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Study 263: Protocol to Model Pesticide Concentration and Mass Loading from Rice Paddy: Theoretical Considerations and Model Evaluation

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January 2010 (corrected October 2010)

1. Introduction

According to Crop Production 2008 Estimates by National Agricultural Statistics Service (USDA, 2008), California is the second largest U.S. rice-growing state with 519 thousand acres for rice production. About 90% of California rice is grown in the Sacramento Valley. Pesticides continue to be a critical and growing component of California rice technology. According to the Pesticide Use Report maintained by Department of Pesticide Regulation, statewide use of pesticides in rice fields was 1.9 million kg in 2008 (DPR, 2008). Pesticides regularly used in the Sacramento Valley for rice production include propanil, copper sulfate, and thiobencarb. Pesticide use has a potential to cause aquatic toxicity since flooded rice fields dominate the landscape of the Sacramento Valley and the agricultural drains in the rice-producing regions are tributaries of the Sacramento River. In late 1970s and early 1980s, fish kills have been reported in the Colusa Basin agricultural drains receiving rice culture discharge contaminated with thiocarbamate herbicides (SWRCB, 1990; Bennett et al., 1998). In 1983 an off taste in the municipal drinking water of the City of Sacramento was attributed to thiobencarb sulfoxide (Cornacchia et al., 1984).

As a result, monitoring program of pesticides from rice discharge water was developed since 1980. In 1990, the Central Valley Regional Water Quality Control Board set performance goals for pesticides used in rice production, as target concentrations not to be exceeded in water both in the agricultural drains and in drinking water sources. To meet the performance goals, Department of Pesticide Regulation instituted a variety of measures, primarily the holding of pesticides on fields or closed water system for sufficient degradation before water release. The compliance with performance goals is mainly verified by monitoring data from sampling sites located on major streams and water treatment plant intakes. Submitted monitoring data are usually associated with low resolutions in both space and time, and thus insufficient to characterize the spatial distribution and the main sources of pesticide residues. Therefore, mathematic models are needed to characterize effects of pesticide use, management practices, and environmental factors on pesticide fate and distribution. In addition, the regulatory burden has evolved currently to consider negative impacts of pesticides on aquatic organisms. Detailed information for pesticide residues, such as the magnitude, timing and frequency of peak concentrations, are required to examine the ecosystem exposure by the use of pesticides in rice paddies. While the monitoring data is usually not available for the required information, continuous modeling at field scale could provide reasonable estimates for a decision making process toward meeting regulatory requirements and improving management practices.

Rice pesticide modeling can be utilized to analyze the mechanisms of pesticide fate and transport processes, and evaluate management practices in controlling pesticide discharge from paddy fields. Successful simulation of rice pesticide fate and transport is based on accurate mathematical description of pesticide behaviors in various components and construction of the relational model that would adequately represent the governing processes in the rice field condition. Therefore, mathematic models are required to handle flood-related pesticide simulations such as pesticide volatilization, partitioning, degradation, and discharge. Currently, a number of simulation models for pesticides used in paddy rice production are available (as reviewed later in this protocol); however, only a few of them have been applied in California rice fields. Rice production in California presents a unique adaptation of rice culture to California's weather, land, and water conditions. Therefore, models developed and calibrated in other regions could not be directly applied to evaluate pesticide fate and transport in rice fields of California. In this study, popular models for rice pesticide simulation will be assessed theoretically and practically for their capability to simulate pesticide fate and distribution under California field conditions. The results of this study are anticipated to provide guidance for model selection and model improvement for use for registration purposes.

2. Objectives

This study is mainly designed to evaluate the capability and limitations of existing models in simulating pesticide fate and transport in rice paddies. Specific objectives include: [1] to review previous studies and determine the importance of each individual transport and transformation processes of rice pesticides; [2] to evaluate available calibration datasets, and provide recommendations for future monitoring studies; [3] to compare the model equations and algorithms of selected models for rice pesticides, and apply them to the field conditions of California rice culture; and [4] to identify model capability and limitations in simulating pesticide fate and transport, and recommend model(s) for further investigation and development for pesticide registration purposes in California.

