EFFECTS OF LEAD WATER IRRIGATION UNDER ZEOLITE STRESS ON RICE GROWTH

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Abstract. This paper aims to study the effects of lead concentration in irrigation water on the yield and growth traits of rice under soil zeolite stress, with the addition of lead accumulation in rice plants, which were tested in a micro zone at the Experimental Base of Water Conservancy in Shenyang Agricultural University of Liaoning Province, China, through the application of different amounts of zeolite (0, 2500, 5000kg·ha^{-1}) and different lead concentrations (0, 0.25, 0.2, 0.15 mg·L^{-1}) in irrigation water. It was concluded that the lead contents in paddy root, stem, leaf and rice significantly varied with different exogenous lead concentrations. With the increase of the concentration, the lead contents in each part were significantly increased. More importantly, the effect on aboveground material weight was greater than that on underground material weight. The water contents of rice were increased with the decrease in the protein content, and starch content was decreased under zeolite stress. When the concentration of lead increased, the effect was more pronounced. Comprehensive test with various factors indicated that the incorporation of zeolite in soil for rice cultivation with lead-contaminated water irrigation or lead contaminated soil could restrain the movement of lead ions into the rice.
Keywords: *zeolite, lead, quality of rice, enrichment ability, interaction*

Introduction

In recent years, the use of one of China's shortage resources-agricultural irrigation water-has seen an increasing trend concerning industries and urban environments due to the acceleration of industrialization and urbanization, and the rapid development of technology, economy, civilization and people's quality of life. Therefore, the condition of agricultural water is getting worse. To make matters worse, irrigation with contaminated water is becoming one of the major methods to deal with the deficiency of water. In such cases, researches about the effects of recycling water irrigation on the yield and quality of agricultural products attract more attention recently (Galvis et al., 2018; Becerra, 2015). Lead is one of the most toxic elements among all known metal contaminations causing fertility deterioration, reproductive organ tumors, decreased immunity as well as physical anomalies (Zhao et al., 2015) of various organisms including humans. The increased lead level in children's body would damage the brain and nervous system, destroying cerebral cortical cells, which results in mental decline and impaired attention (Zhang et al., 2014). The Pb^{2+} in contaminated water will enter soil, get absorbed by root system and accumulate in plants. Once the concentration of Pb^{2+} exceeds a certain level, plants will be poisoned, and eventually Pb^{2+} will enter human bodies through the food chain to damage our health (Chen et al., 2018; Abrahams, 2002; Luo, 2012). It was revealed that lead would accumulate in rice plants to inhibit their growth, and to degrade their yield and quality (Ashraf et al., 2015; Chen et al., 2010). In China, paddy rice is one of the staple food crops for food supply (Khush, 2013; Huang, 2011). Therefore, it is of key

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importance to study how to reduce the absorption and accumulation of lead in paddy rice.

In recent years, many scholars have been focusing on heavy metal contaminated soil treatment with soil conditioner, such as commonly used lime, phosphate, compost, blast furnace slag, molysite, silicate, and zeolite (Gray, 2006; Theodoratos, 2002; Qian, 2009). As a common adsorbent, zeolite can not only improve soil condition, but also purify waste water by removing of heavy metal (Merrikhpour et al., 2013; Shi et al., 2009). Zeolite has porous aluminosilicate mineral, its unique three-dimensional space frame structure makes it have a huge specific surface area, ion has a great adsorption capacity and adsorption exchange capacity, is considered as an economic and efficient heavy metal pollution remediation material, the lead in wastewater has adsorption effect. In addition, some scholars believe that the passivation of zeolite is due to the strong adsorption of heavy metal through its silicon oxygen and aluminum oxygen tetrahedron structure. Zeolite has a certain passivation effect on heavy metal lead in soil, which can effectively inhibit the migration and ecological effectiveness of soil lead (Zhou et al., 2014a). Natural zeolite, as an inorganic soil conditioner, has been widely used to improve the growth and yield of upland crops due to its high cation exchange capacity and intensive affinity for nutrients and water (Malekian et al., 2011; Aghaalikhani et al., 2012; Hazrati, 2017). On top of that, zeolite can also passivate lead in soil to inhibit lead migration and ecological availability in soil (Altaf et al., 2019). Several studies have been conducted for joint use of various soil conditioners (Zhou et al., 2014b, 2017; Wu al., 2016; Yang et al., 2016) for lead-contaminated soil. However, most of these studies are performed in pot experiments with only a few in regional experiments. At the same time, most studies focused on the influence of composite conditioners on soil contamination or improvement of wastewater through zeolite, while researches on rice yield, lead concentration and growth traits of paddy plant affected by zeolite and lead-containing water were rare. Therefore, this paper aims to analyze effects of exogenous lead on the yield of rice under soil zeolite stress, lead accumulation in rice plant, and growth traits through paddy rice planting in small regions to provide a reference for finding ways to reduce lead contamination in paddy rice.

