Original Research Article

Study on the accumulation characteristics of heavy metal cadmium in maize seedling stage under different soil conditions

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Abstract: In order to study the differences in cadmium accumulation characteristics of maize seedlings under different soil cadmium conditions, field experiments were carried out with common maize varieties in the region as experimental materials and the accumulation and enrichment ability of maize cadmium as the research object. The results showed that the accumulation and enrichment ability of maize varieties to cadmium were different under the conditions of soil cadmium content of 0.86 mg/kg and 0.18 mg/kg. In Liuyang base, the Cd enrichment coefficient of seedling root of Xiangnongtianyu 3 was the largest, which was 1.64. The Cd enrichment coefficient of seedling root of Xianghuiyu 1 was the smallest, which was 0.59. The Cd enrichment coefficient of seedling leaf of Xiangnongyu 22 was the largest, which was 1.35. The Cd enrichment coefficient of seedling leaf of Xiangnongbainuo 2 was the smallest, which was 0.56. The root enrichment coefficient of Xiangnongtianyu 3 at seedling stage was the largest, which was 4.25, and that of Xiangnongbainuo 2 was the smallest, which was 2.36. The leaf Cd enrichment coefficient of Xiangnongyu 22 at seedling stage was the largest, which was 4.33, and that of Xiangnongyu 36 at seedling stage was the smallest, which was 1.75. These maize varieties were planted in the soil with 0.18 mg/kg cadmium content, but most of them showed strong enrichment ability. Therefore, field experiment and demonstration are necessary and important measures to promote the planting of maize varieties in areas with moderate and mild cadmium pollution.

Keywords: Maize; Seedling stage; Enrichment coefficient; Transport coefficient; Cadmium

1. Introduction

Cadmium (Cd) is a heavy metal with strong biological toxicity and is a non-essential element for crop growth and development[1]. Soil cadmium (Cd) pollution not only affects the yield and quality of crops, but also poses a threat to the ecosystem, and directly threatens through the accumulation of the food chain. Threaten human health[2]. Once cadmium enters the human body, it can cause damage to kidney, liver, bones and other organs, reproductive system, blood system and nervous system[3].Most of the cadmium in human intake mainly comes from crops. Therefore, reducing the intake of cadmium by the human body requires reducing the accumulation of cadmium in crops. At present, the control of cadmium in farmland is mainly achieved through the following ways : controlling the content of heavy metals in agricultural inputs to reduce input ; applying soil amendments[4] to reduce the availability of cadmium in soil ; planting cadmium hyperaccumulator plants[5] to reduce the total amount of cadmium in the soil ; in order to reduce the absorption and accumulation of cadmium in crops, the dominant crop varieties with high tolerance and low accumulation of cadmium were selected and planted[6]. In this study, eight different maize varieties were selected to study the accumulation and enrichment of soil heavy metal Cd in different maize varieties at seedling stage under different cadmium content farmland soil conditions through field experiments, aiming to provide some reference for maize planting and promotion in Hunan Province.

2. Materials and methods

2.1. Test site

In 2022, the soil with cadmium content of 0.86 mg / kg and 0.18 mg / kg were selected to carry out field experiments. The experimental sites are located in Dahu Town, Liuyang City, Hunan Province and Yunyuan Base of Hunan Agricultural University. According to the "Soil Environmental Quality : Risk Control Standard for Soil Pollution in Agricultural Land" (GB 15618-2018), the Cd content in the soil of the two bases was higher than the risk screening value of soil pollution in agricultural land, and lower than the risk control value of soil pollution in agricultural land.

Soil background : (1) Dahu Town, Liuyang City, Hunan Province : The pH value of the tested soil was 4.88, the total N was 1.56, the total phosphorus was 0.57, the total potassium was 19.49, the organic matter was 28.10, the available phosphorus was 7.63, the available potassium was 254.17, the available nitrogen was 395.62, and the total cadmium was 0.86 mg/kg ; (2) Nuyuan base of Hunan Agricultural University : The pH value of the tested soil was 4.75, the total nitrogen was 1.00, the total phosphorus was 0.88, the total potassium was 14.78, the organic matter was 20.22, the available phosphorus was 12.15, the available potassium was 283.83, the alkali-hydrolyzable nitrogen was 155.78, and the total cadmium was 0.18 mg/kg.

