Evaluation for Suppressive Effects of Additives on Cadmium Uptake of Komatsuna Grown in Cadmium-contaminated Soil

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Abstract

To evaluate the suppressive effect of five additives on cadmium (Cd) uptake by komatsuna (Brassica rapa var. perviridis cv. Early komatsuna), a pot experiment with Cd-contaminated acidic soil was conducted in a greenhouse. Autoclaved lightweight aerated concrete (ALC), lherzolite (Lherzo), gypsum made from waste plasterboard (Gyp-w), magnesia cement (Magwhite) and calcium carbonate containing less than 10% pure gypsum (Cacar-G) were added to the soil (1%, w/v). The shoot Cd concentration of the plants was considerably suppressed by the application of Cacar-G and Magwhite, following by ALC moderately, Lherzo and Gyp-w slightly. The order was similar to that of the additives which increased the soil pH. In addition, the order except Gyp-w was in agreement with that of the additives which decreased the exchangeable Cd concentration in the soil. Gyp-w increased the water-soluble Cd concentration in the soil. We presumed that the Cd uptake of the plants might be controlled by the soil pH and the level of water-soluble and exchangeable Cd. It is concluded that Cacar-G and Magwhite are considerably effective soil amendments in the suppression of the Cd uptake by the plants; ALC is moderately effective, whereas Lherzo and Gyp-w are scarcely effective when they are added at 1% concentration to the soil.

Key Words: Additive, cadmium, exchangeable cadmium, komatsuna, soil pH, water-soluble cadmium.

1. Introduction

The itai-itai disease caused by the consumption of food contaminated with cadmium (Cd) affected a significant number of people in Japan[1]. The evidence suggests that Cd emissions had contaminated a river and found their way into crops that were irrigated with the contaminated water. Cadmium is highly toxic to organisms, and its accumulation in the food chain leads to serious problems for human consumers.

The management of Cd emissions into the environment is a requisite for avoiding significant ecological risks[2-5]. To protect human health from Cd toxicity, the Codex Alimentarius Commission[6] adopted Cd standards for staple crops and set limits of 0.1 mg Cd / kg for stem and root vegetables, 0.2 mg Cd / kg for leafy vegetables, and 0.05 mg Cd / kg for other vegetables. It is generally agreed that the transfer of Cd into crops and food chains from Cd-contaminated soil and water must be reduced.

Several methodologies of remediation on
Cd-contaminated soil and groundwater have been investigated\(^5\). One of them focuses on the reduction of the bioavailability of Cd in soil. Increased soil pH decreases Cd bioavailability\(^5\)\. Singh et al.\(^10\) reported that the Cd concentration in wheat and carrots grown on alum shale soil (naturally metal-rich soil) decreased substantially when the soil pH was raised from 5.5 to 7.5 by the addition of calcium carbonate. Yoshida and Sugito\(^11\) found that the application of various manures with calcium carbonate decreased the Cd uptake of soybean. Hasegawa et al.\(^12\) showed that the application of autoclaved lightweight aerated concrete (ALC), a fertilizer rich in calcium silicate, to clayey soil suppressed the Cd uptake of rice plant when the soil pH was above 7. As a result, liming to increase the soil pH has been proposed as an effective method to reduce Cd uptake by crops.

In most soils, the major portion of the total Cd is associated with the solid phase, and the minor portion is in solution\(^5\)\. The soil Cd may form part of soluble components, may be weakly adsorbed to clay or strongly adsorbed to Fe and Mn oxides, may be complexed with humic colloids, or may participate in the formation of hardly soluble precipitates. Kashem and Singh\(^10\) applied a sequential extraction method which separated the soil Cd into a water-soluble, exchangeable, carbonate-bound, oxide-bound, organically bound, and residual fraction. The method showed us the distribution of the soil Cd.