Materials and methods

Material for experiment

This study used a local, mid-late season rice (Oryza sativa L.) cultivar, Shennong 9816, bred by the Rice Research Institute of Shenyang Agricultural University and characterized by high yield, good quality, and strong disease resistance, with brown earth soil for the base. All physicochemical indices are as follows: pH value 7.41; organic substance contents 20.48 $g \cdot kg^{-1}$; total nitrogen contents 1.3 $g \cdot kg^{-1}$, rapidly available phosphorus 20.69 $mg \cdot kg^{-1}$; rapidly available potassium 50.11 $mg \cdot kg^{-1}$. Applied regular fertilizers are as follows: potassium sulfate 100 $kg \cdot ha^{-1}$; carbamide 300 $kg \cdot ha^{-1}$; monocalcium phosphate 200 $kg \cdot ha^{-1}$. The irrigation water is from the comprehensive experiment base of College of Water Resource. As verified through inspection, the irrigation water met potable water standards, with lead concentrations < 0.06 $\mu g \cdot L^{-1}$.

Methods

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The experiment was carried out in non-weighing lysimeters at the College of Water Resource of Shenyang Agricultural University of Liaoning Province, China (42°08′57″ N, 120°30′45″ E, 47 m altitude), during one rice-growing seasons (May to October in 2018). The study area has a temperate continental monsoon climate with 7.5 °C average annual air temperature. Average annual rainfall is 672.9 mm, with the main rainy season from June to September. The regional area for experiment (3.5 m long × 1.2m wide × 0.3m deep) were constructed from concrete blocks and sealed with waterproof paint to prevent seepage between plots. In order to prevent irrigation water in the micro zone from being diluted by rain and thus affecting the test results, transparent awnings were set up, covered by rainy days, and all opened on sunny days, and the planting rate between rice plants was 20 × 25 cm. The experiment has two factors (lead and zeolite) with four levels of lead concentration and three zeolite application rates. There were nine treatment methods as shown in *Table 1*. Each treatment was repeated 3 times. Zeolite was applied all at once during soil harrowing before fertilization and transplantation of paddy plant. During the growth delaying period, all of the nine treatment the areas were irrigated with water from the experiment base, and since seedling establishment period, the areas were irrigated with water of different lead concentrations. The CK area was irrigated with clean water.

Table 1. *Factors and levels of the experiment*

Treatment	**CK**	**I**	**III**	**IV**	**V**
W_0/kg·ha^{-1}	0	2 500	2 500	2 500	2 500
Pb/mg·L^{-1}	0	0	0.15	0.2	0.25
Treatment	**CK**	**II**	**VI**	**VII**	**VIII**
W_0/kg·ha^{-1}	0	5 000	5 000	5 000	5 000
Pb/mg·L^{-1}	0	0	0.15	0.2	0.25

The sampling procedure consisted of randomly taking 5 plants for each treatment during the maturity period of the paddy rice. A soil auger was used to obtain 0.5-1 kg of soil at a depth of 0-20 cm. The roots were carefully rinsed from the soil with a hydropneumatic device and detached from their nodal bases. For the growth traits measurements, the height of the sample plants, the tiller number and the biomass of the substances above ground and below ground were all taken. The samples were then treated as follows. The soil samples were dried naturally in the shade, ground and screened with a 100 mesh screen. The plants were oven-dried, crushed with a plant pulverizer, ground into powder via a mortar, and screened with a 100 mesh screen.

Using a GB5009.12-2017 A pressure dissolution vessel was used to treat samples via the digestion method, and an atomic absorption spectrophotometer (HITACHI Z-2000) (*Fig. 1*) was used to determine the lead content via the flame method. The FOSS (*Fig. 2*) was utilized to determine rice qualities, such as water content, protein, and amylase.

Data processing

The analysis software SPSS19.0 was used for one-way ANOVA. Notable comparison of data was made by using Duncan inspecting method ($P < 0.05$). Software Design-Expert 8.0 was used to calculate the optimum point.