3. Personnel

This study will be conducted by Environmental Scientist Yuzhou Luo under the supervision of Senior Environmental Scientist Sheryl Gill and the guidance of Research Scientists III: Bruce Johnson, Frank Spurlock, and John Troiano.

Questions concerning this protocol should be directed to project leader Yuzhou Luo at (916) 445-2090 or by email at yluo@cdpr.ca.gov.

4. Study Plan

4.1 Model Selection

Three rice models were selected for model evaluation (Table 1). PFAM (Pesticide in Flooded Agriculture Model) was developed by USEPA Office of Pesticides (USEPA, 2009). PFAM was designed specifically for use in a regulatory setting responding to the data available during a regulatory assessment. The model considered chemical transformation processes, i.e., hydrolysis, bacterial metabolism, photolysis, and sorption in two regions of littoral region and benthic region. Mathematic formulations are heavily borrowed from the USEPA EXAMS model (Burns, 2000). Changes of temperature, water levels, wind speed, etc and the resulting changes in degradation rates occur on a daily time step. A Windows-based GUI (graphic user interface) is also available.

Table 1. Summary of selected models in this study

Model	Institute	Notes
PFAM (Young, 2009)	USEPA	R&D release, FORTRAN program
PCPF (Watanabe and Takagi, 2000a, 2000b)	Tokyo University of Agriculture and Technology	VBA Macro
RICEWQ (Williams *et al.*, 2008)	Waterborne Environmental, Inc.	FORTRAN program

PCPF (Pesticide Concentration in Paddy Field) is a lumped-parameter model that simulates the fate and transport of pesticides in the two compartments of paddy water and paddy soil at daily time step. In addition to irrigation, precipitation, overflow/controlled drainage, and evapotranspiration, the model also considers water loss by lateral seepage and vertical percolation. The model program was coded using Visual Basic for Application in Microsoft Excel. A more detailed model description is documented by Watanabe and Takagi (2000a; 2000b)

RICEWQ (Rice Water Quality) was developed to evaluate the dissipation and runoff of agrochemicals from their use on aquatic crops. The latest version of RICEWQ (1.7.3) was released by Waterborne Environmental Inc. in 2008 (Williams et al., 2008). Major components of the model include water balance, pesticide application, crop growth, and water quality. Water quality algorithms were derived in part from the USDA SWRRBWQ model (Simulator for Water Resources in Rural Basins – Water Quality) (Arnold *et al.*, 1991). A Windows-based GUI is available but not all functions are implemented in the model.

4.2 Data Collection

Collection of data for model evaluation will continue through the entire project. Models will be applied to the 16 rice fields taken from 5 studies in Colusa and Glenn Counties (Table 2). Field conditions (such as rice paddy dimension, soil properties, and weather), management practices, and measured data are retrieved from digital or printed versions of the papers and reports. All data are reorganized into a uniform format, consistent with the general requirements of model data inputs. For example, dates for seeding and application are recorded by Julian days, while water management and sampling are labeled in a relative way of "days after application" (DAA). Formatted datasets would significantly facilitate future model parameterization and subsequent evaluation processes. Detailed data for field characteristics and pesticide measurements were provided in the Appendix.

Table 2. Summary of field experiments used for model comparison

Reference	Year	Area, ha	Pesticide
Study 1 (Ross and Sava, 1986)	1983	37	thiobencarb
	1983	41	molinate
Study 2 (Ross *et al.*, 1989)	1987	45	bentazon
	1987	33	bentazon
	1987	58	bentazon
Study 3 (Nicosia *et al.*, 1991a)	1988	24	carbofuran
	1988	34	carbofuran
	1988	32	carbofuran
Study 4 (Nicosia *et al.*, 1991b)	1989	24	bensulfuron methyl
	1989	16	bensulfuron methyl
	1989	17	bensulfuron methyl
Study 5 (Kollman *et al.*, 1992)	1991	15.1	methyl parathion
	1991	34.4	methyl parathion
	1991	41.8	methyl parathion
	1991	36.4	methyl parathion
	1991	28.3	methyl parathion

4.3 Model Evaluation

Model evaluation and comparison will involve two phases: theoretical comparison based on model descriptions, assumptions, and equations taken from literatures and practical evaluation by comparing model predictions to monitoring data in selected field conditions (Table 2).

