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Fate and Transport of Nursery-Box-Applied Tricyclazole and Imidacloprid in Paddy Fields

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Abstract The fate and transport of tricyclazole and imidacloprid in paddy plots after nursery-box application was monitored. Water and surface soil samples were collected over a period of 35 days. Rates of dissipation from paddy waters and soils were also measured. Dissipation of the two pesticides from paddy water can be described by first-order kinetics. In the soil, only the dissipation of imidacloprid fitted to the simple first-order kinetics, whereas tricyclazole concentrations fluctuated until the end of the monitoring period. Mean half-life (DT_{50}) values for tricyclazole were 11.8 and 305 days, respectively, in paddy water and surface soil. The corresponding values of imidacloprid were 2.0 and 12.5 days, respectively, in water and in surface soil. Less than 0.9% of tricyclazole and 0.1% of imidacloprid were lost through runoff during the monitoring period even under 6.3 cm of rainfall. The pesticide formulation seemed to affect the environmental fate of these pesticides when these results were compared to those of other studies.

Keywords Tricyclazole · Imidacloprid · Dissipation · Nursery box · Paddy fields

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1 Introduction

Japanese rivers are usually found to be contaminated with a number of pesticides, including fungicides and insecticides, commonly used in paddy fields (Sudo et al. 2002; Tanabe et al. 2001). Therefore, many pesticide manufacturers in Japan are now seeking to develop products that are safer for the environment and more convenient for its aging farmers. For these purposes, various formulations have been developed, such as flowable formulations for direct application, microcapsules, nursery-box treatment, etc.

As most rice seedlings are prepared in nursery boxes for machine transplanting in Japan and East Asia, pesticide formulations designed specifically for application in these boxes are desirable. The nursery-box treatment, where pesticides are applied directly to rice seedlings in the nursery boxes before transplanting to protect rice plants from pests in early growth stage, has been practiced in Japan since the 1970s (Asaka et al. 1978). This nursery-box treatment has now become more and more popular in Japan and East Asia. However, the effect of this formulation to the fate and transport of the nursery-box-applied pesticides should be investigated to assess their risk to the environment.

Tricyclazole (5-methyl-1,2,4-triazolo[3,4-b]benzothiazole), a systemic fungicide, is commonly used to control the rice blast in Asian countries. However, information about the fate and transport of tricyclazole in paddy fields is very limited, especially in paddy-plot scale. The only study on tricyclazole, which was sprayed in a basin, reported high concentrations of tricyclazole in water at the outlet of the paddy farms (Padovani et al. 2006). Therefore, more studies to investigate the fate and transport of tricyclazole in paddy plots are desirable to evaluate the potential risk of tricyclazole to the environment.

Imidacloprid (1-[(6-chloro-3-pyridinyl)-methyl]-*N*-nitro-2-imidazoli-dinimine) is a systemic chloronicotinyl insecticide, which is used effectively against insects which suck rice and other crops worldwide (Sanchez-Bayo and Goka 2006). This insecticide is effective at low doses, and it can be used in many forms including broadcasting, spraying, or nursery-box treatment, in a variety of crops. Imidacloprid has been carefully evaluated because of its potential to leach into surface and ground water and to persist in soil (PMRA 2001). However, the risk of imidacloprid in the nursery-box treatment has not been evaluated.

This study aims to investigate the environmental fate and transport of granular tricyclazole and imidacloprid, which are combined in a commercial product for nursery-box treatment of rice, through the monitoring of pesticide concentrations and detailed water balance in experimental paddy plots.

2 Materials and Methods

2.1 Field Experiment

Pesticide fate and transport monitoring was conducted at the experimental farm of Tokyo University of Agriculture and Technology (TUAT) in Fuchu, Tokyo in 2006. Two small paddy plots of similar size (90 m^2) were set up inside a standard paddy plot (3,000 m^2) using a plastic bund with enforced soil between two plastic sheets (Fig. 1). The soil in these plots was a light clayey soil with an organic carbon content of 3.6%.

The two studied plots were designed to be in duplicate, named as P1 and P2 (Fig. 1). Therefore, they were both intermittently irrigated after rice transplanting. The irrigation started when the water level was lower than 3 cm and ceased when the level reached 5 cm. In both the plots, a high drainage gate was installed with the height from the paddy soil surface to the top of the drainage gate reaching 7.0 cm. This setup provided a minimum excess water storage depth (EWSD), and the distance between the paddy water level and the top of the drainage gate was 2 cm during the monitoring period (Phong et al. 2008c; Watanabe et al. 2007).