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Figure 1. *Photo of HITACHI Z-2000*

Figure 2. *Photo of FOSS*

Results and analysis

Lead accumulation in soil and paddy plant under soil zeolite stress

Table 2 shows the lead contents of the root, stem, leaf and rice unit masses at treatment I was 1.27, 0.87, 0.96 and 0.91 times that of the CK group respectively. The Pb content per unit mass of soil increases from treatment III to treatment V, however, no obvious difference was observed. The maximum value of Pb content in soil at treatment V was 2.06 times that of treatment I ($P < 0.05$). The Pb content per unit mass of root first rose and then dropped, and difference among various treatment methods was obvious. The maximum value of Pb content in roots at treatment IV was 2.13 times that of treatment I ($P < 0.05$). The values of Pb content per unit mass of stems, leaves and rice increases, and values of treatment V were 146%, 159% and 146% ($P < 0.05$) that of treatment I, respectively. The Pb content per unit mass of roots, stems, leaves and rice under treatment II were 1.48, 0.84, 0.81 and 0.81 times that of CK group. The Pb content per unit mass of soil increased from treatment VI to treatment VIII, but the difference seemed to be non-significant. The maximum value of Pb content in soil at treatment VIII was 1.83 times that of treatment II ($P < 0.05$). The Pb content per unit mass of roots first rose and then dropped, and the difference among various treatment was significant. The maximum value of Pb content in roots at treatment VII was 1.93 times that of treatment II ($P < 0.05$). The values of Pb content per unit mass of stem, leaf and rice increased and the values of treatment VIII were 142%, 169% and 139%

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that of treatment II ($P < 0.05$). With 0.15 $mg \cdot L^{-1}$ extraneous lead concentration, the Pb content per unit mass of roots under 5000 $kg \cdot ha^{-1}$ zeolite application is 18.39% higher than that of 2500 $kg \cdot ha^{-1}$ zeolite application, while the Pb content per unit mass of stem, leaf and rice was lower by 18.10%, 24% and 10.84% respectively. Treated with 0.20 $mg \cdot L^{-1}$ extraneous lead concentration, the Pb content per unit mass of roots increased by 5.01%, while the Pb content per unit mass of stem, leaf and rice declined by 14.63%, 13.27% and 11.70% respectively. Treated with 0.25 $mg \cdot L^{-1}$ extraneous lead concentration, the Pb content per unit mass of roots rose by 2.38%, while the Pb content per unit mass of stem, leaf and rice declined by 5.29%, 9.77% and 15.87%, respectively.

Table 2. *Effects of exogenous Pb on Pb contents of rice seedlings under zeolite stress ($mg \cdot kg^{-1}$)*

Treatment	Soil	Root	Stem	Leaf	Rice
CK	32.89 + 0.00c	20.42 + 0.00e	3.44 + 0.00cd	2.87 + 0.00b	0.94 + 0.00c
I	32.89 + 0.00c	26.04 + 0.00d	3.00 + 0.00e	2.76 + 0.00b	0.86 + 0.00cd
II	33.91 + 0.00c	30.30 + 0.00d	2.89 + 0.00e	2.35 + 0.00bc	0.76 + 0.00d
III	64.49 + 3.58ab	41.60 + 6.14c	2.21 + 0.03f	2.00 + 0.57cd	0.83 + 0.01cd
IV	65.47 + 0.61ab	55.71 + 0.54a	3.76 + 0.14bc	2.94 + 0.63b	0.94 + 0.00c
V	67.84 + 1.94a	46.16 + 1.18b	4.34 + 0.05a	4.40 + 0.05a	1.26 + 0.15a
VI	61.05 + 4.86b	49.25 + 4.24b	1.81 + 0.72f	1.52 + 0.05d	0.74 + 0.01d
VII	61.59 + 4.78b	58.50 + 0.67a	3.21 + 0.11de	2.55 + 0.03bc	0.83 + 0.01cd
VIII	62.11 + 4.11b	47.26 + 1.41b	4.11 + 0.14ab	3.97 + 0.54a	1.06 + 0.13b

Different lowercase indicates significant differences ($P < 0.05$) among treatments

Effects of exogenous Pb on biomass of rice seedlings

The biomass of rice at maturation period is given in *Table 3*. *Table 3* shows the biomass of root, shoot and whole plant in treatment I was higher than that of the CK group by 45.08%, 8.58% and 11.48% respectively. The biomass of root, shoot and whole plant in treatment III was 0.71, 1.16 and 1.10 times that of treatment I. According to the coefficients, the biomass of each part of the plants first rose and then dropped with the increase of exogenous Pb concentration. The biomass of root in treatment IV was 8.65% less than that of treatment I, while the biomass of shoot and whole plant in treatment IV was more than that of treatment I by 4.22% and 4.08%, but all values were still higher than CK group. The difference between treatment IV and treatment V was significant. In addition, the height of rice was positively correlated with the dry weight of the whole plant with a correlation coefficient of 0.359 ($P < 0.05$).

