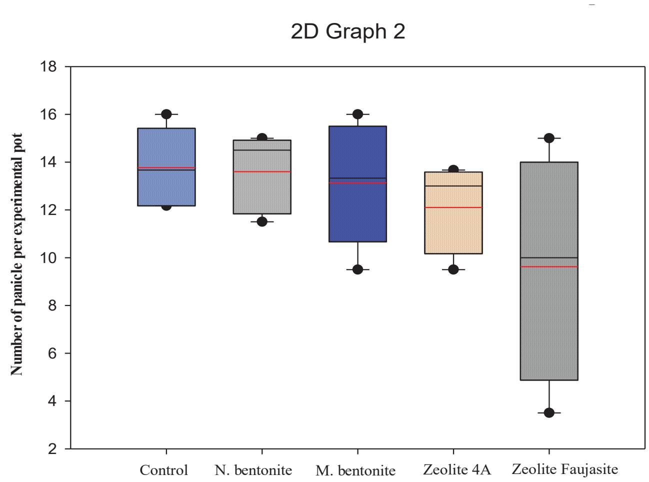


Fig. 6. Number of rice panicles based on the type of mineral added.

was significantly affected by the amount of minerals added to the cultivated soil environment, especially for Faujasite zeolite at the levels of 0.4-0.5% by weight (Fig. 6).

Effects on the length and weight of rice grain: The obtained average rice grain length ranged from 5.88 to 6.25 mm, meanwhile, this value in the control sample was 6.27 mm. With the average grain length of the blight-resistant Bac Thom No. 7 cultivated under the standard conditions of 6.2 - 6.3 mm, all four experiments in this study yielded lower mean grain lengths than those in the control sample (Table 6). The weight of 1,000 grains of rice listed from 4 experimental formulas in this study ranged from 18.47 to 18.85 grams/1,000 seeds (Fig. 7). Both agronomic indicators of rice yield (the length and weight of 1,000 grains) showed that these values in the mineral-added formulas were lower than in the control ($p<0.05$, $n=12$) and lower than in the normal growth conditions of the rice varieties, which are 6.2-6.3 cm and 19.0, respectively [32].

Table 6. The length and weight of 1000 rice grains (n=3).

Additives	Parameters	Control	Level 1	Level 2	Level 3	Level 4	Level 5
Natural bentonite	Length of seed (mm)	6.29±0.01	6.14±0.02	6.13±0.01	6.18±0.05	6.01±0.13	6.25±0.04
	Weight of 1000 grains (g)	19.46±0.05	18.61±0.28	18.86±0.13	18.72±0.16	18.59±0.10	18.71±0.21
Modified bentonite	Length of seed (mm)	6.22±0.04	6.11±0.09	6.07±0.15	5.88±0.15	6.02±0.17	5.88±0.18
	Weight of 1000 grains (g)	19.20±0.22	18.55±0.26	18.52±0.12	18.46±0.04	18.33±0.26	18.51±0.19
Zeolite 4A	Length of seed (mm)	6.30±0.02	6.23±0.05	6.17±0.13	6.16±0.08	6.09±0.18	6.01±0.21
	Weight of 1000 grains (g)	19.29±0.34	18.92±0.28	18.93±0.18	18.97±0.17	18.86±0.06	18.55±0.21
Zeolite Faujasite	Length of seed (mm)	6.26±0.03	5.99±0.15	5.99±0.10	6.21±0.04	6.01±0.04	6.25±0.02
	Weight of 1000 grains (g)	19.24±0.20	18.51±0.09	18.89±0.10	18.80±0.28	18.35±0.24	18.69±0.35