The water balance variables including irrigation, surface runoff, precipitation, and evapotranspiration (ET) were monitored. The volume of the irrigation water was measured with a flow meter connected to a data logger. The depth of the paddy water was monitored with a water level sensor (LSP-100, UIJIN Co., Ltd., Tokyo), and the volume of the surface runoff through the rectangular weir was calculated using the paddy water level data. The ET was observed using a water level sensor in a lysimeter box (35×50×30 cm) containing 15 cm of puddled soil in a flood condition with four growing rice plants. Percolation was calculated from the

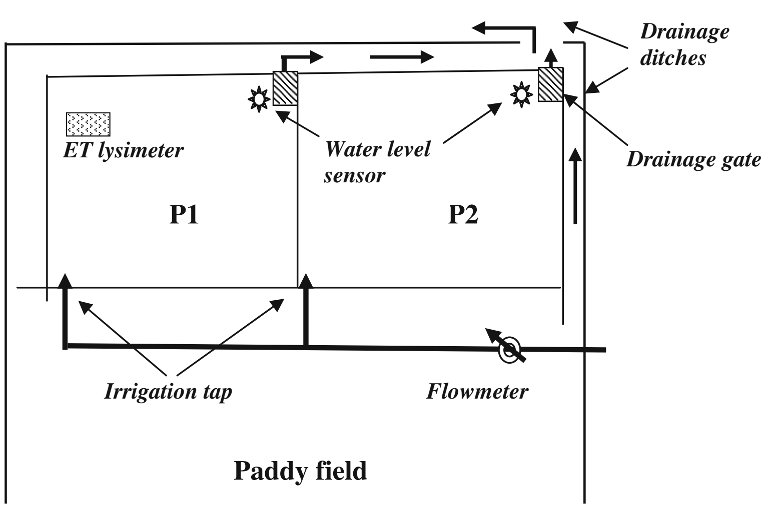

Fig. 1 Layout of experimental plots

water balance conservation equation (Watanabe et al. 2007).

Tricyclazole and imidacloprid were applied as a commercial granular formulation, BEAM admire (4% tricyclazole and 2% imidacloprid) to the nursery boxes that contained 14-day-old rice seedlings (*Oryza sativa* L. cv. var. Kinuhikari). The pesticide product was first applied over the rice seedling homogeneously so that the granules lie on the surface soil layer of the nursery box (Fig. 2). The application rate was 10 kg/ha. Immediately after pesticide application, the rice seedlings in the nursery boxes were transplanted by a machine with a spacing of 16× 30 cm on May 10, 2006. The transplanting machine took a few seedlings with the pesticide granules from the nursery box and drove them into paddy soil ~2.5 cm below the soil surface (Fig. 2).

2.2 Sampling

The paddy water and surface soil samples were taken at 1, 3, 7, 14, 21, and 35 days after treatment (DAT). At each sampling, five 100-ml samples of the paddy water taken from five spots were mixed together to make one composite water sample for one plot. Similarly, five 50-g surface soil samples (0–1 cm depth) were also taken from these spots to make the composite soil sample. The samples were kept frozen until chemical analysis.

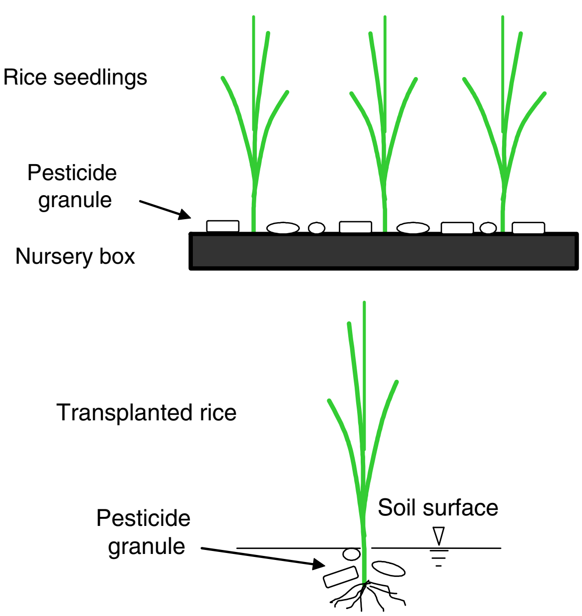

Fig. 2 Pesticide product in the nursery box and after transplanting

2.3 Chemical Analysis

2.3.1 Chemicals

Tricyclazole and imidacloprid standards (≥99% purity) and analytical grade solvents purchased from Wako Pure Chemical Industries (Osaka, Japan) were used for the chemical analysis. Water was produced with a Milli-Q Water Purification System (Millipore, Billerica, MA, USA). The solid-phase extraction cartridges for water extraction were Sep-Pak PS2-Plus (Waters, Milford, MA, USA), which was packed with styrene-divinyl benzene copolymer sorbent.

