Runoff characteristics of pesticides from paddy fields and reduction of risk to the aquatic environment

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Abstract Simultaneous rice-transplanting and subsequent application of pesticides to the paddy fields in the catchment of a rural river on weekends from late May to mid June caused high concentrations and high loadings of pesticides in the river. Imperfections in irrigation water management and the overflow discharge from paddy fields during heavy storm events increased the risk of drinking water contamination and threatened the aquatic ecosystems. Several pesticides were detected at nearly ten ppb in the biofilms on the river bed. In order to reduce the risks due to runoff pesticides, it is necessary to improve the management of irrigation and to strengthen the biodegradation capacity of biofilms on the river bed by maintaining a long retention time in drainage channels.

Keywords Biodegradation; biofilm; passing downstream; pesticide; river water; runoff behavior

Introduction
Japan has the highest yield of rice per cultivated acreage in the world due to the application of large quantities of fertilizers and pesticides. About half the pesticides currently applied in Japan are for use in paddy fields. Throughout most of Japan the frequency of rainfall is high and most rainfall is intense and of short duration. Therefore, these pesticides, which were discharged from paddy fields to rivers, have increased the risk of tap water contamination and threaten aquatic ecosystems (Ebise et al., 1995; Nagafuchi et al., 1995; Inoue and Ebise, 1999).

We have observed changes in pesticide runoff loadings and standing biomass of biofilm on the bed of the River Amano. The runoff behavior of pesticides and other pollutants, together with changes on passing downstream, have been observed every three days for the past four years (Figure 1). The R. Yodo, which is fed by the R. Amano 27 km upstream from the mouth of the former, is a very important source of drinking water supply for the megalopolis of Osaka on the lower reach.

In the catchment area most farmers, who manage small-scale paddy fields, are also office and factory workers; they transplant rice seedlings with a transplanting machine and apply herbicides to the paddy fields manually using various sprays all on the same weekends from late May to mid-June. Under the conditions resulting from the cooperative growth of seedlings, the timing of transplantation converges to about one particular week, because of the growth stage of seedlings and the suitability of these conditions for operating the transplanting machine. There is a recommended period before and after transplanting for the application of pesticides. It is for such reasons as these that high concentrations and loadings of pesticides occur in Japanese rural rivers during a particular period.

Outline of observation
The runoff characteristics and changes in pesticides and other pollutants in the R. Amano were established by observation every third day during 1997–2000 at three sites down the river. The catchment area furthest downstream is 49.8 km², 40.4 km² at the midstream
site and 16.9 km² at the upstream site; stream length is about 15 km and water depth about several tens of centimetres in dry-weather days. Almost all the paddy fields are located in the upper and middle parts of the catchment.

The intensive transplanting of rice seedlings is concentrated on weekends in early June in this catchment, and the application of herbicides to the paddy field is done manually on all the fields on the following weekends in mid June. Any pesticide applied to the paddy fields is discharged mainly to rivers due to imperfections in irrigation water management and overflow during heavy storm events. The concentration of a pesticide dissolved in impounded water in paddy fields generally remains at a high level (as an example, about 500 mg m⁻³) for a few days after application. However, if there is a strong storm within three days of pesticide application, high concentrations and loadings appear in the runoff water to the river.

Though observations of pesticide runoff loading were conducted from late May to early September, observations of other water quality indicators were done for a longer period, early May to early December.

**Runoff behavior of pesticides**

As examples, Figures 2 (a), (b) and (c) show the runoff behavior of herbicide, insecticide and fungicide concentrations at the upstream, midstream and downstream sites on the R. Amano respectively, and Figure 3 shows their loadings at the midstream site in 1997. The concentrations of most herbicides generally became higher just after their application, and their loadings showed a high peak during the storm runoff period. Not only was the application of pesticides in the catchment area almost simultaneous, but also the same types of pesticide tended to be applied to the paddy fields of the catchment. The peaks of herbicide concentrations showed quite similar values at the upper, middle and lower sites. The peaks of insecticide concentrations occurred from mid June to mid July. In the case of fungicide, most peaks appeared over a relatively long period, from late July to late August.
The runoff behavior of pesticides in the cases of other observation years was similar to Figure 2 (a), (b), (c) and Figure 3, but the peaks of concentrations and loadings in the river differed from year to year. There was great difference in their total rainfalls in the irrigation period among the observation years. Based on the weather conditions, local advisers recommend the time and frequency of application (Nagafuchi et al. 1996). Therefore, the runoff behavior of pesticides in rivers is strongly influenced by weather conditions, especially, storm events.

Changes in pesticide loadings on passing downstream

In general, the concentration of an organic substance decreases on passing downstream due to dilution, decomposition and adsorption, provided that there is no further input load. As
there was no further input of pesticides during the passage from the midstream to the downstream site, the mass balance of pesticide loadings could be evaluated simply. The length of this stretch of the river is 1.2 km and the travel time of the water is a little less than one hour under the runoff conditions occurring on dry-weather days. The decrease in organic substances in one hour due to biochemical decomposition is estimated to be 3% under normal conditions of apparent self-purification of 0.4 day\(^{-1}\), provided that the decomposition is a first-order reaction. However, several pesticides decreased in loading by several tens of percent during passage down this stretch. As these decreases are much larger than are likely to occur by normal decomposition, much of the decrease is probably due to adsorption by biofilm and sediment in the river bed.

Decreases in the concentrations and loadings of pesticides and other organic pollutants
were seen during the process. In biofilm grown on unglazed tiles (98 × 98 × 4 mm) laid on the river bed for about two weeks, many pesticides, for example, esprocarb and IBP, were detected often at concentrations of nearly ten mg m–3. The biofilm was composed mostly of bacteria, periphyton and protozoa. These observations suggest that decrease in pesticide loadings can be expected due to the long retention time and biodegradation in the biofilm.

**Methods for reducing risks**

The decrease of pesticide loadings during downstream flow is caused mainly by the adsorption on bottom sediment and biodegradation by the associated biofilm. However, in order to reduce the risk of pesticide runoff, it is necessary to cut the over-application of pesticides to paddy fields and to improve the management of irrigation water. Furthermore, to reduce the amount of pesticide runoff from paddy fields, the application of pesticides must be decentralized appropriately over a relatively long time span by shifting the rice-transplanting workdays regionally within the catchment. It is also important to avoid applying pesticides on any day when a rain event is forecasted within a few subsequent days.

Moreover, to decrease the risk to drinking water and the ecosystem in the lower reaches of the river, chemical decomposition and microbial biodegradation in the drainage channels of paddy fields must be strengthened by increasing the aquatic purification capacity due to an extended residence time by putting down many traps and other obstacles on the bed, as an example, in zigzag fashion set from both sides. Cement or brick blocks provide an example.

Pesticides of high water solubility are easy to discharge in large quantities from paddy fields to a river (Numabe et al., 1992; Ebise et al., 1993), so it is necessary for the farmer to use a pesticide with low water solubility instead of ones with high solubility.

**Conclusion**

The simultaneous application of pesticides at about one week after the intensive rice-transplantation on weekends from late May to mid June in paddy fields of the catchment area of the R. Amano caused high concentration and loadings in sources of drinking water supply. This was due to their high water solubility, to imperfections in irrigation water management and to storm runoff events. Consequently, to decrease the risk to the aquatic environment of the river posed by pesticides from paddy fields, improvements are urgently required in pesticide application methods, the management practice for the irrigation water discharged from paddy fields and strengthening of the biodegradation capacity of biofilms in the bed of discharge channels. It is important that pesticides with high water solubility should no longer be used on paddy fields.

**References**


