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The input–output balance of cadmium in a paddy field of Tokyo

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Abstract

Field monitoring was practiced from 2001 to 2003 to evaluate the input (irrigation, atmospheric deposition, and fertilizer application) and the output (uptake and accumulation into the above-ground biomass of rice plants and leaching) of cadmium (Cd) in a contaminated paddy field in Tokyo. The cadmium concentrations of irrigated water, open-bulk precipitation, soil solution (leaching water), rice plants collected at the harvesting stage and the chemical fertilizer and the cow manure compost applied were determined. The Cd flux of each factor was calculated by multiplying the Cd concentration by the volume or mass of the media. The annual input–output balance of Cd in the paddy field in 2001 and 2002 was estimated to be -6.23 g ha^{-1} and -2.49 g ha^{-1}, respectively, indicating the loss of Cd from the paddy field, although the losses accounted for only 0.28% and 0.11% of the total amount of Cd in the ploughed layer soil in 2001 and 2002, respectively. Among the factors involved, the input from fertilizers (including manure compost) and the output due to the uptake by rice plants played a major role in the balance. The former largely depended on the types and amounts of fertilizers applied, and the latter on the water management practices in the paddy field, such as flooding and drainage of the surface water.

Keywords: Atmospheric deposition; Fertilizer application; Monitoring; Remediation; Rice plants; Water management

1. Introduction

Cadmium (Cd) is a toxic heavy metal for human beings and can cause serious renal dysfunction and a kind of osteomalacia ("Itai-itai disease") when the element accumulates in the body. In 2004, the area of arable land polluted by heavy metals (cadmium, copper, and/or arsenic) in Japan amounted to 7327 ha, i.e., 0.16% of the total area of arable land. The Cd-polluted area represented 92.6% of the total polluted area (Ministry of the Environment, 2005).

Rice is a staple crop for the Japanese population and the largest source of Cd for Japanese (Tsukahara et al., 2003). The current maximum Cd concentrations allowed in brown rice and polished rice in Japan (on air-dried matter bases) are 1.0 mg kg^{-1} and 0.9 mg kg^{-1}, respectively. In April of 2006, a lower allowance value for polished rice (0.4 mg kg^{-1}) was adopted by the Codex Committee on Food Additives and Contaminants (CCFAC) established by FAO/WHO. This would have some influences on the rice production in Japan, especially in Cd-contaminated areas.

To assess the risk of contamination by toxic elements in crops and to develop effective remedial practices for the polluted lands, the evaluation of the input–output balance of those elements in the fields, as well as the understanding of the behavior of those elements in air–water–soil–plant systems, will provide fundamental information. Iimura and Ito (1978) conducted a five-year lysimeter experiment

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to evaluate the balance of cadmium, zinc, copper, and lead in three kinds of paddy soils with different levels of contamination. However, there were few reports on the estimation of the input–output balance of Cd in paddy fields on the field scale. The objectives of this study are to estimate the input–output balance of Cd in an actual Cd-contaminated paddy field and to evaluate the contribution of each factor to the balance.

2. Materials and methods

2.1. Site description

The field-monitoring practices were conducted at the Hommachi Farm, Field Science Center for Education and Research of Tokyo University of Agriculture and Technology (TUAT) (Fig. 1). This farm is located on the Tama River alluvial lowland plain in Fuchu City, Tokyo (35°39′N, 139°28′E) and consists of 13 rice paddy fields with a total area of 2.4 ha. The soil is classified as Aquic Fluvents (Soil Survey Staff, 1990). It was reported in 1970 that the irrigation water of the field derived from the Fuchu Irrigation Canal had been polluted by Cd from a merging industrial effluent (Fuchu City, 1978). Since then, the ground water from a 150-m depth has been used for irrigation on this farm (Saito and Shimoda, 1984; Okazaki and Saito, 1989).

A paddy field with an area of 0.11 ha was selected and monitoring was performed from 2001 to 2003. The design of the experiment is briefly summarized in Table 1.

2.2. Estimation of the water balance in the paddy field

In order to estimate the input of Cd from irrigation water in 2002 and the output by leaching in 2001, the volume of the irrigation water supplied into and the percolating water from the experimental field had to be estimated. In the present study, these values were indirectly calculated using the following water balance equation:

$$\mathrm{Irri} + \mathrm{Pre} = \mathrm{ET} + \mathrm{Per}, \tag{1}$$

where Irri represents the total volume of irrigation water in the rice cultivation period, Pre, that of precipitation, ET, evapotranspiration, and Per, percolation.

The water balance in 2001 was estimated as the average value of the all paddy fields in the study site. During the rice cultivation period, Irri had been recorded at the time of sampling by reading the water flow gauge attached on the ground water outlet. Pre was cited from the meteorological data recorded at the study site, and the data collected at the nearest AMeDAS station from this site (35°41.0′N, 139°28.9′E) was also used when the data at the study site was absent. ET was calculated as the potential evapotranspiration from the following equation (Thornthwaite, 1948; Land Development Technology Research Center, 1993):

$$\mathrm{ET} = 16(10T_i/I)^a(\mathrm{mm\ month}^{-1}), \tag{2}$$

where T_i represents the mean monthly temperature (°C),

$$a = (0.675I^3 - 77.1I^2 + 17920I + 492390) \times 10^{-6},$$

$$I = \sum_{i=1}^{12}(T_i/5)^{1.514}.$$

T_i was obtained from the meteorological data recorded in the study site. ET was corrected by multiplying the ET value calculated from Eq. (2) by the correction factor for the length of the daytime according to the latitude. Per was calculated from Eq. (1). During the non-cultivation period, the water balance was calculated in the same way as that in the rice cultivation period, except for Irri, which was assumed to be 0.

The water balance in 2002 was estimated from the data obtained in the experimental paddy field. During the rice cultivation period, ET was estimated by reading the

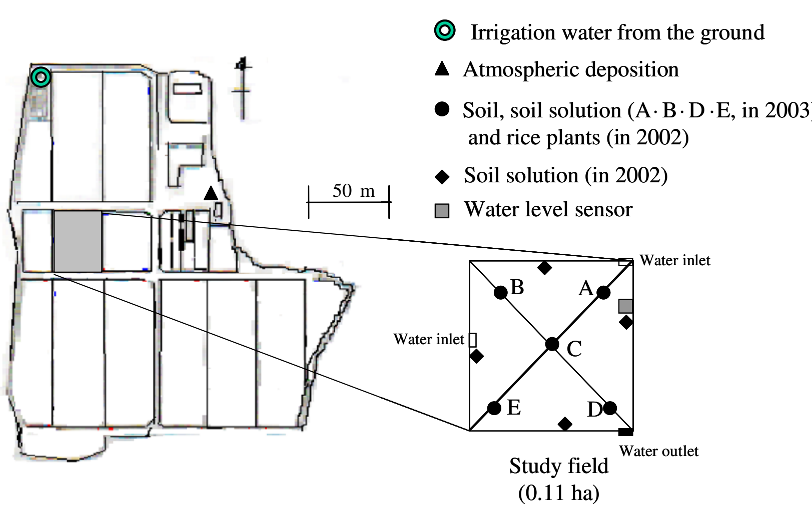

Fig. 1. Sampling and monitoring points in the study site.