2.3.2 LC-DAD Analyses

Analyses were performed on the Waters Alliance HPLC System consisting of the 2695 Separations Module and the 2996 photo diode array detector. The system was controlled by the MassLynx software from a computer. The analytical column was a Wakosil-II 5C18 AR column (4.6 mm×150 mm, 5 μm particle size, Wako Pure Chemical Industries, Osaka, Japan) which was kept at 40°C during the analytical run. The detection was performed at 230 nm for tricyclazole and at 270 nm for imidacloprid. The pump was set in isocratic mode at the rate of 1 ml/min with the mobile phase of acetonitrile/water (20:80, *v*/*v*). The volume of the sample injection was 20 μl.

2.4 Sample Extraction

2.4.1 Water Sample Extraction

Water samples were thawed at ambient temperature and filtered through 1.2-μm glass fiber filters (GF/C, Whatman, Maidstone, UK) before extraction. The solid-phase cartridge was preconditioned with 5 ml of methanol and washed with 5 ml of water. Subsequently, an appropriate volume of water sample was passed through the cartridge without allowing the cartridge bed to dry, and the eluate was discarded. After this enrichment procedure, the cartridges were dried by pulling the air through for about 20 min before the adsorbed chemicals were eluted with

5.0 ml of methanol. The eluate was evaporated under vacuum pressure and the residue was redissolved in 1 ml of acetonitrile/water (20:80, *v*/*v*) and kept at 4°C for high-performance liquid chromatography (HPLC) analysis.

2.4.2 Soil Sample Extraction

Soil samples were dried at room temperature, and 20 g of soil was extracted by sonication with 100 ml of acetone for 20 min. The liquid phase was separated from the soil by passing through a 1.2-μm glass fiber filters (GF/C, Whatman, Maidstone, UK). Soil residue was washed again twice with 40 ml of acetone. All the extracts were combined and then the organic solvent was evaporated. The residual water was made up to 50 ml with pure water. Following this, the procedure was similar to that described earlier for water samples.

3 Results and Discussion

3.1 Water Balance

Water balance components, including irrigation, discharge, percolation, and ET of the two experimental plots during the 35-day monitoring period are shown in Table 1. The precipitation amount was similar to the monthly average value of precipitation for the period. The amount was scattered into several rainfall events, but there were only two significant rainfalls of more than 2 cm that could cause water overflow in the studied plots, which occurred at 14 and 30 DAT, respectively. Eventually, only one overflow event occurred upon a rainfall of 6.3 cm at 14 DAT.

There was a significant difference in terms of percolation between the two plots, possibly because of the inconsistency of the bed-soil layer, which was consistently observed in earlier experiments (Phong et al. 2008c). This difference consequently resulted in a higher irrigation requirement for P1. These different percolation rates may also affect the transport of pesticides in paddy fields, which is discussed in detail in Section 3.2.

With the same setup and the use of the intermittent irrigation scheme, the depth of paddy water was similar between P1 and P2 during the monitoring period (Fig. 3). More than 2 cm of EWSD in the studied plots effectively utilized rainfall water and helped to control the overflow caused by excessive rainfall. Of the total precipitation of 19.3 cm during the monitoring, only 2.4 and 2.9 cm overflowed from P1 and P2, respectively. Detailed analysis of water level data indicated that the main reason for the difference in overflow value was the difference in percolation rate under a very intense rainfall. However, the overflow water accounted for less than 9% of the water output, a situation much better than the spillover irrigation scheme often practiced in Japan (Watanabe et al. 2007).