Several materials rich in magnesium or calcium that may possess the potential to reduce the bioavailability of Cd in soil have been produced by factories in Japan. We considered the following materials worthy of attention. The first material was "Lherzolite" (Lherzo). Lherzo is a stone rich in magnesium, and is pulverized into fine powder on quarrying. Kashem et al.\(^5\) reported that the application of Lherzo in Cd-contaminated soil reduced the Cd uptake of Japanese mustard spinach and the exchangeable Cd of the soil, and increased the soil pH. The second material was "Gypsum-waste" (Gyp-w) made from waste plasterboard. We hypothesized that Gyp-w may be useful to reduce the bioavailability of Cd in the Cd-contaminated soil. The third material was the powder of "Magnesia cement" (Magwhite) which concreted soil under alkaline conditions and contained high levels of magnesium. The last material was "Calcium carbonate-Gypsum" (Cacar-G) which contained less than 10% of refined gypsum, and which was developed as the suppressive amendment on the Cd uptake of rice plants. Cacar-G was uninvestigated the effects on the Cd uptake of upland crops yet.

The comparison of ALC with the four materials about the effectiveness on the Cd uptake of upland crops has not yet been researched. Then, we evaluated the suppressive effects of ALC and the four materials on the Cd uptake of komatsuna (Brassica rapa var. pereiridis cv. Early komatsuna) grown with the same concentration of the materials in acidic Cd-contaminated soil. Furthermore, we compared the materials about the persistency of the suppressive effects on the Cd uptake through the repeated cultivation.

2. Materials and Methods

Additives

Five materials were used as additives in the present study. ALC (Taihei Bussan Corp., Tokyo, Japan) was an alkaline material mainly produced for use in the construction of buildings. ALC contained 18% SiO\(_2\), was porous with 75% air volume, and was crushed into pieces 4 mm in diameter. ALC was partially used as a soil amendment for liming and a fertilizer for supplying silicate. Lherzo (Miyamori Saiseki Corp., Iwate, Japan) contained 39% SiO\(_2\) and 36% MgO. The Lherzo powder was produced as the by-product of quarrying. Gyp-w (Ecotic Toboku Corp., Miyagi, Japan) was made from waste plasterboard, CaSO\(_4\)·2H\(_2\)O, was ground and passed through a 3 mm sieve. Magwhite was produced by Tobu Chemical Corp. (Saitama, Japan). It contained 84% MgO. Cacar-G was developed by Mitsubishi Materials Corp. (Tokyo, Japan). We measured the alkalinity of the materials, defined as the percentages in dry weight of CaO and MgO extracted by 0.5 mol / L HCl. The alkalinity of ALC, Lherzo, Gyp-w, Magwhite and Cacar-G, were 37.0, 21.9, 32.4, 56.1, and 44.2, respectively.

Soil Properties

The upper layer (0-20 cm depth) soil\(^15\) contaminated with Cd was collected from an upland field in the vicinity of a closed mine in Miyagi
Preface of Japan. The soil was classified into the order of Inceptisols according to the properties of Umbric surface and Cambic subsurface horizons\(^\text{16}\). The organic carbon content was 2.4% and cation exchange capacity (extraction with 1 mol/L ammonium acetate, pH 7.0) was 22.4 cmol/kg. The soil had 58% sand and 10% clay, then, the texture was categorized as a sandy loam\(^\text{19}\). The pH value (soil (w): water (v) = 1: 2.5) was 5.3. The concentrations of Cd extracted by 0.1 mol/L HCl and that of total Cd\(^{10}\) were 3.1 and 4.6 mg/kg of oven-dried soil, respectively.