In theoretical comparison, models will be compared by the following aspects:
[1] Input parameters and methods for parameter estimation
[2] Compartments, phases, processes, and mechanisms included in models
[3] Numerical methods for dynamic mass balance
[4] Adjustment of rate constants to environmental conditions (temperature, pH, radiation)
[5] Flexibility for pesticide-specific properties, e.g., slow release, biphasic degradation
[6] Flexibility for flood-related management, e.g., continuous flood, emergency release, weir height control, irrigation rate control, pre-flood pesticide application
[7] Availability of output variables

An integrated model environment is proposed to facilitate model application with case studies. All models in this study will be incorporated into this interface and driven by a single standard input dataset. Input data of landscape characteristics, weather condition, rice management, and pesticide application are taken from the literature of field experiments (Table 2). GIS-based spatial analysis is utilized to support model parameterization. For example, if soil property or daily weather data are not available in the literature, the data could be automatically retrieved from geo-referenced databases according to the field location. The model environment will include functions for model initialization, simulation, and sensitivity analysis.

The resultant model environment will be applied to the field data in Table 2. To generate useful information on water holding periods to meet the performance goals, the models are anticipated to provide reasonable estimation on peak concentration of pesticides in effluent flows. Therefore, model evaluation will focus on the magnitude and timing of predicted peak concentrations in comparison with measured data. Statistics for model performance will be reported for un-calibrated model predictions relative to measured data. Selected statistics include the Nash-Sutcliffe efficiency (NSE) and percent bias (PBIAS) for predicted and measured time series of pesticide concentrations, and/or loadings (Legates and McCabe, 1999; Moriasi *et al.*, 2007). Input uncertainty for landscape parameters and chemical properties will be collected from the literature. Table 3 shows an example of model input parameters applied for stochastic simulations. Sensitivity analysis will be performed based on Latin Hypercube Sampling and Monte Carlo simulations (Luo and Yang, 2007).

Table 3. Chemical properties and environmental parameters in sensitivity analysis

Parameter	Description	Unit
BD	Bulk density of bed sediment	g/cm3
DD	Depth of active sediment layer	cm
FOCDP	Organic carbon content in sediment	%
HENRYK	Henry’s law constant	Pa-m3/mol
KOC	Soil organic carbon normalized partition coefficient	L/kg
HLD	Half-life in saturated soil (sediment)	Day
HLHYDRO	Hydrolysis half-life in water (PH7)	Day
HLPHOTO	Aqueous near-surface photolysis half-life	Day
HLS	Half-life in unsaturated soil	Day
HLW	Metabolism half-life in water	Day
S	Solubility	mg/L
SEEP	Seepage rate	cm/ha/day
SS	Suspended sediment concentration	mg/L
TEMP	Average air temperature	K
VP	Vapor pressure	Pa
WIND	Average wind speed	m/s

5. Timeline and Expected Deliverables

02/10	03	04	05	06	07	08	09	10	11	12	01/11	2	3	4
[1]	▨	▨												
			[2]	▨	▨									
[3.1]	▨	▨				[3.2]	▨	▨						
									[4]	▨	▨			
												[5]	▨	▨

[1] Model collection and evaluation based on theoretical considerations. A report will be generated for comparison of model assumption, processes, mechanisms, and suggestions for potential model improvement.

[2] Interface development. A graphic user interface will be developed for rice pesticide models.
[3] Model application to the field condition of California rice culture, with [3.1] data collection and [3.2] model application to selected field scenarios. Report for model performance in case studies will be submitted.
[4] Sensitivity analysis to determine the key parameters and governing processes in rice pesticide fate and transport simulated by each model. Report for sensitivity analysis will be submitted.
[5] Final report preparation.