3.2 Fate and Transport of Tricyclazole

3.2.1 In Paddy Water

Tricyclazole concentrations in paddy water reached 21.2 and 24.2 μg/l for P1 and P2, respectively, at 1 DAT and remained relatively stable until 7 DAT. After 7 DAT, the compound dissipated quicker and reached 2.0 and 3.3 μg/l, for P1 and P2, at the end of the monitoring period (35 DAT). Similar concentra-

Table 1 Water balance in the paddy plots

	P1		P2	
	Total water depth (cm)	Daily average water depth (cm/day)	Total water depth (cm)	Daily average water depth (cm/day)
Input				
Irrigation	34.7	0.96	24.7	0.67
Precipitation	19.1	0.53	19.1	0.53
Total	53.8	1.49	43.8	1.20
Output				
Discharge	2.4	0.07	2.9	0.08
Percolation	40.3	1.12	28.0	0.78
ET	10.3	0.29	10.3	0.29
Total	53.0	1.48	41.1	1.17

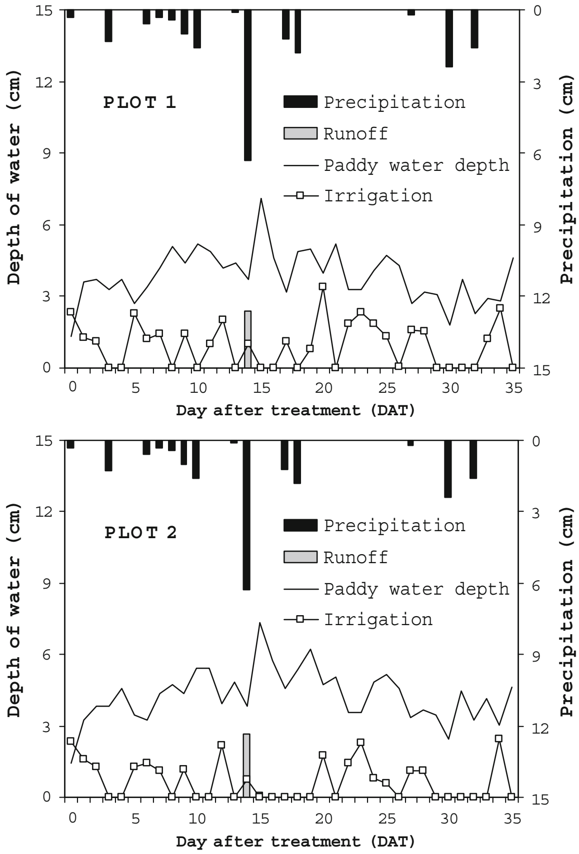

Fig. 3 Water balance monitoring in plot 1 and plot 2

tions were observed in every sampling date between the two plots (Fig. 4). The nursery-box formulation in this study produced an initial concentration of tricyclazole in paddy water which was lower than that caused by spray formulation (water-soluble emulsion). Depending on the canopy coverage and the application rate (ranging from 154 to 241.9 g/ha), the tricyclazole concentrations in water caused by the spray solutions can range from 26.7 to 142.2 μg/l (Phong et al. 2008a, b). Meanwhile, Padovani et al. (2006) reported that the maximum concentration of tricyclazole measured at the outlet of paddy farm in Italy was less than 15.6 μg/l at 2 DAT for an application rate of 600 g/ha. However, the distribution of tricyclazole concentration within the farm was not measured. Since the seedling was driven ~2.5 cm below the soil surface upon transplanting, most of the applied pesticide mass was supposed to reside under the soil surface or around the plant roots (Fig. 2). This phenomena and the effect of the formulation probably contributed to the lower initial tricyclazole concentration in this study.

The dissipation process in both plots followed a first-order kinetics ($p<0.05$) during the monitoring. Using the entire data set, DT_{50} values of tricyclazole of 11.4 and 12.1 days were calculated for P1 and P2, respectively (Table 2). The half-life of tricyclazole found in this study was longer than that reported earlier for tricyclazole as well as other pesticides in Japanese paddy water. Phong et al. (2008b) reported the half-lives in paddy water from 2.1 to 5 days for tricyclazole applied in the form of a spraying solution. Watanabe et al. (2007) reviewed some half-lives of common broadcast herbicides in Japan and found that most of them were in the range of 2–6 days. The longer half-life of tricyclazole in this study was also possibly due to the effect of the application method and that of the formulation.