**Pot Experiment**

Pots were filled with 1 L of the soil that had been passed through a 4 mm sieve, and 1.0% (w/v) additives (either ALC, Lherzo, Gyp-w, Magwhite, or Cacar-G) as well as 0.1% (w/v) chemical fertilizer (N: P\(_2\)O\(_5\): K\(_2\)O (%) = 10: 10: 10) were added. Each treatment was performed in triplicate. In addition, additive-free treatment (Addi-f) was performed whereby the pot received no additive but the fertilizer. Nine seeds of komatsuna (Brassica rapa var. periuviridis cv. Early komatsuna; Atariya Noen Corp., Katori, Japan) were sown in each pot, and the pots were kept in a greenhouse under natural light. After germination, seedlings were thinned to 3 plants per pot. The shoots of the plants (that is, the edible parts) were harvested and an aliquot of the soil was sampled after 28 days cultivation. The soils sampled from each pot were air-dried and passed through a 2-mm sieve. Each pot was used for repeated cultivation; the fertilizer (0.1%, w/v) was applied again before new seeds were added. Two rounds of cultivation were performed in Addi-f, Lherzo and Gyp-w treatments, three rounds were performed in ALC, and five rounds were performed in Magwhite and Cacar-G treatments. Further cultivation in Addi-f, Lherzo, Gyp-w and ALC treatments was not feasible because of drastically repressed plant growth.

**Plant Analysis**

The shoots collected after 28 days cultivation were dried at 65°C for 2 days, then weighed, ground, and digested with the mixture of 60% nitric acid and 60% perchloric acid (5 (v): 1 (v)). Cadmium in the digested solutions was measured by atomic absorption spectrophotometry (AAS, 170-30 Hitachi, Tokyo, Japan).

**Soil Analysis**

The soil pH was analyzed before and after all cultivation. The soil pH was measured in purified water (1 (w): 2.5 (v)) using a glass electrode (HM-20S TOA DKK, Tokyo, Japan).

Cadmium in the soil was fractionated, and the Cd concentration in each fraction was measured by the sequential method of Kashem and Singh\(^\text{10}\). However, in this study, as the Cd concentration of the sixth fraction (F6; residual Cd) was few at the exploratory experiment, we did not analyze the sixth fraction.

The procedures for the fractionation were as follows. The first fraction (F1; water soluble Cd) was extracted by shaking (100 rpm) for one hour with purified water (1 (w): 10 (v)). The second fraction (F2; exchangeable Cd) was extracted by shaking for two hours with 1 mol/L ammonium acetate at pH 7.0 (1 (w): 10 (v)). The third fraction (F3; carbonate-bound Cd) was extracted by shaking for two hours with 1 mol/L ammonium acetate at pH 5.0 (1 (w): 10 (v)). The fourth fraction (F4; oxide-bound Cd) was extracted by occasional shaking for six hours in a water bath at 80°C with 0.04 mol/L hydroxilamine hydrochloride in 25% (v/v) acetic acid (1 (w): 10 (v)) at pH 3.0. The fifth fraction (F5; organically bound Cd), was extracted with 0.8 mol/L ammonium acetate dissolved in 5% (v/v) nitric acid (1 (w): 10 (v))) after decomposition of organic matter with 30% H\(_2\)O\(_2\), (at pH 2.0) for 5.5 hours at 80°C (1 (w): 7.5 (v)). All extracted suspensions were centrifuged at 11,000 g for 0.5 hour. The standard deviations of the pH values of the suspensions extracted at pH 7.0 (F2), 5.0 (F3), and 3.0 (F4) were 0.17, 0.03, and 0.007, respectively, showing that the extracting solutions were buffered sufficiently. Extracted Cd was determined by AAS.

The soil Cd concentration in five fractions was analyzed on the original soil and the each treatment soil before cultivation and after the first and last cultivation. In addition, the analysis was performed after the third cultivation in Magwhite and Cacar-G.

All reagents used in these experiments were

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analytical grade, and the containers were soaked in 0.1 mol / L nitric acid and rinsed thoroughly in pure water before use.

Statistical Analysis

Multiple comparison analysis was performed using the computer “Origin 5” at Iwate University (Morioka, Japan). The pair-wise comparisons between the treatments were performed using the Ryan-Einot-Gabriel-Welsch Multiple Range Test ($P < 0.05$).

