

Modeling the Fate and Transport of Pesticide in an Irrigated Rice Area

Samuel R. Simon and Ireneo C. Agulto

Abstract— For fast, effective, economical assessment and continuous monitoring of level of concentration of pesticide in water, development and use of a model play a very important role. This study aimed to assess the extent of pesticide contamination of water and develop a model that can be used to determine the fate and transport of pesticide in irrigated rice area. The computer program developed simulates the concentration of pesticide residue in the ponded and drainage water by mathematically tracking total mass of chemical residues from the loading point to the drainage stream in terms of mass balance. Correlation analysis and test of significance reveals that the model can accurately simulate the actual pesticide concentration in an irrigated rice field. Enhancement of the model by taking into consideration the advection process in the drainage stream and linking of the model to other available models is recommended.

Keywords—fate and transport of pesticide, irrigated rice area, insecticide concentration, modeling.

I. INTRODUCTION

RICE culture presents a distinctive problem with respect to pesticide run-off because of high seasonal rainfall, water management practices, and proximity of cropland to surface-water bodies typical of rice-growing areas^[1]. In the Philippines, rice production can be considered major contributor to pesticide contamination of the environment. It is a common practice of draining water from treated paddy fields into irrigation canals 2-3 weeks before rice is harvested. Runoff allows lateral movement of chemicals away from the rice field when it is deliberately drained, or when excess rainfall and irrigation water flow causes the field bunds to overflow. In a rice irrigation system, all runoff from rice fields is collected in the main drainage system. This ultimately discharges the effluent into water bodies such as river, lake, or the sea^[2]. Many of river and canal systems in the Philippines received inputs of potentially contaminated wastewaters either from point sources and/or diffuse run-off from agricultural land^[3]. Moreover, 37% of total water pollution originates from agricultural practices, which include animal wastes and fertilizer and pesticide runoffs^[4].

In the Philippines, assessment and monitoring of the level of pesticide contamination of bodies of surface water near rice production areas are seldom done because they are complex and cumbersome and water analysis is expensive. The absence

of model that uses local data that can accurately simulate the level of contamination by pesticide in paddy and runoff water from irrigated rice areas append further to the problem. The study aimed to assess the extent of pesticide contamination of water in the paddy field and drainage channel and develop a model that can be used to determine the fate and transport of pesticide in an irrigated rice area.

II. METHODOLOGY

Present agriculture system which involves the utilization of high yielding varieties, especially in rice farming, promotes the reliance on agrochemicals, both fertilizers and pesticides to ensure high yield and income. Farmers nowadays are constrained to use pesticides such as herbicides, to control weeds; molluscicides to eradicate snails; and insecticides, fungicides, nematocides and rodenticides for specific applications. However, according to numerous studies, the heavy use of pesticide has negative effect on the human health and the environment.

The seemingly becoming limited water resources like bodies of surface water near agricultural production areas are contaminated by run-off water carrying pesticide residues from the paddy system and groundwater is also affected to some extent due to the leaching of pesticides applied in the paddy field. In the light of these negative impacts of indiscriminate use of pesticides, the need to monitor and assess the level of concentration of pesticide in a paddy field becomes imperative. Moreover, considering the complexity and high costs of monitoring and assessment, the need for a model to be used for predicting pesticide concentration both in the ponded and drainage water for simplicity and reduced cost of monitoring is essential. Results of such assessment and monitoring can be very useful information in crafting production and management practices in order to minimize the negative effects of using pesticides. Moreover, proper authorities will also be guided on the formulation of appropriate programs to implement for reduced monitoring costs and for effective control strategies of its harmful effects to society and environment.

Three (3) 144 sq. m. paddy plots planted with MS 16 variety of rice were used. A standard 8-inch rainfall gauge was installed in the area to measure daily rainfall depths. The experiment was setup such that the entry and exit of water were fully controlled. Paddy dikes were constructed in such a manner that no amount of water enters the paddy field from sources other than rainfall and the intended irrigation and unintentional drainage and leakage as well. The field was irrigated using water pumps with groundwater as the source.

Samuel R. Simon is with the Isabela State University – Cabagan Campus, Cabagan, 3328, Isabela, Philippines (corresponding author's e-mail: bongstream@yahoo.com).

Ireneo C. Agulto is with Central Luzon State University, Science City of Muñoz, Nueva Ecija, Philippines (e-mail: ireneoagulto@yahoo.com).

The experimental plots were sprayed at zero day with Lambda cyhalothrin at the rate of 24.8 µg/L and were utilized for the collection of water samples for pesticide concentration analysis. A drainage channel was constructed and used for the collection of drainage water sample. Water sampling from the paddy field was done following standard protocol at 0, 1, 2, 3, 5, 7 and 14 days after the initial pesticide application. Paddy plots were intentionally drained on the same days and water samples from the drainage channel were collected for pesticide residue concentration analysis. The water samples were analyze at the National Pesticide Analytical Laboratory using as liquid chromatography method. Data on pesticide concentrations collected from plots and drainage channel were used to calibrate and test the accurateness of the concentration as simulated by the model that was developed.