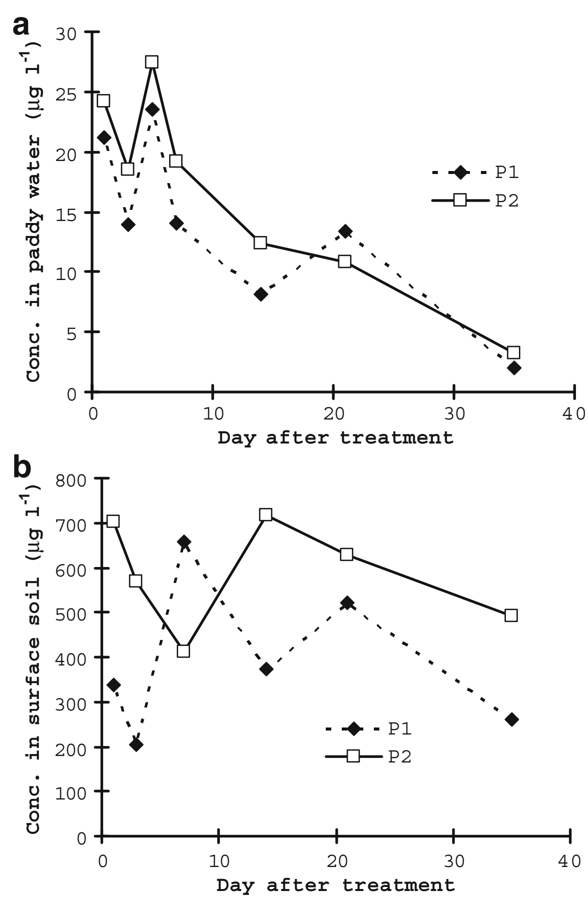

Fig. 4 Dissipation of tricyclazole in **a** paddy water and **b** surface soil

Table 2 Dissipation kinetics of tricyclazole and imidacloprid in paddy water and surface soil

	Tricyclazole		Imidacloprid[a]	
	Plot 1	Plot 2	Plot 1	Plot 2
Paddy water				
Equation	$y=-0.061x+3.15$	$y=-0.057x+3.34$	$y=-0.36x+4.04$	$y=-0.34x+4.15$
R^2	0.786	0.929	0.976	0.960
DT_{50}[b] (day)	11.4 (7.1, 28.6)	12.1 (9.2, 17.8)	1.9 (1.5, 2.7)	2.0 (1.5, 3.3)
Surface soil				
Equation	$y=-0.003x+6.40$	$y=-0.002x+5.92$	$y=-0.053x+5.37$	$y=-0.057x+5.51$
R^2	0.040	0.002	0.931	0.877
DT_{50}[b] (day)	407[c]	203[c]	12.9 (9.4, 20.8)	12.0 (8.0, 25.1)

[a] Dissipation of imidacloprid was calculated for the first 14 days

[b] Lower and upper 95% confidence intervals are provided in parentheses

[c] Confidence interval could not be determined

3.2.2 In Paddy Surface Soil

The concentrations of tricyclazole in the soil fluctuated around average values during the monitoring period. While the tricyclazole concentrations in paddy water were similar between the two plots, tricyclazole concentrations in the soil were significantly different (Fig. 4). Mean concentrations of tricyclazole were 392.4±169.5 and 587.5±119.7 μg/kg for P1 and P2, respectively. Linear regression of the data gave almost horizontal lines with low correlation coefficients. A similar situation was also observed by Liu et al. (2008), in which tricyclazole did not decrease but fluctuated around the initial concentration during a 56-day monitoring period. For the dissipation of tricyclazole in paddy soil, longer monitoring period seems to be required for the accurate estimation of the DT_{50} values. However, for the relative comparison with other studies, estimation of the DT_{50} for tricyclazole in soil by the first-order kinetics was used in this study. The values were 408 days in P1 and 204 days in P2. In another report by Fernandes et al. (2006), the soil half-life for tricyclazole varied from 97 to 913 days, depending on the soil types—amended or unamended with organic compound. Another source (Vogue et al. 1994) cited a soil half-life of only 21 days for tricyclazole.

The ratios between the concentrations in water and the soil ranged from 16 to 58 days during the monitoring period, except for the high ratios of more than 130 at 35 DAT. The values of the earlier period were similar to the upper range of soil/water distribution coefficient of tricyclazole in Table 3. In this study, tricyclazole was more bound to the soil than in the sorption batch of experiments, thus reducing the risk of leaching to the surface and ground water. The phenomenon that the K_d of tricyclazole increased along the monitoring period was similar to that of other pesticides. Several researchers have reported the increase of K_d of pesticides over a period of time (aging effect; Mamy and Barriuso 2007; Louchart and Voltz 2007). This effect may contribute to the persistence of tricyclazole in soil in this study.