3. Results and Discussion

Plant Growth

The applications of Cacar-G, Magwhite, ALC and Lherzo ameliorated komatsuna growth (Figure 1A). The shoot dry weight of the plants grown with ALC in the first and second cultivation, with Lherzo in the first cultivation and with Magwhite and Cacar-G in all cultivation, was significantly higher than that of the plants grown with Addi-f, as shown by the statistical analysis. However, the dry weight of the plants grown with Gyp-w was similar to that with Addi-f. The dry weight with ALC in the third and with Lherzo in the second cultivation decreased drastically compared to the previous rounds of the cultivation. The dry weight with Magwhite was higher in the second and third cultivation than in the first. And that with Magwhite and Cacar-G in fourth and fifth cultivation decreased in half. In the second cultivation, the plants with Addi-f, Lherzo and Gyp-w did not grow normally and showed necrotic symptoms. In contrast, the plants with Magwhite and Cacar-G grew well without abnormal symptoms even in the fifth cultivation. Thus, the effects of the additives varied considerably. We presumed that the plant growth was significantly ameliorated by the application of Cacar-G, Magwhite, ALC and Lherzo, but the span of the amelioration by Lherzo and ALC was shorter than that of Cacar-G and Magwhite, and the amelioration by Gyp-w was not found.

Plant Cd Concentration and contents

The shoot Cd concentration of the plants grown with Cacar-G and Magwhite was much lower than in the application of five additives, and the beneficial effect of Cacar-G and Magwhite was persistent through all the cultivation (Figure 1B). The Cd concentration with ALC decreased in the first and second cultivations, but not in the third. The Cd concentration with Lherzo and Gyp-w was not substantially decreased. The shoot Cd concentration with Addi-f, ALC, Lherzo and Gyp-w increased through subsequent rounds of cultivation (Figure 1B); in parallel with the decreases of dry weight (Figure 1A). Macnicol et al.\(^\text{18}\) reported that tissue Cd concentration resulting in 10% yield loss was 10-20 mg / kg in dried weight. In this study, it was seemed that the plant growth significantly repressed when the shoot Cd concentrations became over 20 mg / kg. This was almost in line with the report of Macnicol et al.\(^\text{19}\). This interpretation also agreed with the fact that the shoot Cd concentrations of the plants grown well with Magwhite and Cacar-G were significantly lower. It was presumed that the application of Cacar-G and Magwhite significantly reduced the shoot Cd concentration of the plants till the fifth cultivation, and ALC reduced it in the first cultivation only, however, Lherzo and Gyp-w did not reduce it even the first cultivation significantly.

The shoot Cd contents of the plants grown with Lherzo in the first and with ALC in the second cultivation were more than twice of that found in Addi-f (Figure 1C). This seemed due to the occurrence of the plant growth (Figure 1A) with constant Cd accumulation rates. The shoot Cd contents of the plants with Gyp-w, Magwhite and Cacar-G were lower than that of the plants with Addi-f (Figure 1C). The low Cd contents in Gyp-w were probably due to the decrease of the plant growth, whereas those of the plants with Magwhite and Cacar-G were correlated with the low shoot Cd concentration.

Change of Soil pH

The soil pH was considerably raised by the application of Magwhite and Cacar-G (Figure 2). When Magwhite and Cacar-G were added, the soil pH increased to 8.2 and 7.6 before the cultivation, respectively, and continued the level above 7 even after the fifth cultivation. The soil pH of Addi-f, ALC, Lherzo, and Gyp-w treatments before the cultivation was 5.0, 6.2, 5.2, and 5.0, respectively, and it decreased gradually after the second cultivation. The application of Magwhite and
Figure 1  Effects of additives (1%, w/v) on A: shoot dry weight and B: shoot Cd concentration C; shoot Cd content of komatsuna grown on Cd-contaminated soils in subsequent rounds of cultivation. The additives are lherzolite (Lherzo), gypsum made from waste plasterboard (Gyp-w), autoclaved lightweight aerated concrete (ALC), magnesia cement (Magwhite) and calcium carbonate mixed pure gypsum (Cacar-G). Additive-free (Addi-f) and Lherzo and Gyp-w treatments cultivated the plants two rounds, while the ALC treatment cultivated three rounds, and Magwhite and Cacar-G treatments cultivated five rounds. The additives were only applied before the first cultivation, and chemical fertilizers were repeatedly applied before the cultivation. Bars represent the mean ± standard deviation of 3 replicates. Bars marked with the same letter do not differ significantly ($P < 0.05$, Ryan-Einot-Gabriel-Welsch Multiple Range Test). D. W., dry weight.
Cacar-G significantly raised the soil pH, following with ALC and Lherzo, Gyp-w did not raised.