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Appendix. Field Characteristics and Measured Data

Data from Kollman et al. (1992)

Summary: Five fields in Colusa county and Glenn county with methyl parathion application in 1991

Field ID	Size (ha)	Soil	Seeding, Date (Julian)	Application, Date (Julian)	Management, Date (DAA), depth (mm)
1	15.1	Wekoda silty clay OC=1%	4/21 (111)	5/1 (121)	Depth=8.8-19.2 (14.7)
2	34.4	Wekoda silty clay OC=.5%	5/1 (121)	5/11 (131)	5/27 (16) drain Depth=4.3-9.0 (6.85)
3	41.8	Wekoda silty clay OC=1%	5/5 (125)	5/17 (137)	6/2 (16) drain 6/6 (20) flood Depth=3.9-13.8 (10.7)
4	36.4	Wekoda silty clay OC=1%	5/5 (125)	5/17 (137)	6/2 (16) drain 6/6 (20) flood Depth=3.3-11.8 (8.5)
5	28.3	Sunnyvale clay OC=1%	5/14 (134)	5/28 (148)	Soil incorporation 5/31 (3) flood to 9.5 6/1 (4) flood to 14.1 Depth=5.3-14.1 (9.3)

Notes:
Wekoda silty clay (Aquic Chromoxererts), 4% sand/ 51% silt/ 45% clay
Sunnyvale clay (Typic Calciaquoll), 14% sand/ 40% silt/ 47% clay
Application rate = 0.7 kg/ha for all fields
DAA="days after application"

Table 4. Measurements, Field 1

DAA	Water depth (cm)	Concentration (µg/L)		Mass (kg/ha)
		Mean	±Range	
2*	19.2	121.3	29.444	.2329
3	18.8	70.88	6.307	.13297
4	18.4	43.58	10.875	.08001
5	17.3	37.51	5.056	.06475
7	16.9	14.12	2.390	.02381
9	13.5	6.09	0.141	.0082
11	13.1	3.25	0.191	.00425
15	10.1	1.89	0.728	.0019
19	8.8	0.54	0.035	.00047
23	11.3	0.3	0.078	.00034

* Measurements for field 1 at 2 DAA are questionable and not used in the statistical analysis (Kollman et al., 1992).

Table 5. Measurements, Field 2

DAA	Water depth (cm)	Concentration (µg/L)		Mass (kg/ha)
		Mean	±Range	
2	9	162.1	0.141	.14602
3	8.6	86.29	4.073	.07428
4	8.1	37.42	1.138	.03064
5	6.9	18.28	.445	.01262
7	5.6	6.78	.226	.0038
9	7.8	7.14	.382	.00557
11	4.5	2.14	.332	.00096
15	4.3	.67	.042	.00029

Table 6. Measurements, Field 3

DAA	Water depth (cm)	Concentration (µg/L)		Mass (kg/ha)
		Mean	±Range	
2	13.8	204.1	14.284	.27969
3	13.3	80.11	31.24	.10580
4	12.9	36.84	18.717	.04719
5	13.2	14.89	10.239	.0152
7	12.0	2.18	1.089	.0026
9	10.1	.77	.403	.00077
11	9.5	.37	.156	.00035
15	7.3	.2	.035	.00014
23	3.9	.06	0	.00002

Table 7. Measurements, Field 4

DAA	Water depth (cm)	Concentration (µg/L)		Mass (kg/ha)
		Mean	±Range	
2	11.8	117.25	8.839	.14127
3	11.4	56.04	2.836	.06523
4	10.4	28.73	9.129	.03051
5	10.7	6.64	.94	.00725
7	8.8	.62	.141	.00056
9	6.1	.21	.021	.00013
11	7.1	.12	.021	.00009
15	3.3	.1	.007	.00003
23	6.8	<.05	0	<.00003

Comments by authors: even with same application and similar field conditions, the initial concentration and mass in field 3 is twice of those in 4. Therefore, a normalized concentration/mass by the initial ones would be used in model evaluation to reflect the differences in initial recovery and any other factors (check connectivity, hydrologic conditions, irrigation method, …) over fields.