1.2 Experimental design

Randomized block experimental design was used in both regions. The planting density was 3200 plants/mu. Before sowing, the plot was divided into 24 plots with a length of 3 m and a width of 1.2m. Each variety was repeated three times. They were sown in the Yunyuan Base of Hunan Agricultural University and Dahu Town, Liuyang City, Hunan Province in 2021, respectively. Artificial dibbling, ordinary maize seeds 2 grains per hole, fresh maize seeds 3 grains per hole, N, P, K ternary compound fertilizer (effective N, P, K content≥15%) 50 kg / ($667m^2$) as base fertilizer. Maize seedling field management with ordinary cultivation.

2.3. Types of supply

In this experiment, four common maize varieties (Xiangnongyu 36, Xiangnongyu 22, Xianghuiyu 1 and Xiangnongyu 27) and four fresh maize varieties (Xiangnongbainuo 2, Huitian 192, Huziheinuo 1 and Xiangnongtianyu 3) were selected from the new varieties cultivated (introduced) by Hunan Agricultural University in recent years.

2.4. Sample collection

The field soil was sampled by random five plum blossom point distribution method, uniformly mixed, stored at low temperature (4°C) and air-dried for use ; maize samples were taken by five-point ' Z ' random sampling method.

2.5. Determination method

The content of Cd in maize seedling stage was determined according to the method of GB 5009.15-2014 ' Determination of cadmium in food safety national standard food '.

2.6. Data statistics and analysis

Using Office 2012 for data collation ; analysis of variance was performed using SPSS 20.0 (different lowercase letters indicate significant differences between different treatments $P < 0.05$).

3. Results and analysis

3.1. Analysis of cadmium (Cd) accumulation characteristics of different maize varieties at seedling stage

3.1.1. Analysis of Cd content in seedling stage of different maize varieties in Liuyang base

There were differences in Cd content in roots of different varieties at seedling stage. The Cd content of Xiangnongtianyu 3 was the highest (1.41 mg/kg), which was significantly higher than that of other varieties. The Cd content of Xianghuiyu 1 was the lowest (0.50 mg / kg), which was significantly lower than that of other varieties. There were differences in Cd content in leaves of different varieties at seedling stage. The Cd content of Xiangnongyu 22 was the highest (1.16 mg/kg), which was significantly higher than that of other varieties. The Cd content of Xiangnongbainuo 2 was the lowest (0.43 mg/kg), which was significantly lower than that of other varieties except Xiangnongyu 36 and Xianghuiyu 1.

Table 1. Cadmium content analysis of different maize varieties at seedling stages in Liuyang site (mg/kg).

Variety	Root	Leaf
Xiangnongyu 36	0.76±0.03c	0.45±0.06ef
Xiangnongyu 22	0.73±0.01c	1.16±0.04a
Xiangnongyu 27	0.67±0.05c	0.52±0.07e
Xianghuiyu 1	0.50±0.03d	0.48±0.04ef
Huitian 192	0.99±0.12b	0.61±0.05d
Xiangnongtianyu 3	1.41±0.12a	0.84±0.02b
Huziheinuo 1	0.77±0.01c	0.72±0.04c
Xiangnongbainuo 2	0.56±0.06d	0.43±0.06f

3.1.2. Analysis of Cd content in seedling stage of different maize varieties in Yunyuan base

The Cd content in seedling roots of Xiangnongtianyu 3 was the highest (0.76 mg/kg), which was significantly higher than that of other varieties, followed by Xiangnongyu 22 (0.69 mg/kg), and Xiangnongbainuo 2 (0.42 mg/kg). The Cd content of seedling leaves of Xiangnongyu 22 was the highest, which was significantly higher than that of other varieties. The Cd content of seedling leaves of Xiangnongtianyu 3 was the second, which was 0.54 mg/kg. The Cd content of seedling leaves of Xiangnongyu 36 was the lowest, which was 0.32 mg/kg.

Table 2. Cadmium content analysis of different maize varieties at seedling stages in Yunyuan site(mg/kg).