Hasegawa et al.\textsuperscript{12} reported that the application of ALC at 2.5 kg/m\textsuperscript{2} maintained the soil pH above 7 and the rice plant growth constant over a 4 year period. We believed that the amount of ALC added in our experiments (equivalent to 1 kg/m\textsuperscript{2}) was not sufficient to maintain the soil pH high for prolonged periods, and that it lead to the decrease of the plant growth (Figure 1A). The same was true for our experiments with Lherzo. In any case, the effects of Magwhite and Cacar-G on the soil pH and the plant growth were clearly more persistent than those of ALC and Lherzo, while Gyp-w showed no significant effects at all. The intensity of the effects on the soil pH correlated with the alkalinity of the additives, except for Gyp-w. The sulfate contained in Gyp-w may be responsible for the lack of effectiveness of this additive. In the case of ALC and Lherzo, higher doses seem required to raise the soil pH to similar levels as Magwhite Cacar-G do. However, the decreased shoot dry weight in the first cultivation of the Magwhite treatment as compared to the Cacar-G (Figure 1A) might have been due to the very high soil pH caused by the Magwhite application. The soil management plans need to take into accounts such harmful effects of soil alkalinity.

Relationship between soil pH and plant dry weight, Cd concentration, and Cd contents

When the soil pH value was below 5, the shoot dry weight was low (Figure 3A). The decrease of the shoot dry weight with Addi-f and Gyp-w (Figure 1A) was probably caused by the soil acidity\textsuperscript{15}. Similarly, in the last cultivation with ALC and Lherzo, the decrease of the soil pH reduced the shoot dry weight (Figure 1A and 2).

When the soil pH value was above 5.2, the shoot dry weight was middle or high (Figure 3A). The middle group consisted of the first cultivation with Magwhite, and the fourth and fifth cultivation with Magwhite and Cacar-G (Figure 1A and 2). The first cultivation with Magwhite performed too high soil pH (mentioned above, Change of Soil pH). The fourth and fifth cultivation with Magwhite and Cacar-G would have the potential of growth injury due to continuous cropping. So the plant growth would be suppressed moderately despite the fact that the soil pH was high. It was shown that the plant grew well at the soil pH of 5.2 to 8 which was caused by the application of the additives, within the third cultivation.

The shoot Cd concentration decreased exponentially according to the increase of the soil pH ($R^2 = 0.910$; Figure 3B). It was low around the high pH range caused by Magwhite and Cacar-G.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{soil_pH.png}
\caption{Soil pH before and after cultivation of komatsuna. Soil pH was measured in a soil / water suspension (1:2.5, w / v). Each bar represents the mean ± standard deviation of 3 replicates. Bars marked with the same letter do not differ significantly ($P < 0.05$, Ryan-Einot-Gabriel-Welsch Multiple Range Test).}
\end{figure}
Suppressive Effects of Additives on Cadmium Uptake of Komatsuna

By contrast, below the 5 units of the pH, the shoot Cd concentration was high and dispersed. It was indicated that the application of Magwhite and Cacar-G with 1% concentration in the soil decreased surely the Cd uptake of the plants under high soil pH. But, in the present study, the cases of the different amount of the additives; more amount of ALC, Lherzo and Gyp-w, or less amount of Magwhite and Cacar-G, were not analyzed. We convinced that a further research was essential.