The masses of tricyclazole in water and surface soil at 1 DAT were calculated from tricyclazole concentrations in these compartments. Tricyclazole masses in the paddy water compartment in P1 and P2 were both 55 mg due to the similar concentration of tricyclazole

Table 3 Physicochemical properties of tricyclazole and imidacloprid (Tomlin 2003)

	Solubility in water (mg/l)	Octanol–water coefficient ($\log K_{ow}$)	Distribution coefficient (K_d)	Photolytic stability (DT_{50})
Tricyclazole	596	1.42	4–22	Stable
Imidacloprid	610	0.57	0.956–4.18[a]	5 h

[a] California DPR (2006)

in paddy water. Meanwhile, the masses in the 1-cm depth soil surface of P1 and P2 contained approximately 372 and 773 mg of tricyclazole, respectively. The total masses of tricyclazole in water and the 1-cm soil surface in the two plots at 1 DAT were equivalent to 12.4% and 23.7% of the initial applied mass in P1 and P2, respectively.

3.3 Fate and Transport of Imidacloprid

3.3.1 In Paddy Water

Dissipation curves for imidacloprid in paddy water are shown in Fig. 5. Imidacloprid dissipation in paddy water showed a clearer trend than that of tricyclazole. The insecticide reached the maximum concentrations of 58.6 and 73.9 μg/l at 1 DAT. Although having an application rate that is half of that of tricyclazole, initial concentrations of imidacloprid were approximately three times higher than those of tricyclazole. Imidacloprid dissipated quickly in paddy water. Imidacloprid concentrations decreased to less than 1 μg/l at 14 DAT and remained in this range of concentration until the end of the monitoring period. Sanchez-Bayo and Goka (2006) reported a much higher imidacloprid concentration of 240 μg/l at 2 h after transplanting with similar application rate. However, the concentrations of imidacloprid in the two studies became similar after 1 month at around 1 μg/l. Similar initial concentrations of imidacloprid, from 40 to 90 μg/l, were reported by Kanrar et al. (2006) for broadcast formulation. However, the application rates for broadcast product were two to five times lower than that of the nursery-box application.

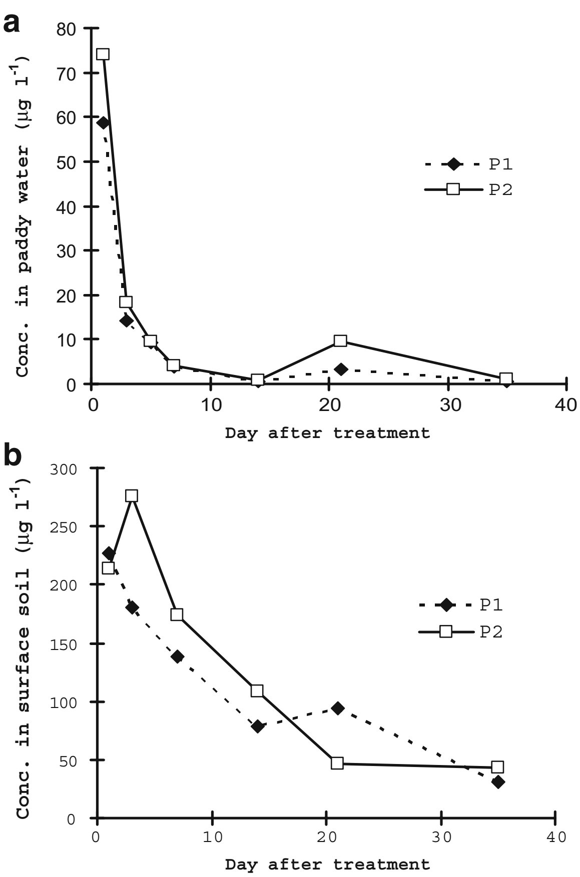

Fig. 5 Dissipation of imidacloprid in **a** paddy water and **b** surface soil

Imidacloprid dissipated in paddy water following a first-order kinetics process in both the plots ($p<0.01$) during the first 14 days of the monitoring period. During this period, the DT_{50} values of imidacloprid were determined as 1.9 and 2.0 days for P1 and P2, respectively (Table 2). The short half-lives of imidacloprid in paddy water determined in this study were in agreement with other researches reported earlier. Sanchez-Bayo and Goka (2006) calculated a field half-life of 4 days for imidacloprid in water for the first month after transplanting, while Kanrar et al. (2006) reported aquatic half-lives from 1.55 to 2.78 days for imidacloprid applied in the form of broadcasting granule in Indian paddies. In China, Wu et al. (2004) found similar half-life values of 2.6–2.7 days for imidacloprid in paddy water. Imidacloprid persists in water without light for a long period (DT_{50}=39 days; Sarkar et al. 1999), whereas it is very sensitive to photolysis. Photolytic half-lives of imidacloprid range from only 43 min in HPLC grade water to 144 min in tap water with the presence of TiO_2 (Wamhoff and Schneider 1999). Sarkar et al. (1999) also reported a significant influence of pH and type of formulation to the persistence of imidacloprid in water.