Table 8. Measurements, Field 5

DAA	Water depth (cm)	Concentration (µg/L)		Mass (kg/ha)
		Mean	±Range	
3	9.5	66.43	8.04	.06354
4	14.1	44.53	11.738	.06321
5	12.6	21.73	2.213	.02757
7	11.1	4.04	.396	.00451
9	5.3	1.07	.424	.00057
11	8.2	.84	.226	.00069
15	7.3	.2	0	.00015
19	9.1	.25	.1354	.00023
23	6.8	<.05	0	<.00003

Data from Nicosia et al. (1990)

Summary: Three fields in Colusa county and Glenn county with soil-incorporated carbofuran application in 1988

Table 9. Field conditions

Field ID	Size (ha)	Soil	Seeding, Date (Julian)	Application, Date (Julian)	Management, Date (DAA), depth (mm)
1	24	[a] OC=2.4%	4/27 (118)	4/16 (107) 1.10 kg/ha 1.10 kg/ha	4/26 (10), flood Depth=11
2	34	[a] OC=2.2%	4/18 (109)	4/12 (103) 1.21 kg/ha 1.81 kg/ha	4/18 (6), flood 5/27 (45), drain 5/28 (46), flood Depth=15.1
3	32	[b] OC=2.8%	4/20 (111)	4/14 (105) .64 kg/ha .66 kg/ha	4/18 (4), flood 5/31 (47), drain 6/1 (48), flood Depth=18.3

[a] mix of Hiilgate clay (Typic Pelloxerert), and Myers clay (Entic Chromoxerert)
[b] Willows clay (Typic Pelloxerert)
First application rates are for the whole field, latter ones for the bottom paddy only
<u>Background concentration in soil = 0.02mg/kg</u>

Table 10. Measurements, Field 1 (water depth = 11 cm)

DAA	Water depth (cm)	Concentration (µg/L)		Mass (kg/ha)
		Mean	±Range	
10		4.239385		0.004663
23		4.730442		0.005203
36		15.95714		0.017553
37		12.81358		0.014095
38		11.44168		0.012586
39		14.09263		0.015502
42		6.245313		0.00687
43		2.806244		0.003087
44		2.168743		0.002386
45		3.893758		0.004283
46		2.623974		0.002886
47		2.600059		0.00286
49		2.89999		0.00319
50		1.603442		0.001764
51		0.482293		0.000531
52		0.500001		0.00055
53		0.477207		0.000525
54		0.787499		0.000866
55		0.400001		0.00044
56		0.4		0.00044
57		0.426041		0.000469
58		0.863541		0.00095
59		0.437499		0.000481
60		0.85476		0.00094
61		1.746881		0.001922
62		2.533337		0.002787
63		5.251031		0.005776
64		4.100059		0.00451
65		4.523196		0.004976
66		4.537515		0.004991
67		2.007293		0.002208
68		2.027087		0.00223
69		1.075001		0.001183
70		0.692709		0.000762
71		0.633333		0.000697
72		1		0.0011
73		0.983332		0.001082
74		0.600001		0.00066
75		0.600001		0.00066
76		0.599999		0.00066
77		0.594793		0.000654
78		0.500001		0.00055
79		0.499999		0.00055
80		0.500001		0.00055
81		0.791668		0.000871
82		1.000001		0.0011

Table 11. Measurements, Field 2 (water depth = 15.1 cm)

