Effects of pesticides on soil and water microflora and mesofauna in wetland ricefields: A summary of current knowlege and extrapolation to temperate environments

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Summary

This review summarizes information on the behavior of pesticides and their impacts on micro-organisms and non target invertebrates, that was collected in or is applicable to temperate wetland ricefields. An extensive bibliographic survey shows that current knowledge is fragmentary and partly outdated. Pesticides applied on soil at recommended levels rarely had a detrimental effect on microbial populations or their activities. They affected more invertebrate populations than the microflora, inducing the blooming of individual species of floodwater zooplankton and reducing populations of aquatic oligochaetes in soil. Available information raises concerns regarding the long term effects of pesticides on (1) microorganisms, primary producers, and invertebrates of importance to soil fertility, (2) predators of rice pests and vectors, and (3) microbial metabolism of pestides.

Introduction

Modern technologies, which utilize optimum management practices, fertilizer-responsive varieties, fertilizers, and pesticides, have tremendously increased wetland rice yield but have markedly modified traditional rice-growing environments. There is indirect evidence that crop intensification has decreased species diversity in ricefields (Roger *et al.* 1991), but the other possible long- and short-term environmental impacts are far from being fully assessed. The greatest pressure exerted on the microbial, faunal, and floral communities of ricefields is due to fertilizer and pesticide use. Both have significant impacts on population composition and dynamics. Therefore, it is important to understand and predict how agrochemicals, especially pesticides, may affect soil fertility through their effects on microflora and the populations of invertebrates responsible for recycling and translocating nutrients. There is also a concern about the enhanced use of pesticides that might cause (1) environmental hazards, (2) biological imbalance in ricefield populations, and (3) a reduced efficiency because of shifts toward soil microorganisms more efficient in pesticide degradation.

We recently summarized (1) the result of a biblographic survey of the environmental impacts of pesticide use in ricefields and (2) studies in experimental plots and field surveys to assess long term impacts of pesticides, conducted by the authors in the Philippines (Roger *et al.* 1995). Computerized databases were established and quantitative data on the effects on ricefield microflora were tabulated and analyzed. This paper utilizes the above information for assessing or extrapolating pesticide impacts on soil microflora and aquatic invertebrates in temperate rice environments.

Table 1. Methods used for quantitative studies of pesticide in ricefields.

Type of experimental design	Number of reports		
	Fate	Algological studies	Bacteriological studies
Cultures of microorganisms	0	130	2
Cultures of microorganisms with soil	1	6	0
Soil in test tubes or beakers	40	0	24
Pot experiments	8	3	21
Microcosms	6	0	0
Field experiments	8	10	14
Method not available	0	0	10
Total	**63**	**149**	**71**

Early studies of the fate of pesticides in soils have dealt mostly with temperate uplands. During the 1970's, interest in ricefields developed (Sethunathan and Siddarammappa 1978) with about 100 papers published. The number fell to about 50 in the 1980's. Since 1990 very few studies have delt with ricefields. Most information on pesticide fate in ricefields arises from experiments with 20-100g unplanted soil (Table 1), which underestimate degradation because of the absence of rhizospheric effects and variations of environmental conditions (light, wind, temperature, redox). Microcosm studies easily lead to eroneous conclusions if environmental conditions are not properly reproduced (Higashi 1987). Field experiments are less numerous.

Two hundred and fourty references of the database present quantitative estimates of the effects of pesticides on ricefield microorganisms or their activities. The quantitative analysis and interpretation of this information is subject to caution because:

1. Organisms and pesticides studied do not constitute a representative sample of the numerous combinations occuring in ricefields. Data for phototrophs (149 refs) are mostly on herbicides and cyanobacteria. They are more abundant than those on heterotrophs (91 refs) (Table 1), which deal mostly with insecticides (Table 2).
2. Most studies are (1) toxicity tests with algal cultures, and (2) laboratory experiments with a few grams of soil. Less than 8% of the quantitative studies were conducted *in situ*. Experiments with microbial cultures give an index of the strain's sensitivity to pesticides, but results can hardly be extrapolated to field conditions because toxicity is likely to be lower *in situ* where degradation is enhanced by soil microflora, nonbiological decomposition, leaching, volatilization, and soil adsorption. Toxicity depends on the initial population, its nutrient status, the method of pesticide application, and the degradation products. These factors markedly differ *in vitro* and *in situ*.
3. Many studies used pesticide concentrations higher than those resulting from the recommended level for field application (RLFA). Our database tabulates 1,045 values on phototrophs, among which 638 were obtained at concentrations higher than the RLFA, probably because studies aimed at establishing lethal concentrations for the strains rather than the possible effects *in situ*. Such data are of little value for drawing conclusions, except when no effect was recorded.

Pesticide behavior in wetland ricefields

General characteristics of pesticide behavior in wetland soils

In ricefields, as in any agricultural ecosystem, pesticide persistence, efficacy of pest control, and potential for environmental contamination are governed by transfer and degradation processes. Transfer includes sorption-desorption, runoff, percolation, volatilization, absorption by plants or animals. Degradation includes microbial, chemical, and photodecomposition; and plant detoxication. Pesticide transfer and degradation depend on (1) physical, chemical and biological properties of the soil, (2) climatic factors, (3) methods of application, and (4) synergistic/antagonistic effects. However, pesticide behavior in ricefields presents characteristics specific to wetland conditions.

