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Development of a Simulation Model (PADDY) for Predicting Pesticide Behavior in Rice Paddy Fields*

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1. Introduction

Recently, public concern has been growing over the adverse effects on human health and ecosystems caused by pesticide use. In Japan, more than half of all agricultural land is paddy fields, and pesticides are used extensively in paddy fields to control pests and weeds that affect rice plants. There is a possibility that some of the applied pesticides are transported into public waters such as rivers and lakes, so it is important to predict both toxicity and exposure of pesticides to humans and ecosystems. Simulation models have thus been developed and are used routinely for the environmental exposure assessment of pesticides in the EU and US. However, only a few models have been developed for evaluating pesticide behavior in paddy fields, because the major agricultural lands are upland fields in the EU and US.

In this study, we developed and validated a pesticide paddy field model (PADDY) for predicting pesticide concentrations in a paddy field and the amount of pesticide runoff to adjacent water bodies. We also modified the PADDY model for calculation of water balance in paddy field with site-specific conditions. This study also covered predicting pesticide concentrations in drainage canals and rivers based on the PADDY model.

2. Development of the PADDY Model for Predicting Pesticide Concentrations in a Paddy Field

The behavior of pesticides in paddy fields was assessed by considering the major pesticide fate and transport processes on the basis of a compartment system : dissolution of pesticide from granules into paddy water, adsorption and desorption between paddy water and soil solids, runoff, leaching, volatilization from paddy water, and degradation in paddy water and soil solids. The mass balance equations of pesticides in the compartments were derived from kinetics. The mathematical model, PADDY, was constructed by numerical solution techniques. A method for measuring the pesticide parameters was also developed for the model simulation. To validate this model, a field experiment was carried out in a paddy field using molinate and simetryn and the concentrations of these pesticides were measured in water and soil. The experimental results were in reasonably good agreement with those predicted by the PADDY model. The PADDY model can also calculate the contribution of the fate and transport processes. The major disappearance process of molinate was runoff and volatilization, and that of simetryn was runoff.

3. Improvement of PADDY for Prediction of Pesticide Concentrations in Consideration of Water Balance in Paddy Field

To estimate the behavior of pesticides more accurately, an improved version of the pesticide paddy field model (PADDY-2) was evaluated for the prediction of pesticide concentrations in water and soil in consideration of water balance. To validate the PADDY-2 model, field studies were performed under two different conditions, with water management using molinate and simetryn. One was water-holding management, meaning water depth was maintained at about 4 cm by adjustment of irrigation water supply. The other was continuous irrigation management, in which the outlet of the paddy field was adjusted so that maximum water level was 4 cm and irrigation water was supplied at a fixed flow rate. Calculation of water depth in the field with water-holding management agreed well with the trend of measured values. For both pesticides, concentrations in paddy water were the same during the first day after

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* See Part II for the full Japanese article.

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application on both fields. From the second day, pesticide concentrations in the field managed by continuous irrigation were lower than those in the field managed by water-holding. Good fits between model predictions and field observations were obtained for the two pesticides by considering the water management and hydrological conditions. Runoff loss of pesticides was also calculated by the PADDY-2 model. The estimated runoff of pesticides was great in the field managed by continuous irrigation. From the viewpoint of reducing the environmental load of pesticides due to surface runoff, it is important to regulate the drainage during the water-holding period.

4. Development of Landscape-Scale Simulation Model (PADDY-Large) for Predicting Pesticide Concentrations in River Basin

A landscape-scale simulation model (PADDY-Large) based on the PADDY model was developed for predicting pesticide concentrations in drainage canals and rivers due to runoff from paddy fields. Depending on the irrigation system, each rice-producing area was classified as a "field plot", "farm block", "district", or "river basin" and pesticide behavior was estimated focusing on the main drainage canals in the "district" area. To validate the model, a surveillance of pesticide residues was carried out in a rice-producing area. Herbicide concentrations in the main drainage canal in the area increased in early May, reached a maximum in mid May, and declined to below detection limits by early July. Agreement between simulated and observed concentrations of the herbicide mefenacet in the main canal was obtained by considering actual pesticide use and environmental conditions in the rice-producing area. Therefore, it is anticipated that the PADDY-Large model can predict pesticide concentrations in rivers accurately and that the model is applicable to ecological risk assessment.