DAA	Water depth (cm)	Concentration (µg/L)		Mass (kg/ha)
		Mean	±Range	
6		12.02663		0.01816
7		7.327463		0.011064
8		7.927084		0.01197
9		6.665624		0.010065
10		7.510417		0.011341
11		6.575002		0.009928
12		5.287499		0.007984
13		4.215626		0.006366
14		4.205627		0.00635
15		4.782303		0.007221
16		5.700025		0.008607
29		15.65524		0.023639
30		21.57431		0.032577
31		28.03334		0.04233
32		26.95626		0.040704
33		15.23125		0.022999
36		6.053998		0.009142
37		4.601051		0.006948
38		2.416669		0.003649
39		3.021875		0.004563
40		2.487499		0.003756
41		2.128124		0.003213
42		1.587499		0.002397
43		1.440624		0.002175
44		1.200003		0.001812
45		1.199988		0.001812
48		4.259987		0.006433
49		1.313542		0.001983
50		1.35		0.002039
51		1.022916		0.001545
52		1.237502		0.001869
53		1.585419		0.002394
54		1.393751		0.002105
55		1.253128		0.001892
56		0.78125		0.00118
57		0.616666		0.000931
58		0.999998		0.00151
59		0.593748		0.000897
60		0.400002		0.000604
61		0.400002		0.000604
62		0.399999		0.000604
63		0.399997		0.000604
64		0.578129		0.000873
65		0.699999		0.001057
66		0.7		0.001057

Table 12. Continued- Measurements, Field 2 (water depth = 15.1 cm)

DAA	Water depth (cm)	Concentration (µg/L)		Mass (kg/ha)
		Mean	±Range	
67		1.166676		0.001762
68		1.499999		0.002265
69		1.5		0.002265
70		1.458331		0.002202
71		0.999996		0.00151
72		0.999996		0.00151
73		1		0.00151
74		1.220831		0.001843
75		1.399999		0.002114
76		1.400002		0.002114
77		1.404163		0.00212
78		1.599999		0.002416
79		1.599997		0.002416
80		1.600003		0.002416
81		1.600001		0.002416
82		1.558334		0.002353
83		0.600001		0.000906
84		0.600002		0.000906
85		0.600002		0.000906
86		0.600002		0.000906

Table 13. Measurements, Field 3 (water depth = 18.3 cm)

DAA	Water depth (cm)	Concentration (µg/L)		Mass (kg/ha)
		Mean	±Range	
5		22.80773		0.041738
6		16.675		0.030515
7		10.21055		0.018685
8		15.10625		0.027644
9		14.3		0.026169
10		7.913542		0.014482
11		9.273964		0.016971
12		7.611465		0.013929
13		5.506248		0.010076
14		6.351049		0.011622
15		7.000014		0.01281
34		7.300003		0.013359
35		5.766667		0.010553
36		6.110352		0.011182
37		6.777606		0.012403
38		7.056984		0.012914
39		5.050705		0.009243
40		5.831347		0.010671
41		4.265627		0.007806
42		3.38767		0.006199
43		2.616666		0.004788
44		2.42412		0.004436
45		1.20893		0.002212
46		2.226978		0.004075
47		2.900002		0.005307
50		3.300012		0.006039
51		2.138663		0.003914
52		1.098958		0.002011
53		0.986079		0.001805
54		0.8		0.001464
55		0.875		0.001601
56		1.54375		0.002825
57		0.718751		0.001315
58		1		0.00183

Data from Nicosia et al. (1991)

Summary: Three fields in Colusa county and Glenn county with Bensulfuron Methyl (BSM) application in 1989

Table 14. Field conditions

Field ID	Size (ha)	Soil	Seeding, Date (Julian)	Application, Date (Julian)	Management, Date (DAA), depth (mm)
1	24		4/22 (112)	5/2 (122)	Depth=13.2-18.8 (16) a
2	16		5/2 (122)	5/12 (132)	Depth=4.9-9.1 (7) a
3	17		5/6 (126)	5/16 (136)	Depth=8.25-13.75 (11) b

Application rate =0.07kg/ha

a. for fields 1 and 2, water depths at application are assumed to be max water depths (18.8 and 9.1 cm, respectively)

b. for field 3, range of max and min water depths is assumed to be 50% of average depth (11 cm)

Table 15. Measurements

(a) field 1

DAA	Water depth (cm) [a]	Concentration (µg/L) [a]		Mass (kg/ha) [b]
		Mean	±Range	
1 (5/3)				0.024
3				0.009
8				0.001

(b) field 2

DAA	Water depth (cm)	Concentration (µg/L)		Mass (kg/ha)
		Mean	±Range	
1 (5/13)				0.405
3				0.0162
8				0.0108