3.3.2 In Paddy Surface Soil

Again, the evolution of imidacloprid concentrations in the paddy soil was different from that of tricyclazole. Concentrations were at a maximum within 3 DAT, being 227.2 and 276.2 μg/kg for P1 and P2, respectively (Fig. 5). Imidacloprid gradually dissipated in paddy soil in both the plots and reached 30.9 and 43.3 μg/kg at 35 DAT in P1 and P2, respectively. In another study, Sanchez-Bayo and Goka (2006) reported lower and more stable concentrations of imidacloprid in paddy soil (13±9 μg/kg) throughout the 118-day experiment. The soil concentrations of imidacloprid were not significantly different between the two plots.

Linear regression of the data set earned lines with high correlation coefficients (Table 2). The half-lives of imidacloprid in paddy soil were determined as 12.9 and 12.1 days for P1 and P2, respectively. These values are comparable with those provided by Wu et al. (2004) where soil half-lives of imidacloprid in Chinese paddies varied from 12.1 to 24.1 days. In Indian paddies, Kanrar et al. (2006) reported soil half-lives of imidacloprid from 8.36 to 12.54 days. However, an estimation of soil half-life from concentrations of imidacloprid in paddy soil obtained by Sanchez-Bayo and Goka (2006) seemed to result in a longer value. Other field studies also show that imidacloprid can persist in soil, with a half-life ranging from 27 to 229 days, depending on the field condition (CDPR 2006). The main degradation route of imidacloprid in soil is also photolysis. In the absence of light, the longest half-life of imidacloprid is 229 days (CDPR 2006). This persistence in soil makes imidacloprid suitable for seed treatment because it allows continual availability for root uptake (CDPR 2006).

Maximum amounts of imidacloprid recovered from paddy water were 211 and 266 mg in P1 and P2 at 1 DAT, respectively. The corresponding amounts of imidacloprid in surface soils in P1 and P2 were 250 and 235 mg, respectively. The total mass of imidacloprid recovered from paddy water and 1-cm paddy surface soil for 1 DAT was 25.6% and 27.8% of the applied mass for P1 and P2, respectively.

The ratios between the imidacloprid concentrations in water and the soil in two plots ranged from about 2.9 at 1 DAT to 47.6 at the end of monitoring period, except for the extreme values of 178.9 and 158.3 in P1 and P2 at 14 DAT. Only the values of 1 DAT fell in the range of K_d reported in the literature (Table 3). Similar to the case of tricyclazole, the K_d of imidacloprid strongly increased along the monitoring period. The increase of K_d value over time of imidacloprid was reported earlier (Cox et al. 1997; Oi 1999), but with a smaller magnitude. However, Louchart and Voltz (2007) reported a similar strong effect of aging on the adsorption of pesticides in which the K_d values of three herbicides increased from 30 to 164 times of those similar to that found in the literature. This characteristic made the pesticide less available for runoff and leaching. The results also suggest the low leaching potential of imidacloprid in the field, despite its high water solubility.

3.4 Water Management and Pesticide Runoff from Paddy Field

The effectiveness of water holding and EWSD practices in Japanese paddy fields have been discussed earlier (Phong et al. 2006, 2008c; Watanabe et al. 2007). In this study, the water was held inside the paddy field by applying an intermittent irrigation scheme and a EWSD of more than 2 cm during the monitoring period. These practices were effective in preventing overflow except on one occasion when there was a rainfall of 6.3 cm at 14 DAT. However, the amount of pesticide runoff in this rainfall event was small compared to other data reported in the literature, especially when tricyclazole and imidacloprid are relatively soluble (Table 3). P1 with 2.4 cm of water overflow lost 0.5% of the applied mass of tricyclazole and 0.05% of the applied mass of imidacloprid. Meanwhile, P2 with 2.9 cm of water overflow lost 0.9% and 0.1% of the applied mass of tricyclazole and imidacloprid, respectively. This is likely because pesticide concentrations in paddy water were already low at 14 DAT when the pesticide runoff occurred. In earlier studies, the greatest runoff losses of pesticides with similar solubility like molinate and simetryn were 40.5% and 60.4% under continuous irrigation scheme (Inao et al. 2001). More moderate losses of simetryn from 0.21% to 18.07% were reported for paddy plots applying the intermittent irrigation and EWSD practices (Phong et al. 2008c). The lowest loss of 0.21% of the applied mass of simetryn was from a plot with a similar setup as in this study. These results again indicate the necessity of applying water management practices to reduce the risk of pesticide runoff to the environment.