Variety	Root	Leaf
Xiangnongyu 36	0.60±0.09bc	0.32±0.02e
Xiangnongyu 22	0.69±0.1ab	0.78±0.03a
Xiangnongyu 27	0.53±0.08cd	0.40±0.04de
Xianghuiyu 1	0.47±0.04d	0.38±0.03de
Huitian 192	0.63±0.08bc	0.43±0.07cd
Xiangnongtianyu 3	0.76±0.03a	0.54±0.06b
Huziheinuo 1	0.64±0.08bc	0.50±0.09bc
Xiangnongbainuo 2	0.42±0.06d	0.34±0.02e

3.2. Analysis of the difference of cadmium enrichment and transport in maize varieties at seedling stage

3.2.1. Analysis of Cd enrichment coefficient of different maize varieties at seedling stage in Liuyang base

Enrichment coefficient can directly show the absorption and accumulation ability of heavy metals in various parts of plants. From **Table 3-3**, it can be seen that there are differences in Cd enrichment coefficients among different maize varieties at seedling stage. The range of Cd enrichment coefficient of Xiangnongyu 36 was 0.53 ~ 0.89, the range of Cd enrichment coefficient of Xiangnongyu 22 was 0.85 ~ 1.35, the range of Cd enrichment coefficient of Xiangnongyu 27 was 0.61 ~ 0.77, the range of Cd enrichment coefficient of Xianghuiyu 1 was 0.56 ~ 0.59, the range of Cd enrichment coefficient of Huitian 192 was 0.71 ~ 1.15, the range of Cd enrichment coefficient of Xiangnongtianyu 3 was 0.98 ~ 1.64, the range of Cd enrichment coefficient of Huziheinuo 1 was 0.84 ~ 0.89, and the range of Cd enrichment coefficient of Xiangnongbainuo 2 was 0.50 ~ 0.65.The Cd enrichment coefficient of seedling roots of Xiangnongtianyu 3 was the largest, which was significantly larger than that of other varieties, followed by Huitian 192, which was 1.15, and the Cd enrichment coefficient of seedling roots of Xianghuiyu 1 was the smallest, which was 0.59. The Cd enrichment coefficient of seedling leaves of Xiangnongyu 22 was the largest, which was significantly larger than that of other varieties, followed by Xiangnongtianyu 3, which was 0.98, and the Cd enrichment coefficient of seedling leaves of Xiangnongbainuo 2 was the smallest, which was 0.56.

Table 3. Cadmium enrichment coefficient analysis of different maize varieties at seedling. stages in Liuyang site

Variety	Root	Leaf
Xiangnongyu 36	0.89±0.03c	0.53±0.08ef
Xiangnongyu 22	0.85±0.01c	1.35±0.04a
Xiangnongyu 27	0.77±0.06c	0.61±0.08e
Xianghuiyu 1	0.59±0.03d	0.56±0.05ef
Huitian 192	1.15±0.14b	0.71±0.05d
Xiangnongtianyu 3	1.64±0.13a	0.98±0.02b
Huziheinuo 1	0.89±0.01c	0.84±0.05c
Xiangnongbainuo 2	0.65±0.07d	0.50±0.07f

3.2.2. Analysis of Cd enrichment coefficient of different maize varieties at seedling stage in Yunyuan base

The range of Cd enrichment coefficient among different maize varieties was also different, and the range of Cd enrichment coefficient of Xiangnongyu 36 was 1.75-3.32. The variation range of Cd enrichment coefficient of Xiangnongyu 22 was 3.82 ~ 4.33, the variation range of Cd enrichment coefficient of Xiangnongyu 27 was 2.21 ~ 2.94, the variation range of Cd enrichment coefficient of Xianghuiyu 1 was 2.12 ~ 2.63, the variation range of Cd enrichment coefficient of Huitian 192 was 2.39 ~ 3.49, the variation range of Cd enrichment coefficient of Xiangnongtianyu 3 was 3.04 ~ 4.25, the variation range of Cd enrichment coefficient of Huziheinuo 1 was 2.79 ~ 3.55, and the variation range of Cd enrichment coefficient of Xiangnongbainuo 2 was 1.90 ~ 2.36.The seedling root enrichment coefficient of Xiangnongtianyu 3 was the largest, 4.25, followed by Xiangnongyu 22, 3.82, and Xiangnongbainuo 2 was the smallest, 2.36. The seedling root enrichment coefficient of Xiangnongtianyu 3 and Xiangnongyu 22 was significantly higher than that of other varieties. The Cd enrichment coefficient of seedling leaves of Xiangnongyu 22 was the highest (4.33), which was significantly higher than that of other varieties, followed by Xiangnongtianyu 3 (3.04), and Xiangnongyu 36 was the lowest.

Table 4. Cadmium enrichment coefficient analysis of different maize varieties at seedling stages in Yunyuan site.