(c) field 3

DAA	Water depth (cm)	Concentration (µg/L)		Mass (kg/ha)
		Mean	±Range	
1 (5/17)				0.0576
3				0.0416
8				0.024

Notes:

a. water depth and concentration are not reported in Nicosia et al. (1991)

b. mass of BSM dissipation in paddy water was calculated based on the percentage in Figure 2 and calculated application rates (0.05, 0.09, and 0.08 kg/ha, for fields 1, 2, and 3, respectively) in Nicosia et al. (1991)

Data from Ross and Sava (1986)

Summary: Two fields in Glenn county with thiobencarb and molinate applications in 1983

Table 16. Field conditions

Field ID	Size (ha)	Soil [a]	Seeding, Date (Julian)	Application, Date (Julian)	Management, Date (DAA), depth (mm)
1	37	[a] OC=?%	5/21 (141)	5/30 (150) 4.48 kg/ha	Depth=21-31 (26) 6/7 (8),drained to 11-23 (17)
2	41	[a] OC=?%	5/27 (147)	6/1 (152) 4.48 kg/ha 6/6 (157) 3.14 kg/ha	Depth=12-24 (18) 6/21 (15) [b], drained completely 6/24 (18) [b], flood to 4-16 (10)

a. mix of Myers clay loam (Entic Chromoxerert)
b. Days after second application

Table 17. Measurements, Field 1

(a) water data

DAA	Water depth (cm)	Concentration (µg/L)		Mass (kg/ha)
		Mean	±Range	
0 (5/30)		79	43	0.23
2		567	222	1.543
4		576	181	1.482
6		515	130	1.218
8		367	120	0.766
16		56	35	0.074
32		8	5	0.013

(b) other data

DAA	Concentration, air (µg/m3)	Evaporative flux (ng/cm2/h)	Concentration, soil (µg/kg)	Concentration, vegetation (µg/kg)
0 (5/30)	1.4 (0.7)	37 (34)	3250 (2000)	78 (275)
1	0.9 (0.4)	8 (6)		
2	0.8 (0.3)	16 (9)	2880 (2490)	691 (429)
3	0.4 (0.1)	6 (4)		
4			3350 (3030)	1750 (2200)
6			3860 (2890)	1360 (1250)
8			2020 (1180)	1280 (1080)
16			2260 (1180)	796 (902)
32			2330 (2770)	169 (138)

DAA	Mass, air (kg/ha)	Mass, Soil (kg/ha)	Mass, vegetation (kg/ha)	
0 (5/30)	0.028	1.578	3.33e-4	
1	0.01			
2	0.019	1.435	5.80e-4	
3	0.007			
4		1.668	1.57e-4	
6		1.920	1.41e-4	
8		1.007	1.98e-4	
16		1.125	1.84e-4	
32		1.159	1.60e-4	

Table 18. Measurements, Field 2

(a) water data

DAA [a]	Water depth (cm)	Concentration (µg/L)		Mass (kg/ha)
		Mean	±Range	
-1		1880	767	
0 (6/6)		3430	420	6.136
2		2450	1500	4.150
4		1760	1300	2.946
8		646	239	0.771
16				
32		13	42	0.012

a. days after the second application

(b) other data

DAA	Concentration, air (µg/m3)	Evaporative flux (ng/cm2/h)	Concentration, soil (µg/kg)	Concentration, vegetation (µg/kg)
-1			1410 (657)	498 (213)
0 (6/6)	37 (34)	575 (64)	1450 (1210)	918 (580)
1	8 (6)	193 (55)		
2	16 (9)	110 (83)	1560 (875)	423 (309)
3	6 (4)	58 (36)		
4			1680 (1150)	380 (325)
8			2210 (1330)	177 (177)
16			1330 (1430)	295 (203)
32			656 (582)	21 (33)

DAA	Mass, air (kg/ha)	Mass, Soil (kg/ha)	Mass, vegetation (kg/ha)	
-1				
0 (6/6)	0.665	0.732	1.20 e-4	
1	0.224			
2	0.127	0.792	2.84 e-4	
3	0.050			
4		0.853	1.98 e-4	
8		1.120	2.64 e-4	
16		0.711	6.60 e-4	
32		0.332	2.59 e-4	