The biomass of root, shoot and whole plant in treatment II was higher than that of the CK group by 63.04%, 2.47% and 14.01% respectively. The biomass of root, shoot and whole plant in treatment VI was 0.93, 1.27 and 1.17 times that of treatment II. According to the coefficients, the biomass of each parts of the plant first rose and then dropped with the increase of exogenous Pb concentration. The biomass of root and whole plant in treatment VII was less than that of treatment II by 34.85% and 5.34% respectively, while the biomass of shoot in under treatment VII was 5.59% more than that of treatment II, but the values were still higher than that of the CK group. There was an obvious difference between treatment VII and VIII. There was positive correlation between the tiller number and dry weight of whole plant with the correlation coefficient at 0.491 ($P < 0.05$). At an extraneous lead concentration of 0.15 $kg \cdot L^{-1}$, the

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dry weight of whole plant applied by 5000 kg·ha^{-1} zeolite was higher than that of 2500 kg·ha^{-1} zeolite by 9.07%, 0.20 mg·L^{-1} by 1.83%, 0.25 mg·L^{-1} by 1.92%.

Table 3. *Effects of the exogenous Pb on the growth of rice under zeolite stress*

Treatment	Biomass (dry weight)/g·treatment^{-1}			Plant height/cm	Tiller number	Coefficient
	Root	Shoot	Whole plant			
CK	24.69 ± 5.06cd	141.24 ± 16.72c	165.93 ± 16.36c	101.00 ± 2.65ab	15.33 ± 4.51ab	—
I	35.82 ± 13.73abc	153.36 ± 7.69abc	184.98 ± 3.57abc	93.33 ± 4.16c	11.00 ± 0.00b	1.11
II	40.25 ± 7.65d	144.73 ± 6.56bc	189.18 ± 16.68abc	101.00 ± 3.00ab	18.67 ± 5.77a	1.14
III	25.30 ± 0.71bcd	177.41 ± 6.69ab	202.7 ± 6.03abc	105.000 ± 1.73a	11.00 ± 3.61b	1.22
IV	32.72 ± 2.54abc	159.84 ± 10.27abc	192.53 ± 8.19abc	105.00 ± 4.36a	14.00 ± 1.73ab	1.16
V	29.04 ± 8.43d	151.89 ± 9.37d	180.93 ± 16.50e	93.33 ± 1.53c	12.00 ± 0.00b	1.09
VI	37.63 ± 4.97cd	183.45 ± 8.50a	221.08 ± 13.21a	102.33 ± 3.79a	13.00 ± 1.00ab	1.33
VII	36.22 ± 5.26d	159.82 ± 7.67abc	196.05 ± 11.25bc	104.33 ± 3.79a	14.00 ± 2.00ab	1.18
VIII	29.13 ± 8.03abcd	155.27 ± 9.93d	184.40 ± 4.87d	96.67 ± 2.31bc	13.67 ± 0.58ab	1.11

The coefficient = total biological yield in all treatments/total biological yield in CK group

Zeolite was applied to paddy soil irrigated with lead wastewater. The effects of different zeolite application rates on rice yield are shown in *Table 4*. *Table 4* shows when the application amount of zeolite was 2500 kg·ha^{-1}, the 0 kg·ha^{-1} group without zeolite was used as the control group. The irrigation with different concentrations of lead water increased the yield of clean water by 5.9%, while the other treatments decreased by 3.77%, 8.7% and 17.6%, respectively. When the amount of zeolite was 5000 kg·ha^{-1}, the rice yield showed an upward trend compared with that of 0 kg·ha^{-1}. The rice yield was 8.84%, 11.20%, 16.84% and 8.50% higher than that of the control group under different concentrations of lead-containing water irrigation, and the difference reached a significant level ($p < 0.05$).

