Application effect of magnesium oxide material on cadmium uptake by wheat (*Triticum aestivum*)

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Abstract
The effect of magnesium oxide material on cadmium uptake by wheat (Ayahikari and Norin No. 61) was investigated in the upland field (Fluvaquept) rotated from paddy rice field of Tokyo, Central Japan. Soil pH was relatively high due to long history of paddy rice cultivation. Magnesium oxide material (also containing antigorite + vermiculite) was used for neutralization to achieve the suppression of cadmium uptake by wheat, associated with improvement of the imbalance of calcium and magnesium with calcium carbonate for a long time. However, the application of magnesium oxide material at the level of 3000 kg/ha, which maintained soil at pH less than 6.5, did not significantly suppress cadmium uptake by two different wheat cultivars. It is suggested more suitable methods are required to suppress cadmium uptake by wheat than the application of magnesium oxide material in the case of this upland field rotated from paddy rice field which showed neutral soil pH.

Key Words
Antigorite, cadmium, vermiculite, wheat grain.

Introduction
Cadmium (Cd) is one of the highly toxic elements for human beings (Kobayashi 1978). Excessive Cd intake has caused serious disease of renal and bone. The Codex Committee on Food Additives and Contaminants has announced allowable limits for Cd concentration in polished rice, wheat grain and vegetables (Codex Committee 2005). Meanwhile, there is no allowable limit on wheat grain in Japan. The large-scale survey of domestic agricultural products revealed that the Cd concentration of 3 % of wheat grain exceeded intake of 0.2 mg/kg that is the international allowable limit proposed by the Codex Committee (Ministry of Agriculture, Forestry, and Fisheries of Japan 2002). With respect to genetic characteristics of wheat for Cd uptake, genotypic differences in cadmium uptake and distribution in wheat cultivated in pot and low Cd concentration field have been reported (Grant *et al.* 2008). Ministry of Agriculture, Forestry, and Fisheries of Japan intend to recommend low Cd uptake wheat cultivars and encouraged to cultivate them in relatively high Cd concentration filed. The wheat cultivar of low Cd uptake accumulated much higher Cd in their roots than those of the cultivar with high Cd uptake. In this study the amount of Cd uptake and accumulation in two different wheat cultivars and application effect of magnesium oxide material to improve the imbalance of calcium and magnesium on Cd uptake by wheat were investigated.

Methods
Magnesium oxide material
The magnesium oxide material (powder) consists of magnesium oxide, antigorite and vermiculite (Figure 1) (Okazaki *et al.* 2008). It was able to adsorb cadmium as cadmium hydroxide on its surface in aqueous solution, which provided the sharp X-ray diffraction pattern. The element composition of the magnesium oxide material is as follows, Na_2O: 0.207 wt %, MgO: 61.41, Al_2O_3: 0.894, SiO_2: 21.11, P_2O_5: 0.913, SO_3: 0.0318, K_2O: 0.0162, CaO: 3.81, TiO_2: 0.0483, V_2O_5: 0.005, Cr_2O_3: 0.163, MnO: 0.107, Fe_2O_3: 4.42, Others: 6.62, Total: 99.76. The magnesium oxide material was pH 10.7 and it surface area was 165.0 m^2/g. Magnesium oxide material was used for neutralization to achieve the suppression of cadmium uptake by wheat, associated with improvement of the imbalance of calcium and magnesium due to applying calcium carbonate for a long time.

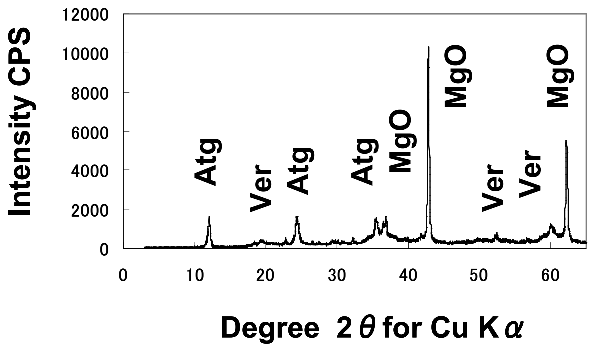

Figure 1. X-ray diffraction pattern of magnesium rich material
Atg: antigorite, Ver: vermiculite, MgO: magnesium oxide.

Soil neutralization by magnesium oxide material

Air-dried soil samples (Fluvaqept) were mixed with 0 to 6 wt % of magnesium oxide material. Twenty five mL of distilled water was added to the mixture of 5 g air-dried soil and magnesium oxide material. The suspension was lightly shaken, left for 24 hours and aerated for 2 min to let CO_2 gas out. The pH was determined by a pH meter equipped with a glass electrode.

Cultivation of wheat

The cultivation experiment of wheat was performed at Honmachi Farm of Tokyo University of Agriculture and Technology, shown in Figure 2, on an alluvial plain derived from Tama River sediment. The application of magnesium oxide material at the rate of 3000 kg/ha according to the previous experimental result (Figure 3) was carried out to neutralize soil acidity in order to suppress Cd uptake by wheat, comparing to control plot. Two different wheat cultivars, Ayahikari and Norin No. 61, were selected from a lot of cultivars in Japan.