A. Model Development

Based on the data gathered from the field and using the physico-chemical properties of the pesticide, a software was developed that can simulate the time and spatial concentration of pesticide in the drainage water from a paddy system by tracking mathematically the total mass of chemical residue in the loading point to the drainage channel in terms of mass balance.

The model herein developed is generally based on the theory as shown in Fig.1.

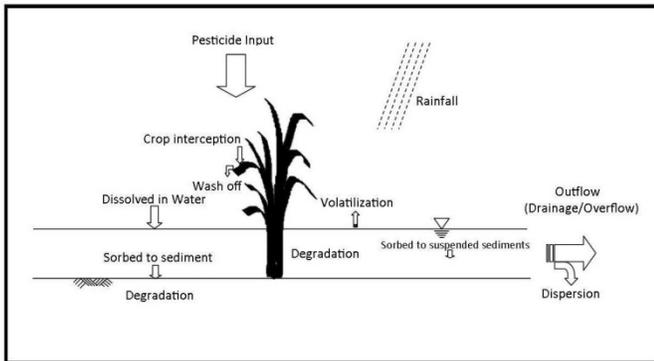


Fig. 1 Fate and transport of pesticide from the paddy field to the drainage channel

B. Equations

The following equations were used in the various parameters involved in the fate and transport of pesticides:

1. Pesticide Concentration in Water

$$M_w = F_{DW} * PI_{cnet} \tag{1}$$

where: M_w - concentration of pesticide in the water (µg/m³)

$$F_{DW} = \frac{1}{1 + K_d C_{SS}} \tag{2}$$

F_{DW} - fraction of chemical mass in dissolved phase^[5]
 K_d - water-sediment partition coefficient, mg/m³.

C_{SS} - concentration of suspended sediment, mg/m³

$$PI_{cnet} = PIC - (PIC * r) \tag{3}$$

PI_{cnet} - net pesticide concentration input, mg/m³
 PI_c - pesticide concentration input
 r - leaf-surface area ratio (%).

2. Pesticide Degradation

$$M_{Wdeg} = M_w \left(1 - e^{-\left(\frac{0.693 * dt}{PHLW}\right)} \right) \tag{4}$$

where: M_{Wdeg} - pesticide degradation in water represented by first-order decay, mg/day
 $PHLW$ - pesticide half-life in water, days
 dt - elapsed time since the initial application of pesticide, days

3. Pesticide Volatilization

$$M_{volat} = \left(k_{volat} \frac{F_{DW} M_w}{D_w} \right) dt \tag{5}$$

where: M_{volat} - pesticide volatilization in water^[5]
 k_{volat} - rate of volatilization, µg/day
 D_w - depth of water in the channel, m
 dt - elapsed time since the initial application of pesticide, days

4. Pesticide Sorbed to Bed Sediment

$$M_{bed} = (K_d * F_{DW} * M_w * k_{bed} * \rho_b * SA) \tag{6}$$

where: M_{bed} - direct partitioning of dissolved residues in the water column to bed sediment, mg^[5]
 k_{bed} - coefficient relating bed-water column and bed sediment mixing/contact time
 ρ_b - bulk density of sediment, g/cc
 SA - surface area of the tributary, m²

5. Pesticide Concentration in Water after Degradation, Volatilization and Sorbtion to Bed Sediment

$$C_w = M_w - (M_{Wdeg} + M_{volat} + M_{bed}) \tag{7}$$

6. Pesticide Sorbed to Sediment

$$M_s = F_{PW} * PI_{cnet} \tag{8}$$

where: $F_{PW} = \frac{K_d C_{SS}}{1 + K_d C_{SS}} \tag{9}$

F_{PW} - fraction of chemical mass sorbed to suspended sediments^[5]

7. Pesticide Degradation in Sediment

$$M_{Sdeg} = M_S \left(1 - e^{-\left(0.693 \frac{dt}{PHLs}\right)} \right) \quad (10)$$

where: PHLs is the pesticide half-life in soil, days

8. Pesticide Concentration in Sediment after Degradation

$$C_s = M_S - M_{Sdeg} - M_{Ssetl} \quad (11)$$

where: $M_{Ssetl} = \left(K_{setl} \frac{FPW * M_S}{Dw} \right) dt \quad (12)$

M_{Ssetl} - chemical adsorbed to suspended sediments but allowed to settle, mg/m³[5]

K_{setl} - settling velocity coefficient directly dependent on the settling velocity of sediment.