3.5 Physicochemical Properties, Formulation, and Environmental Fate

Basic physicochemical properties of tricyclazole and imidacloprid are presented in Table 3. With similar solubility but different K_d, the two compounds behaved differently in this study. The peak concentration value of each compound correlates with their K_d rather than with the solubility. Although tricyclazole has an application rate which is two times higher than that of imidacloprid, the highest tricyclazole concentration in the paddy water was only about a third of that of imidacloprid. Considering that both chemicals were ~2.5 cm below the soil surface when transplantation took place, there was significant potential for interaction with soil before either of the chemicals could diffuse into the bulk paddy water. Thus, the K_d was reasonably having more effect on pesticide concentrations in paddy water than the solubility.

The two pesticides expressed different K_d values at the early period of the experiment, as shown in Sections 3.2 and 3.3. The K_d values of both pesticides also increased during the monitoring. Maximum values were 10 and 16 times higher than those reported in the literature for tricyclazole and imidacloprid, respectively. Calculated K_{oc} of both compounds were also much greater than those reported in the literature. Although K_d may be a good indicator for pesticide fate and transport in the field, the variation of K_d for each pesticide poses a practical problem in using this indicator for predicting its fate and transport. In this study, different properties rather than soil organic matter may have influenced the soil/water partitioning of these chemicals.

One important property affecting the fate of the pesticides in this study was probably the sensitivity of these pesticides to sunlight. Since imidacloprid is very sensitive to photolysis while tricyclazole is not (Table 3), the determined half-lives of imidacloprid were much shorter than those of tricyclazole (Table 2). This is because both were exposed to direct sunlight in paddy water as well as in paddy surface soil (0–1 cm depth).

Another factor that could greatly affect the fate and transport of tricyclazole and imidacloprid in this study is the formulation. The recovery of less than 30% of the applied mass for both pesticides in the area around the rice plant indicated that the nursery-box-applied formulation helped to embed the pesticides into the paddy soil near the root zone so that the pesticides could be easily absorbed by the rice plant. This process may also reduce the effect of environmental factor on the dissipation of pesticides, such as sunlight-mediated photodegradation. This type of formulation could increase the half-life of the pesticide, and in fact the half-life of tricyclazole was observed longer in this study than in other studies with spray formulation.

The environmental friendly property of the nursery-box formulation was clearer when the results of this study are compared to those of other application methods in earlier studies as discussed in Sections 3.2 and 3.3. Concentrations of tricyclazole and imidacloprid produced by the nursery-box formulation were lower than those produced by broadcast formulation (for imidacloprid; Kanrar et al. 2006) or spray formulation (for tricyclazole; Phong et al. 2008a, b) for a similar application rate. Only about 2% of applied tricyclazole was found in paddy water at 1 DAT in this study, while from 10% to 25% of applied tricyclazole was found in the water of rice lysimeters 1 day after spraying (Phong et al. 2008a, b). However, more research is needed to compare this nursery-box-applied formulation with the popular broadcast granules used in other rice-cultivating countries.

4 Conclusions

The fate and transport of tricyclazole and imidacloprid in paddy fields after nursery-box application was investigated in this study. Tricyclazole dissipated at a lower rate than imidacloprid both in paddy water and paddy surface soil due to the sensitivity of imidacloprid to photodegradation. The results were supported by the high reproducibility between data of the two plots in this study, except the case of tricyclazole dissipation in soil. The application of the water holding and EWSD management practices resulted in reduced pesticide runoff with less than 1% of tricyclazole and 0.1% of imidacloprid lost from the plots upon significant rainfall events. The nursery-box-applied formulation has the potential to reduce the risk of rice pesticide to the environment by relatively reducing the concentration of pesticide in paddy water. However, further investigation is required to understand the effect of the formulation to the pesticide fate and transport.

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