Table 4. *Effects of different lead concentrations of irrigation water and different amount of zeolite application on rice yield (g·area^{-1})*

Concentration of irrigation water/mg·L^{-1}	Application amount of zeolite/kg·ha^{-1}		
	0	2500	5000
CK	2058.84 + 105.09ab	2180.88 + 50.64a	2240.88 + 50.64d
0.25	2010.48 + 121.08ab	1655.08 + 44.62a	2235.56 + 50.99b
0.2	2396.04 + 339.83a	2187.84 + 24.9a	2799.68 + 59.51a
0.15	2273.48 + 12.143b	2113.16 + 53.15b	2467.92 + 48.52c

The coefficient = total biological yield in all treatments/total biological yield in CK group

When the concentration of lead water was 0.15, the production of 0 kg·ha^{-1} increased by 10.43%, that of 2500 kg·ha^{-1} increased by 0.1%, and that of 5000 kg·ha^{-1} increased by 10.13% with the addition of different zeolite. When the lead concentration was 0.2 mg·L^{-1}, the 0 kg·ha^{-1} yield increased by 16.38% with different zeolite addition. The yield of 5000 kg·ha^{-1} increased by 24.94% and 14.08% respectively. When the concentration of lead water is 0.25 mg·L^{-1}, the 0 kg·ha^{-1} yield decreases by 2.35% with different zeolite addition. The yield of 5000 kg·ha^{-1} decreased by 0.24% and 24.11% respectively.

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The results showed that when the amount of zeolite in soil was 2500 kg·ha^{-1}, it had an inhibitory effect on rice yield, while when the amount of zeolite was increased to 5000 kg·ha^{-1}, it had an promoting effect on rice yield, and in irrigation water with different lead concentrations, the effect of zeolite on rice yield was different, and it played an promoting role in CK.

Effects of different treatment on nutritional quality of rice

The water content in rice irrigated by lead water fluctuated under soil zeolite stress. *Table 5* shows the water contents of rice at treatment I were higher than that of the CK group. The water contents of rice from treatment III to treatment V were obviously higher than that of treatment I, which indicated that the effect of exogenous Pb on water content were not significant under soil zeolite stress. In this experiment, the protein content in rice irrigated by lead water fluctuated under soil zeolite stress. When irrigated with water of the same lead concentration, the protein content of rice treated with treatment VI-VIII was lower than that of treatment III-V, but higher than the CK group irrigated by clean water. It indicated that exogenous Pb under soil zeolite stress had negative effects on the protein content in rice at different extents. The amylase content in rice fluctuated in a non-significant range. The rice under treatment VIII had the lowest amylon content at 15.6%, which was lower than the CK group by 6.02%. Therefore, the effect seemed significant ($P < 0.05$). The water and amylase contents of rice in different treatment satisfied the green rice standard (water content ≤ 15.5%, amylase content = 13.0% ～ 20.0%).

Table 6 shows the regression equation is based on effect of interaction of zeolite and lead on protein content in rice. It is shown that the effect of interaction of zeolite and lead on protein content in rice is significant, especially the effect of A^2B and AB^2 on the results is quite influential based on the F values, which represents the concentration of zeolite and lead. The effect of lead concentration on protein content is stronger than zeolite amount.

The taste of rice mainly depends on amylase, protein water contents as well as fatty acid value. The taste is in inversely proportional to the amylase and protein contents but proportional to water content. Calculated using software Design-Expert 8.0, the optimum combination is as follows: zeolite 5000 kg·ha^{-1}, lead concentration in water 0.19 mg·L^{-1}. Under such optimum condition, the predicted protein content is 6.96%, water content is 11.07% and amylase content is 16.29%, which all meet the green rice standard.

Table 5. *The notability analysis after different treatments*

Treatment	Water content	Protein content	Amylase content
CK	10.43b	7.33b	16.56b
I	10.47b	8.23a	16.67b
II	11.07a	7.33b	16.63b
III	11.07ab	6.97bc	16.73b
IV	10.26b	6.23d	16.4b
V	10.6b	7.1bc	15.9a
VI	11.07a	7.2bc	16.57b
VII	11.07ab	6.77c	16.67b
VIII	10.8ab	6.1bc	15.6a

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Table 6. *Significance test with coefficient of regression equation*

Source	Quadratic sum	Degree of freedom	Mean square	F value	P value
Model	6.64	8.00	0.83	19.48	0.0165
A-zeolite	0.00	1.00	0.00	0.06	0.8224
B-lead concentration	0.01	1.00	0.01	0.24	0.6549
AB	0.73	1.00	0.73	17.06	0.0258
A^2	0.00	1.00	0.00	0.02	0.9060
B^2	0.02	1.00	0.02	0.47	0.5435
A^2B	1.15	1.00	1.15	27.05	0.0138
AB^2	0.89	1.00	0.89	20.90	0.0196
A^3	0.00	0.00			
B^3	0.06	1.00	0.06	1.48	0.3101