dt - elapsed time since the initial application of pesticide, days

9. Pesticide Concentration in Drainage Stream

$$C_{DW} = (C_W + C_S) * DC \quad (13)$$

where: DC is the dispersion coefficient

III. RESULT AND DISCUSSIONS

A. The Computer Program

The Pesticide Transport Program was developed to simulate the fate and transport of pesticides in the paddy water and drainage stream of an irrigated area. It addresses predominant dissipation pathways while maintaining minimal input requirements for user comfort. The model considers different transformation processes of the pesticide applied in the paddy field and simultaneously tracks the mass balance of the chemical in the water column and benthic sediments. Basic input data needed are the rate of pesticide application, physico-chemical properties of pesticide as well as characteristics of the drainage channel. Output of the program is the daily pesticide concentration in the paddy field and at different lengths of the drainage channel.

Computer system requirements for the model are modest. The Delphi 10 program language was used in the computer program development and it could perfectly run in any computer with any Windows version with very minimal RAM space requirement (less than 3MB). Figs. 2, 3, and 4 show sample interfaces of the computer program.

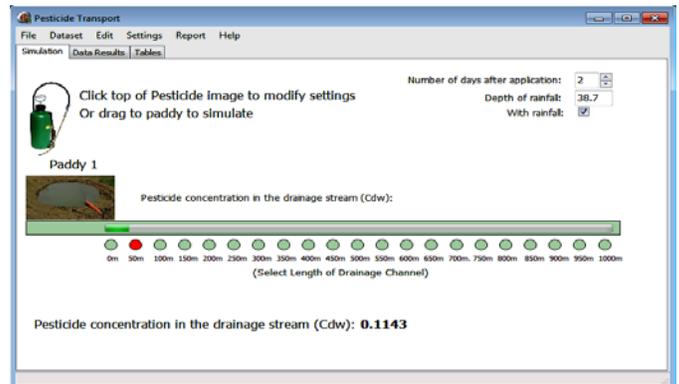


Fig. 2 Sample interface of the computer program

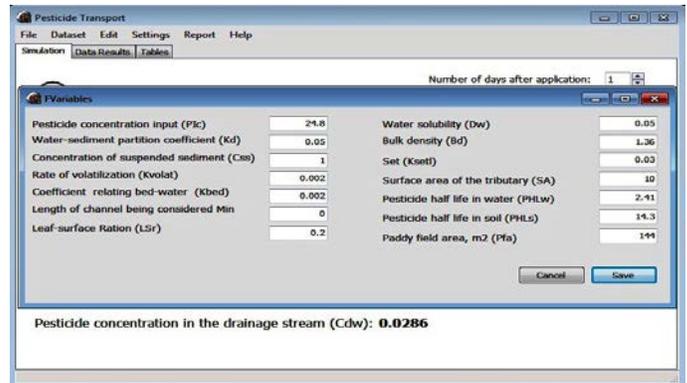


Fig. 3 Sample interface of the computer program

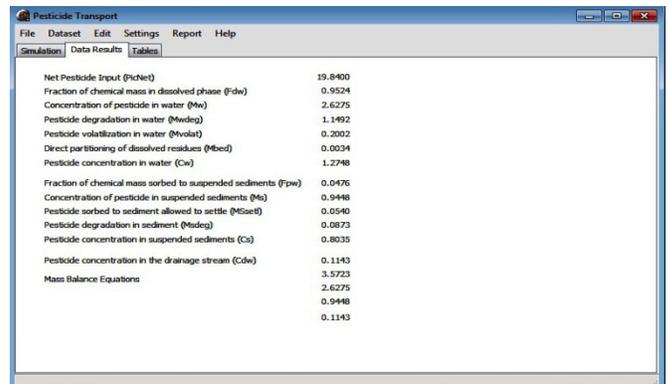


Fig. 4 Sample interface of the computer program

The model was calibrated and tested by comparing simulated data with the data collected on pesticide concentration both in the paddy and drainage water from the experimental plots.

As revealed in Fig. 5, which is the graphical presentation of the observed and simulated pesticide concentrations over time, there exists a non-linear decreasing trend of actual and simulated data of pesticide concentration. Correlation analysis of the data showed that there is a very high positive degree of correlation ($r=0.98$) between the two sets of data. Moreover, test of significance ($t_{comp}=0.2477$) also showed that there is no significant difference between the two sets of data at 5% level of significance. This indicates that the model developed can accurately simulate pesticide concentration in the paddy water over time