Variety	Root	Leaf
Xiangnongyu 36	3.32±0.47bed	1.75±0.11f
Xiangnongyu 22	3.82±0.54ab	4.33±0.15a
Xiangnongyu 27	2.94±0.46cde	2.21±0.24de
Xianghuiyu 1	2.63±0.21de	2.12±0.15def
Huitian 192	3.49±0.43bc	2.39±0.39cd
Xiangnongtianyu 3	4.25±0.17a	3.04±0.31b
Huziheinuo 1	3.55±0.47bc	2.79±0.52bc
Xiangnongbainuo 2	2.36±0.32e	1.90±0.1lef

3.2.3. Analysis of Cd transport coefficient of different maize varieties at seedling stage in Liuyang base

Cd transport coefficient refers to the ratio of Cd content in plant seedlings to Cd content in roots. It is one of the indexes to evaluate the transport and enrichment ability of Cd in plants. From **Table 3-5**, it can be seen that the seedling leaf transport coefficient of Xiangnongyu 22 is the largest, 1.60, which is significantly higher than that of other varieties, followed by Xianghuiyu 1, and Xiangnongyu 36 is the smallest, 0.59.

Table 5. Cadmium transport coefficient analysis of different maize varieties at seedling stages in Liuyang site.

Variety	Leaf
Xiangnongyu 36	0.59±0.10d
Xiangnongyu 22	1.60±0.06a
Xiangnongyu 27	0.79±0.16c
Xianghuiyu 1	0.96±0.11b
Huitian 192	0.62±0.03d
Xiangnongtianyu 3	0.60±0.06d
Huziheinuo 1	0.94±0.05bc
Xiangnongbainuo 2	0.79±0.17c

3.2.4. Analysis of Cd transport coefficient of different maize varieties at seedling stage in Yunyuan base

Among different maize varieties, there were also differences in the transport coefficient. The leaf transport coefficient of Xiangnongyu 22 was the largest, 1.15, which was significantly higher than that of other varieties, followed by Xiangnongbainuo 2, 0.82, Xiangnongyu 36 was the smallest, 0.53.

Table 6. Cadmium transport coefficient analysis of different maize varieties at seedling stages in Yunyuan site.

Variety	Leaf
Xiangnongyu 36	0.53±0.07c
Xiangnongyu 22	1.15±0.19a
Xiangnongyu 27	0.76±0.12bc
Xianghuiyu 1	0.81±0.11b
Huitian 192	0.70±0.2bc
Xiangnongtianyu 3	0.71±0.05bc
Huziheinuo 1	0.79±0.14b
Xiangnongbainuo 2	0.82±0.13b

4. Conclusion

In higher plants, root is the first organ to contact with heavy metal stress. As the main organ to absorb nutrients, the absorption capacity of root will directly affect the growth status, nutritional status and yield level of aboveground part. At the same time, root is easily poisoned by heavy metals, and the amount of heavy metals accumulated in root is significantly higher than that in leaf[7]. This study showed that in Liuyang and Yunyuan bases, except for Xiangnongyu 22, the cadmium content in the roots of the other seven maize varieties at seedling stage was significantly higher than that in the leaves, which was similar to the results of Zhao Zhixin et al.[8], and also similar to the results of Yang Haitao and Li Lele et al.[9-10]. The reason why the cadmium content in the leaves of Xiangnongyu 22 was higher than that in the roots at seedling stage may be related to the characteristics of the root varieties themselves. In Liu Jian[11], Xiangnongyu 22 was a high cadmium accumulation variety.The enrichment coefficient reflects the ability of plants to absorb heavy metals to a certain extent. The higher the enrichment coefficient of each part of the plant, the stronger the ability of plants to accumulate heavy metals. The Cd transport coefficient refers to the ability of heavy metal Cd to be transported from the root part of the maize plant to the aboveground part of the plant. If the Cd transport coefficient is high, the ability of heavy metal Cd to be transported from the root to the aboveground part is stronger. It can be seen from **Table 3** and **Table 4** that except for Xiangnongyu 22, the Cd enrichment coefficient of other varieties at seedling stage was root > leaf. It can be seen that the ability of root to accumulate Cd at seedling stage is greater than that of leaf at seedling stage. The reason may be that the Cd content transported from root to leaf is less, which is basically consistent with Yang et al.[9] who found that the Cd enrichment coefficient of root is greater than that of leaf, which may be caused by the difference of Cd absorption among different varieties.

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