Discussion

Over the recent years, several heavy metal pollution accidents have occurred, threatening lives and health. Much research on heavy metal pollution has been carried out, with some progress achieved. It has been discovered that biochar itself has a high pH value, thus the addition of 5% biochar in soil can enhance its pH value. With the addition of biochar, the effectiveness of Pb and Cd can be reduced, and the state conversion of Pb and Cd can thus be stabilized. The addition of biochar can also improve the physical and chemical properties of soil affected by combined pollution. Moreover, it can effectively adsorb heavy metal ions, therefore promoting the adsorption of Pb and Cd in soil and reducing the biological effectiveness of Pb and Cd (Gao et al., 2016). Under certain conditions, heavy metals in the adsorption and precipitation states were able to be exchanged between soil solutions, thus reducing the pH value and promoting the release of heavy metals in the adsorption state into the soil. In such cases, the absorption of heavy metals by plants will increase. In the current study, the application of zeolite in paddy plant soil irrigated with water of different lead concentrations was demonstrated to inhibit the migration of Pb to paddy plants, thus improving the quality of paddy plants. The effect of the zeolite application in soil on pH values is worth further research.

Several studies have reported that zeolite mixed with urea increased rice grain yields in flooded paddy fields (Kavoosi, 2007; Gevrek et al., 2009; Sepaskhah and Barzegar, 2010), the results are consistent with the experimental results. However, Research on the effect of lead on the growth of toona ciliata indicated that the total biomass of the whole toona ciliata plant decreases significantly with the increase of the Pb stress gradient, while the biomass of the plant organs (withered leaves, leafstalk) increased with the increase of the Pb stress gradient. This differs from the results of the effects on paddy rice biomass in this study. The soil condition was also an important factor found to affect the growth of toona ciliata and Pb absorption and accumulation. With the same Pb stress gradient, alkaline purple calcium soil had an impact on the Pb effectiveness, and was able to reduce the toxic effect of Pb on toona ciliate (Hu et al., 2012). The study demonstrated that when exogenous Pb entered the soil, the original forms of Pb in the soil clearly changed, revealing that exogenous Pb is maintained in a dynamic conversion process. The application of soil conditioner reduced the content of Pb in an effective state and inhibited the migration of Pb in the soil-plant system. It benefited safe production of plants (Chen et al., 2008). The study of Zhao et al. (2012) suggested that a single treatment with low concentrations of Cd and Pb can promote the growth of

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pilea cadierei, but inhibit its growth when the concentration exceeds a certain level. Under a combined treatment with various concentrations, the inhibiting effect on the growth of pilea cadierei was strengthened with the increase of metal concentrations. The Cd and Pb absorbing capacities of the leaf, stalk and root of pilea cadierei demonstrated strong significant positive correlations, with the accumulation in the root being the most influential. Under a combined treatment, the heavy metal accumulation in each part of the plant rose. Total migration of Cd and Pb in the above ground part of pilea cadierei was large. In particular, under Cd-Pb combined treatment, the total migration of Pb in the above ground part was much more than that under a single treatment with the same concentration of Pb. Therefore when the soil is polluted by heavy metals, ornamental plants can be planted to absorb the heavy metal, thus promoting ecological restoration.

Conclusions

(1) *Table 2* shows that most of the lead remains in soil and rice roots, and only a small amount migrates to aboveground plants. The unit content of lead in each part of the paddy plant was affected on different levels. The application of zeolite can reduce above ground plant absorption of Pb, inhibit the migration of Pb into rice and optimize the quality of rice. The effect of zeolite application in soil on pH value is worth further studying.

(2) *Tables 3* and *4* show that shows that for lead water irrigation under soil zeolite stress, the paddy rice plant height, and the above, below ground dry weight and yield all increased significantly. The effect of zeolite was influenced by Pb concentration in the irrigation water. Higher Pb concentrations resulted in a higher inhibition effect.

(3) *Table 5* shows that the water content in rice increased and the protein content decreased with the increase of zeolite addition. Thus, the application of zeolite has a negative effect on protein content. The starch content decreased with the increase of zeolite addition. Under different treatments, both water content and amylose content in the rice satisfy the green rice standard (water content $\leq$ 15.5%; amylose content 13.0-20.0%).

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