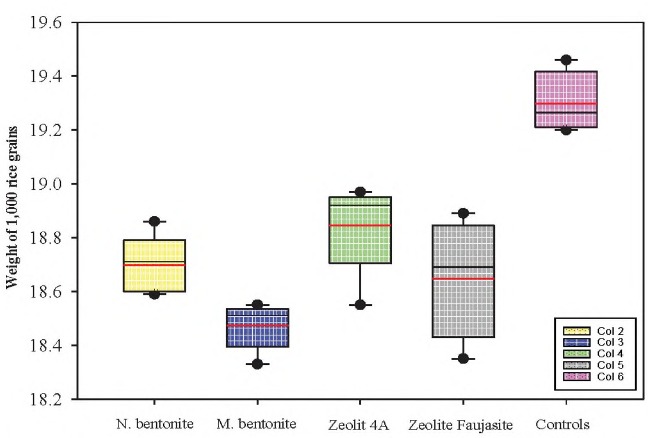


Fig. 7. Weight of 1,000 rice grains under different amount of added minerals.

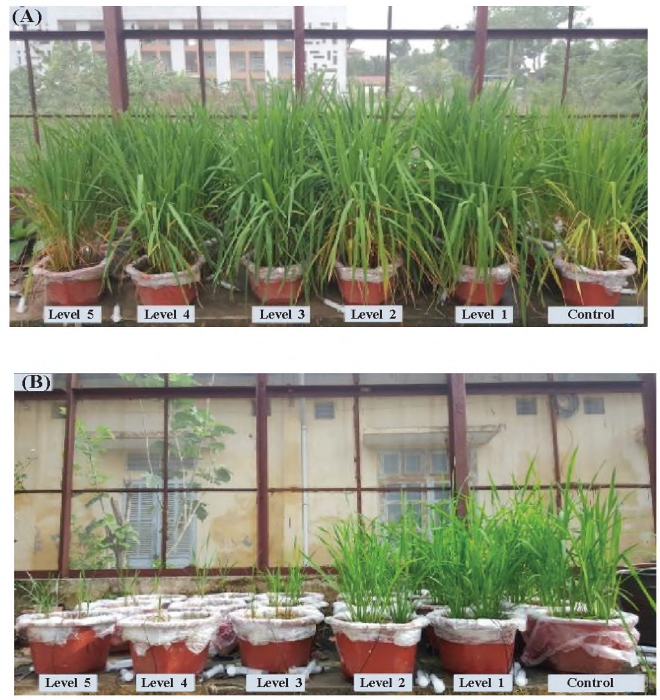


Fig. 8. (A) The relatively uniform growth and (B) the phenomenon of dead of plants with the addition of zeolite Faujasite in the first crop.

The decline in the growth and yield of rice plants can be explained by the fact that materials with a very high cation-exchange capacity (CEC) have claim on the nutrient minerals in the soil and reduce the plant's access to these nutrients thus affecting some agricultural agronomic indicators of the rice plants.

Conclusions

The agricultural soil for rice cultivation in Minh Khai village, Chi Dao commune, Van Lam district, Hung Yen province is acidic (pH_{KCl} ranges from 3.4 to 5.2), has low cation exchange capacity (about 13.2 meq.100 g^{-1}), and is classified from silty to sandy silt. Pb content in soil in the area surrounding the craft village is at a high level, which is 17 times higher than the National Technical Regulation on the allowable limits of heavy metals in soils. The addition of minerals of zeolite and bentonite groups at the rate of 0.1 to 0.5% significantly reduced the mobility of Pb metal in the soil solution extracted by DTPA. The efficiency of reducing the mobile Pb content in soil decreased from 24 to 58% compared with the control sample. The ability to control Pb flexibility in the soil of the zeolite mineral group was higher than that of the bentonite group. The effect of reducing the flexible Pb content in the soil led to a decrease in Pb accumulation in rice and rice plants (R^2=0,66-0,93; n=15). The addition of minerals of the zeolite and bentonite groups had a deterrent effect on the growth and yield of experimental rice plants. The most appropriate mineral supplementation ratio in this study was found to be between 0.1 and 0.2%. From the research results, it is possible to use artificial zeolite minerals from agricultural by-products or modified bentonite minerals to limit the mobility of Pb^{2+} metal in the soil and reduce its accumulation in plants.

COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article

REFERENCES

[1] M.J. McLaughlin, D.R. Parker, J.M. Clarke (1999), "Metals and micronutrients-food safety issues", *Field Crops Research*, **60(1-2)**, pp.143-163.

[2] M.M. Lasat (2000), "Phytoextraction of metals from contaminated soil: A review of plant/soil/metal interaction and assessment of pertinent agronomic issues", *Journal of Hazardous Substances Research*, **2**, pp.1-25.

[3] S.R. Tariq, M. Shafiq, G.A. Chotana (2016), "Distribution of heavy metals in the soils associated with the commonly used pesticides in cotton fields", *Scientifica*, **2016**, DOI: 10.1155/2016/7575239.

[4] N.T. Basta, J.A. Ryan, R.L. Chaney (2005), "Trace element chemistry in residual-treated soil: Key concepts and metal bioavailability", *Journal of Environmental Quality*, **34(1)**, pp.49-63.

[5] K. Weggler, M.J. McLaughlin, R.D. Graham (2004), "Effect of chloride in soil solution on the plant availability of biosolid-borne cadmium", *Journal of Environmental Quality*, **33(2)**, pp.496-504.

[6] S.D. Pam, S.B. Sally, H. Dean, P. Kumi (2003), "Metal bioavailability and speciation in a wetland tailings repository amended with biosolids compost, wood ash, and sulfate", *Journal of Environmental Quality*, **32(3)**, pp.851-864.

[7] Josef Bjuhr (2007), *Trace Metals in Soils Irrigated with Waste Water in a Periurban Area Downstream Hanoi City, Vietnam*, Sveriges lantbruksuniversitet 50pp.

[8] J.J. D'Amore, S.R. Al-Abed, K.G. Scheckel, J.A. Ryan (2005), "Methods for speciation of metals in soils: A review", *Journal of Environmental Quality*, **34**, pp.1707-1745.

[9] G. Uzu, S. Sobanska, Y. Aliouane, P. Pradere, C. Dumat (2009), "Study of lead phytoavailability for atmospheric industrial micronic and sub-micronic particles in relation with lead speciation", *Environmental Pollution*, **157(4)**, pp.1178-1185.

[10] C.B. Tabelin, T. Igarashi (2009), "Mechanisms of arsenic and lead release from hydrothermally altered rock", *Journal of Hazardous Materials*, **169(1-3)**, pp.980-990.

[11] H.A. Elliott, M.R. Liberati, C.P. Huang (1986), "Competitive adsorption of heavy metals by soils", *Journal of Environmental Quality*, **15**, pp.214-219.

[12] S. Sauve, M. McBride, W. Hendershot (1998), "Soil solution speciation of lead (II): Effects of organic matter and pH", *Soil Science Society of America Journal*, **62(3)**, pp.618-621.

[13] F. Margaret, T. Yiping, Z. Ping, B.M. Muray (2013), "Extractability and bioavailability of Pb and As in historically contaminated orchard soil: Effects of compost amendments", *Environmental Pollution*, **177**, pp.90-97.

[14] E.E. Hildebrand, W.E. Blum (1974), "Lead fixation by iron oxides", *Naturwissenschaften*, **61(4)**, pp.169-170.

[15] E. Erdem, N. Karapinar, R. Donat (2004), "The removal of heavy metal cations by natural zeolites", *Journal of Colloid and Interface Science*, **280(2)**, pp.309-314.

[16] S.F. Cheng, Z.Y. Hseu (2002), "In-situ immobilization of cadmium and lead by different amendments in two contaminated soils", *Water, Air, and Soil Pollution*, **140(1-4)**, pp.73-84.

[17] Z. Ioannou, T. Papapostolou, N. Georgoulas, A. Dimirkou (2012), "Use of modified zeolites for the remediation of waters and cultivated soils from Cu (II)", *Water, Air & Soil Pollution*, **223(9)**, pp.5841-5854.