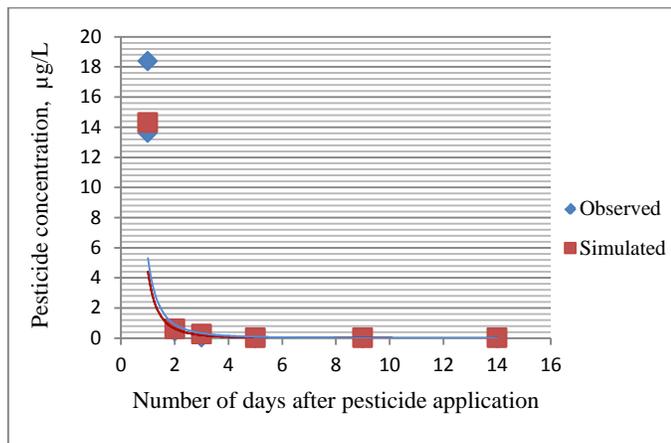


Fig. 5 Daily observed and predicted pesticide concentration

Furthermore, as shown in Fig. 6 (observed and simulated pesticide concentration over distance in the drainage channel), there is also a decreasing non-linear trend in observed and simulated pesticide concentration data over distances in the drainage channel. Correlation coefficient, $r = 0.98$, explains that there is a very high positive relationship between the two sets of data and the test of significance ($t_{\text{comp}} = 0.1464$) at 5% level of significance also proved that there is no significant difference between the two sets of data. This means that the model can correctly simulate actual field data in terms of pesticide concentration at different distances in the drainage channel.

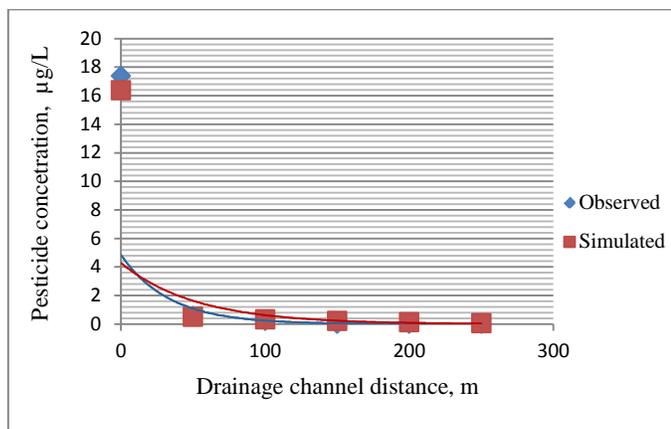


Fig. 6 Observed and simulated pesticide concentration in the drainage stream

ACKNOWLEDGMENT

The authors are very grateful to the Engineering Research and Technology (ERDT) Consortium, the Central Luzon State University and Isabela State University for all the logistic support and the National Analytical Pesticide Laboratory of the Bureau of Plant Industry for the analysis of water samples.

REFERENCES

- [1] W. Williams, A. Ritter, C. Zdinak and S. Cheplick. *User Manual and Program Documentation. RICEWQ: Pesticide runoff model for rice crops*. Waterborne Environmental, Inc. 897-B Harrison Street, S. E. Lessburg, VA 201765. 2008.

- [2] L. Varca *Impacts of agrochemicals on soil and water quality. Pesticide toxicology and chemistry laboratory*. National Crop Protection Center. UPLB, College, Laguna, Philippines. 1995.
- [3] Greenpeace. *Status of water resources in the Philippines*. Greenpeace Southeast Asia 24 K-J corner K-7 Streets, East Kamias, Quezon City, Philippines. October 2007.
- [4] National Economic and Development Authority (NEDA). *Medium Term Philippine Development Plan*. Chapter 3 Environment and Natural Resources. 2004.
- [5] W. Williams, A. Ritter, C. Zdinak and S. Cheplick. *User Manual and Program Documentation. RIVWQ: Chemical transport model for riverine environments*. Waterborne Environmental, Inc. 897-B Harrison Street, S. E. Lessburg, VA 201765. May 2004.

Samuel R. Simon was born in Ilagan, Isabela, Philippines on March 10, 1968, a Licensed Agricultural Engineer and a Licensed Teacher. A graduate of Bachelor of Science in Agricultural Engineering in 1989, Master of Science in Mathematics Education in 2002, both in Isabela State University (ISU), and Doctor of Philosophy in Agricultural Engineering, major in Soil and Water Management, at the Central Luzon State University in Science City of Muñoz, Nueva Ecija, Philippines on 2012.

He rose from the rank of being an INSTRUCTOR in 1990 to being a PROFESSOR at the ISU, Cabagan, Isabela, Philippines. He was employed as a TRADE AND INDUSTRY DEVELOPMENT SPECIALISTS at the Department of Trade and Industry for 10 months in 1989 before becoming a faculty member of the ISU.

Dr. Simon is an active member of the Philippine Society of Agricultural Engineers, Philippine Association of Agriculturists and a Senior Accreditor of the Accrediting Agency for Chartered Colleges and Universities in the Philippines (AACUP). He is at present the Research Coordinator of the ISU Cabagan Campus and is very actively involved in the conduct and publication of numerous researches of the University.