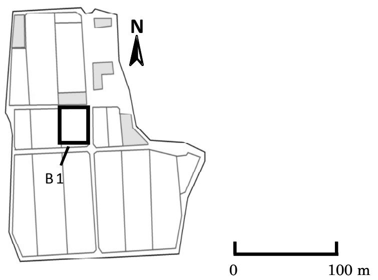

Figure 2. Hommachi Farm, Tokyo University of Agriculture and Technology
B1: 40 m x 27 m, Soil pH: 6.1 ± 0.1

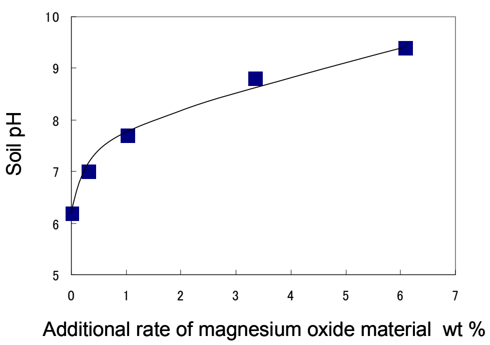

Figure 3. Neutralization of soil with magnesium oxide material

Norin No. 61 was common in Japan and recognized as low Cd uptake cultivar and recommended by Ministry of Agriculture, Forestry, and Fisheries of Japan (2007). Akihikari was newly developed for Japanese wheat noodle. Wheat was seeded in November of 2008 and harvested in July of 2009.

Cd in soil

Soil samples (n=36) at the point of wheat cultivation field were collected from just below harvested wheat. After air-drying soil samples were passed through a 2 mm nylon sieve. Twenty five mL of 0.1 mol/L HCl solution was added to 5 g soil samples. The mixture was shaken by a mechanical end-over-end shaker (Daiki, DIK 2102) at 25 . The extract was filtered with a No. 5 C filter paper (Advantec) and Cd concentration in the filtrate was determined by a flame atomic absorption spectrophotometer (Hitachi Z-5010).

Cd in wheat

Wheat grain samples were collected as whole body, including root. After that, wheat grain samples were washed by tap water and then deionized water, dried at 70 for 36 hours in a ventilated oven and ground with a mixer mill (MM301, Restch) for subsequent Cd analysis. The ground samples were digested using extra-pure water, H_2O_2 and HNO_3 (1:1:8 mL) in teflon containers in a microwave apparatus. The solution was filtered with a 0.45 m Membrane filter (Millipore). The Cd concentration in the digests was determined using Inductively Coupled Plasma Mass Spectrometry (Thermo Fisher, X series).

Statistical analysis

All statistical analyses were performed using JMP 8 (SAS Institute Inc., Cary, NC, USA).

Results

The physicochemical properties of soils in Hommachi Farm of Tokyo University of Agriculture and Technology were described by Sakagami *et al.* (1978). The mean value of 0.1 mol/L HCl extractable Cd concentration in soil was 0.99 ± 0.07 mg/kg dry weight (DW), which is almost 3 times of median total Cd concentration (HNO_3 + H_2SO_4 digestion) in soils of Japan. This area including Hommachi Farm was polluted by Cd-polluted irrigation water through Fuchu Irrigation Canal for paddy rice cultivation. Kikuchi *et al.* (2009) reported that wheat has greater uptake and accumulation of Cd than rice. Although the extraction of Cd in soil with 0.025 mol/L HCl solution was suitable for prediction of Cd concentration in wheat grain (Ibaraki 2003), 0.1 mol/L HCl solution was used in this study to determine Cd concentration in soil, because of easy comparison with much data accumulated in Japan. Wheat can accumulate Cd in grain at low level of 0.1 mol/L HCl extractable cadmium (0.3 mg/kg DW). This upland field still revealed the past Cd pollution through irrigation systems for paddy rice, indicating that the region around the inlet of irrigation gave higher Cd concentration than those in the central and outlet regions.

The mean value, standard deviation (SD) and coefficient of variance (CV) of Cd concentration in grain of different wheat cultivars cultivated in the experiment site is shown in Table 1. The mean value of Cd concentration in Akihikari of the control plot was 0.236 ± 0.0592 mg/kg fresh weight (FW),

Table 1. Cadmium concentration in wheat grain.

		Cd mg/kg FW Mean	SD	CV (%)
Ayahikari	Control	0.236	0.0592	25.1
	MgO	0.237	0.0060	2.55
Norin No. 61	Control	0.146	0.0524	35.8
	MgO	0.153	0.0508	33.2

MgO: 3000 kg/ha application of magnesium oxide material

which provided a higher value than the allowable limit (0.2 mg/kg FW) of the Codex Committee. The variations of Cd concentration in wheat grain coincided with the result of Kusa *et al.* (2005). The application of magnesium oxide material at the rate of 3000 kg/ha did not suppress Cd uptake by Ayahikari. In case of Norin No. 61, the mean value of Cd concentration in wheat grain was 0.146 ± 0.0524 mg/kg FW, is a lower value than for Akihikari. The effect of magnesium oxide material on Cd uptake by Norin No. 61 was minimal, due to the relatively higher soil pH.

Conclusion

There were significant differences of Cd uptake between two different wheat cultivars; Ayahikari and Norin No. 61. The application of magnesium oxide material at the rate of 3000 kg/ha in the upland field rotated from paddy rice field did not affect Cd uptake by wheat. It is suggested that more suitable methods to suppress cadmium uptake by wheat than the application of magnesium oxide material should be used for upland fields rotated from paddy rice fields which have neutral soil pH.

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