[18] S.R. Mallampati, Y. Mitoma, T. Okuda, S. Sakita, M. Kakeda (2012), "Enhanced heavy metal immobilization in soil by grinding with addition of nanometallic Ca/CaO dispersion mixture", *Chemosphere*, **89(6)**, pp.717-723.

[19] A. Argiri, Z. Ioannou, A. Dimirkou (2013), "Impact of new soil amendments on the uptake of lead by crops", *Communications in Soil Science and Plant Analysis*, **44(1-4)**, pp.566-573.

[20] B. Gworek B (1992), "Lead inactivation in soils by zeolites", *Plant and Soil*, **143(1)**, pp.71-74.

[21] A. Moirou, A. Xenidis, I. Paspaliaris (2001), "Stabilization Pb, Zn, and Cd-contaminated soil by means of natural zeolite", *Soil and Sediment Contamination*, **10(3)**, pp.251-267.

[22] X. Xian (1989), "Effect of pH on chemical forms and plant availability of cadmium, zinc and lead in polluted soils", *Water, Air and Soil Pollution*, **45**, pp.265-273.

[23] Quoc Hung Phan (2011), *Study on Removal of Lead (Pb), Copper (Cu) and Zinc (Zn) in Paddy Soil by Biological Technology*, Doctoral thesis, Hanoi University of Agriculture (in Vietnamese).

[24] Viet Ha Cao (2012), "Evaluation for lead and copper pollution in agricultural land in Van Lam district, Hung Yen province", *Journal of Science and Development*, **10(4)**, pp.648-653 (in Vietnamese).

[25] T. Noguchi, T. Itai, N.M. Tue, T. Agusa, N.N. Ha, S. Horai, P.T.K. Trang, P.H. Viet, S. Takahashi, S. Tanabe (2014), "Exposure assessment of lead to workers and children in the battery recycling craft village, Dong Mai, Vietnam", *Journal of Material Cycles and Waste Management*, **16(1)**, pp.46-51.

[26] F. Takashi, E. Akifumi, A. Tetsuro, M.T. Nguyen, S. Go, T. Shin, H.V. Pham, T. Shinsuke, T. Hidetaka (2016), "Lead contamination in surface soil on roads from used lead-acid battery recycling in Dong Mai, Northern Vietnam", *Journal of Material Cycles and Waste Management*, **18(4)**, pp.599-607.

[27] D. Houben, L. Evrard, P. Sonnet (2013), "Mobility, bioavailability and pH-dependent leaching of cadmium, zinc and lead in a contaminated soil amended with biochar", *Chemosphere*, **92(11)**, pp.1450-1457.

[28] Ministry of Natural Resources and Environment (2015), *Circular No.60/2015/TT-BTNMT on Promulgation of National Technical Regulation on Soil Evaluation* (in Vietnamese).

[29] J. Liu, K. Li, J. Xu, Z. Zhang, T. Ma, X. Lu, J. Yang, Q. Zhu (2003), "Lead toxicity, uptake, and translocation in different rice cultivars", *Plant Science*, **165(4)**, pp.793-802.

[30] X. Bi, L. Ren, M. Gong, Y. He, L. Wang, Z. Ma (2010), "Transfer of cadmium and lead from soil to mangoes in an uncontaminated area, Hainan Island, China", *Geoderma*, **155**, pp.115-120.

[31] N. Hung, I. Kosinova (2019), "Environmental toxicology of cadmium and lead (in the case of Long Khang, Vietnam)", *Russian Agricultural Sciences*, **45(3)**, pp.271-275.

[32] Thi Le Nguyen, Hong Quang Vu, Thi Thu Nguyen, Thi Hue Nguyen, Van Hoan Nguyen, Chi Dung Nguyen (2014), "Result of breeding Bac Thom No.7 resistance leaf blight variety", *Journal of Science and Development*, **12(2)**, pp.131-138 (in Vietnamese).