In the present study, the water content of the plants was 92% (data not shown). The Codex Alimentarius Commission sets a threshold of 0.2 mg Cd / kg in fresh weight of leafy vegetables. The 0.2 mg Cd / kg in fresh weight translated into 2.5 mg Cd / kg in dry weight at our experiments (recalculated by using 92% of the water content of the plants). The pH value is 8.2 corresponding to 2.5 mg Cd / kg in dry weight on the basis of the function shown in Figure 3B. Thus, the soil pH should be 8.2 or higher to obtain plants with acceptable Cd concentrations on this contaminated soil. Raising the soil pH to such a high level is impracticable in the field. However, most crops on upland fields are generally grown on neutral or weak acidic soils. In our experiments, the soil pH of 8.2 was hardly ever established because of the low plant growth (Figure 1A and 2). Therefore, the application of alkaline amendments alone does not seem to be sufficient to satisfy the criterion of the Codex Alimentarius Commission. In addition, the soil pH above 8.2 is harmful and adversely affects

Figure 3  Relationship between shoot Cd concentration and soil pH after cultivation. Data-points represent the mean of 3 replicates.
the plant growth. Complementary methods will have to be applied to reduce the Cd uptake by crops.

The shoot Cd content showed a peak between pH 5 and 6 (Figure 3C). The fact that the shoot Cd content decreased drastically at low soil pH condition was due to the strong inhibition of the plant growth in acidic soil (compare Figure 1A and 2). And, at high soil pH condition, the shoot Cd content decreased according as the reduction of the shoot Cd concentration.

Change of Soil Cd Concentration in different fractions

The water soluble Cd concentration in the soil (F1) significantly increased with Gyp-w, and decreased with Cacar-G, Magwhite and ALC, as compared to Addi-f until last cultivation (Figure 4A). That with Lherzo was similar to Addi-f.

The exchangeable Cd concentration (F2) decreased with Cacar-G and Magwhite, and also decreased to some extent with ALC and Gyp-w, while Lherzo had no significant effect (Figure 4B). This decrease with Cacar-G and Magwhite showed the same tendency of the increase of the dry weight (Figure 1A) and the soil pH (Figure 2), and the decrease of plant Cd concentration (Figure 1B). In the case of ALC, the exchangeable Cd concentration (F2) decreased after the first cultivation, but slightly decreased after the third. This result is in line with the findings that beneficial effects of ALC on plant dry weight and shoot Cd concentration were evident only in the first and second cultivation (Figure 1). On the other hand, though the exchangeable Cd concentration (F2) after the first cultivation with Lherzo was similar to Addi-f, the dry weight was significantly ameliorated (Figure 1A). As regards Lherzo, the exchangeable Cd concentration (F2) in the soil may not be the sole factor controlling the plant growth. And more, though the exchangeable Cd concentration (F2) with Gyp-w was lower than Lherzo, the dry weight with Gyp-w was ameliorated less than Lherzo. We supposed that the amount of the water-soluble (F1) and exchangeable Cd (F2) of Gyp-w was higher than that of Lherzo. Kashem13 reported that the plant growth was affected by the water-soluble (F1) and exchangeable Cd (F2). And then, Gyp-w did not ameliorate the plant growth better than Lherzo (Figure 1A). In Magwhite and Cacar-G, after the fifth cultivation the exchangeable Cd concentration was increased. The increase might accompany with the decrease of the dry weight of the plants (Figure 1A).

The carbonate-bound Cd concentration (F3) was increased before the cultivation with Magwhite, Cacar-G and ALC, but decreased after the first cultivation (Figure 4C). In contrast, it did not decrease after the first cultivation with Addi-f, Lherzo and Gyp-w.

Before the cultivation, the oxide-bound Cd concentration (F4) in the soil with Magwhite and Cacar-G had was higher than in the original soil, while that with ALC, Lherzo and Gyp-w was similar to Addi-f (Figure 4D). Intriguingly, the oxide-bound Cd (F4) in all treatments increased after the first cultivation.

Figure 4E indicates that organically bound Cd concentration of (F5) was generally low. Christensen and Haung14 reported that humified organic matter was intimately bound to the mineral colloids. Therefore, the organically bound Cd (F5) may be unchanged by the application of additives.