Data from Ross et al. (1989)
Summary: Two fields in Yuba, Glenn, and Butte counties with bentazon application in 1987

Table 19. Field conditions

Field ID	Size (ha)	Soil	Seeding, Date (Julian)	Application, Date (Julian)	Management, Date (DAA), depth (mm) [a]
1	45	Canejo loam (Pachic Haploxerolls) OC=?%	4/19 (109)	5/27 (147) 1.12 kg/ha	Drained before application 5/31 (4) ~6/3 (7). flood Depth=2.25~3.75 (3)
2	33	Myers clay loam (Entic Chromoxerets) OC=?%	4/20 (110)	5/28 (148) 1.12 kg/ha	Drained before application 6/1 (4) ~6/4 (7). flood Depth=2.25~3.75 (3)
3	58	Clay OC=?%	4/30 (120)	6/12 (163) 1.12 kg/ha	Drained before application 6/16 (4) ~6/19 (7). flood Depth=2.25~3.75 (3)

a. range of max and min water depths is assumed to be 50% of average depth

Table 20. Measurements

(a) Field 1

DAA	Water depth (cm)	Concentration (µg/L)		Mass (kg/ha)
		Mean	±Range	
0	0.370165	1524.359	513.1601	0.047183
1	0.183747	1799.441	115.4701	0.025563
2	3.616379	365.8548	500.8326	0.061397
3	4.608909	196.7887	470.8857	0.04523
4	3.711744	79.1791	116.6726	0.021121
5	5.638587	55.10526	45.07771	0.022851
6	4.723197	113.5	109.0245	0.047742
7	5.053031	111.0256	76.86352	0.051548
8	8.142683	121.7333	81.85353	0.07246
10	7.024651	50.40994	49.16045	0.032206
12	10.98648	50.05492	59.11404	0.048466
16	12.88282	25.17401	20.6207	0.027671
32	13.13626	17.16667	12.37437	0.020981
har	18.26363	ND	ND	ND

(b) Field 2

DAA	Water depth (cm)	Concentration (µg/L)		Mass (kg/ha)
		Mean	±Range	
0	0.3729	1327.059	152.7525	0.04642
1	0.317776	1411.765	212.132	0.030968
2	3.573367	196.1111	626.2683	0.031959
3	5.415114	298.9182	373.1398	0.084374
4	6.513019	242.1007	263.5077	0.148449
5	10.85866	159.3103	169.2139	0.152099
6	15.16991	75.94972	96.20203	0.111893
7	15.36378	103.5	143.0682	0.153333
8	14.92485	92.88889	129.2685	0.137613
10	15.18999	62.83152	93.97368	0.095152
12	16.75241	65.67568	111.4038	0.11
16	17.85667	65.07442	81.38968	0.115152
32	15.72146	26.55236	37.89487	0.041741
har	22.4149	1.409	1.732412	ND

(c) Field 3

DAA	Water depth (cm)	Concentration (μg/L)		Mass (kg/ha)
		Mean	±Range	
0	NA	NA	NA	NA
1	NA	NA	NA	NA
2	4.746343	296.0494	301.7173	0.126878
3	8.869315	131.7452	171.6081	0.109439
4	11.10674	50.77438	63.99573	0.054535
5	9.493943	54.48315	45.74203	0.051312
6	10.83437	42.39602	25.71874	0.045088
7	11.83386	68.27761	40.05625	0.072613
8	11.03753	24.67539	13.45561	0.024937
10	10.04432	47.5918	39.03498	0.046081
12	8.993049	32.4994	25.33009	0.028716
16	8.526221	21.85229	14.80721	0.01769
32	21.8035	2.405542	1.167619	0.005053
har	9.826974	0.694828	0.377492	ND

Average water depth, concentration, and mass are based on the average values at the three measured paddies in each field. If only two paddies are measured in a specific day, average will be based on those two measurements. If less than two paddies are measured, NA is provided.