Relationship between Soil pH and Soil Cd concentration in different fractions

The water-soluble Cd concentration (F1) decreased with increasing the soil pH (Figure 5A). The exchangeable Cd concentration (F2) was negatively related to the soil pH ($R^2 = 0.835$, Figure 5B). The same was true for the sum of water-soluble and exchangeable Cd (F1 + F2) ($R^2 = 0.789$, Figure 5F). The carbonate-bound Cd (F3), oxide-bound Cd (F4) showed unclearly correlation with the soil pH (Figure 5C, and D). And organically bound Cd (F5) was low and constant all the soil pH. The water-soluble and exchangeable Cd concentration of the soil was decreased as accompanied with the increase of the soil pH. These results suggested that the soil pH controlled the level of phytoavailable Cd (F1 + F2) in the soil10, consequently affecting the levels of plant Cd uptake in the shoots. It was indicated that the most effective additives were Magwhite and Cacar-G.

4. Conclusions

Cacar-G and Magwhite were the feasible soil
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Figure 4  Soil Cd concentration of A; water-soluble (Fraction F1), B; exchangeable (F2), C; carbonate-bound (F3), D; oxide-bound (F4), and E; organically bound (F5). The data indicates original soil (without additives and fertilizers) and the soil before and after the cultivation with ALC, Lherzo, Gyp-w, Magwhite, Cacar-G, and Addi-f. Bars represent the mean + standard deviation of 3 replicates. Bars marked with the same small letter do not differ significantly ($P< 0.05$, Ryan-Einot-Gabriel-Welsch Multiple Range Test). D. S., dried soil.
Figure 5  Relationship between Cd concentration in different fractions of the soil and soil pH. The pH dependence of A; water-soluble Cd (Fraction F1), B; exchangeable Cd (F2), C; carbonate-bound Cd (F3), D; oxide-bound Cd (F4), E; organically bound Cd (F5), and F; the sum of water-soluble and exchangeable Cd (F1 + F2) are shown. The data indicates original soil (without additives and fertilizers) and the soil before and after the cultivation with ALC, Lherzo, Gyp-w, Magwhite, Cacar-G, and Addi-f. Data-points represent the mean of 3 replicates.
amendments for the suppression of Cd uptake by komatsuna, and ALC and lherzo followed, however, Gyp-w was no suppressive effect. The application of Magwhite and Cacar-G in 1% of the soil increased especially the soil pH, and decreased the water-soluble and exchangeable Cd concentration in the soil. Magwhite and Cacar-G evoked the increasing of the soil pH that might control the phytoavailable Cd. Cacar-G and Magwhite would show the new aptitude for the suppressive soil amendment of Cd uptake of the upland field crops.

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カドミウム汚染土壌で生育したコマツナに対する
土壤添加剤類のカドミウム吸収抑制効果

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要  要

コマツナ（Brassica rapa var. perviridis cv. Early komatsuna）のカドミウム吸収に対する5種類の土壤添加剤の抑制効果を評価するために、酸性のカドミウム汚染土壌を用いたポット栽培実験を温室で行なった。軽量気泡コンクリート粉末（ALC）、レルゾライト（Lherzo）、廃石膏ボード粉末（Gyp-w）、マグネシアセメント（Magwhite）と10%未満の硫酸カルシウムを含んでいる炭酸カルシウム（Cacar-G）を、カドミウム汚染土壌に対し1%濃度で加えてコマツナを栽培した。コマツナの吸収カドミウム濃度は、Cacar-GとMagwhite区で低く、ALC区が続き、LherzoとGyp-w区では高くなった。カドミウム吸収抑制効果の高いCacar-GとMagwhiteは、土壌pHを上昇させ、土壌中の交換態カドミウム濃度を低下させていた。Gyp-wは土壌中の水溶態カドミウム濃度を上昇させた。コマツナのカドミウム吸収は土壌のpH、水溶態と交換態のカドミウム量に影響されていた。Cacar-GとMagwhiteが、コマツナのカドミウム吸収抑制に効果的な添加剤であり、ALCはやや効果的であり、LherzoとGyp-wは効果が少ないと示唆された。

キーワード：添加剤、カドミウム、交換態カドミウム、コマツナ、土壌pH、水溶態カドミウム