In uplands, pesticides remain at the soil surface until incorporated by cultivation or watering. In wetlands, the presence of floodwater and puddled soil accelerates dilution, with variations according to solubility. If a pesticide applied on a nonflooded soil remains in the first two cm, 1 kg/ha of active ingredient (a.i.) corresponds to 10 ppm d.w. soil (bulk density 0.5). With a water-soluble pesticide distributed in 10 cm water and 10 cm puddled soil, 1 kg/ha a.i. corresponds to 0.4 ppm.

Pesticide degradation in tropical ricefields is favored by (1) reducing conditions and (2) temperature and pH ranges favoring microbial activity. Volatilization is favored by high temperature and gas exchange occuring between the soil and the atmosphere through the rice plant (Siddaramappa and Watanabe 1979). As a result, pesticide degradation is often faster in flooded than nonflooded soils (Fig. 1a). A usually longer persistance of pesticides in sterilized soils demonstrates the importance of microbial degradation (Fig.1b). In uplands, bacteria and fungi are considered to be mainly responsible for pesticide transformations. In wetlands, fungi are probably less important, whereas the role of algae may be significant as shown for parathion (Sato and Kubo 1964).

Repeated application of a pesticide can enhance the growth of the specific decomposing microflora and reduce its persistence, as observed with Lindane, Diazinon, and Aldicarb (Read 1987) but not with Carbofuran and Benthiocarb (see Roger *et al.* 1994). Bacteria able to degrade a given pesticide were isolated from tropical and temperate (Watanabe 1978) ricefields previously treated with it.

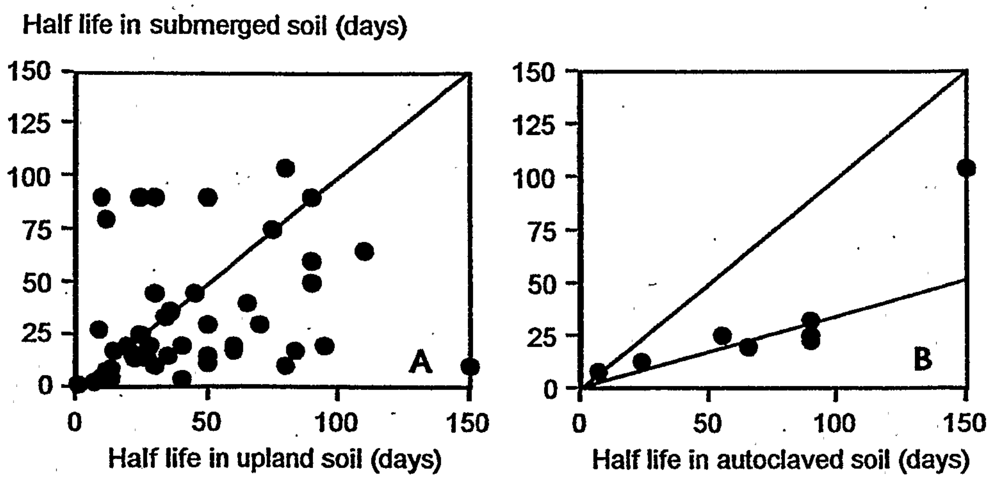

Fig 1. Comparison of the half life of 36 pesticides in flooded and nonflooded soils (A) and 9 pesticides in autoclaved and nonautoclaved flooded soils (B).

Repeated application was also reported to change the metabolic pattern of decomposition both in tropical and temperate (Moon and Kuwatsuka 1984) rice. With Benthiocarb this led to environmental problems. Benthiocarb is generally detoxified by hydrolysis, but its repeated application to flooded soil favoured the multiplication of anaerobic bacteria that decompose it by reductive dechlorination, resulting in the formation of a very phytotoxic compound (Moon and Kuwatsuka 1984).

Comparison between tropical and temperate conditions

Pesticide fate is affected by several factors that are not likely to markedly differ in temperate and tropical environments, i.e. soil physico-chemical properties and the method of pesticide application.

Climate is the major factor likely to cause differences in pesticide behavior in temperate and tropical rice. Pesticide photo-decomposition, volatilization, and, mostly, microbial degradation are expected to be faster in the tropics. However, few data are available to verify this hypothesis. The half life of 43 pesticides was determined in flooded soils (reported in 54 papers) but chemicals tested in temperate conditions are different from those tested under tropical conditions. Yuh-Lin Chen (1980) reported that Butachlor half life in floodwater was 0.8 days under hot and sunny weather, and 5.5 days under cold and cloudy weather. Gamma hexa-chloro hexane (HCH) decomposed faster at 35°C than at 25°C in a flooded soil (Yoshida and Castro 1970). High temperature decreases adsorption by soil and favors desorption, which may result in higher pesticide concentration in soil water and faster disparition (Guenzi and Beard 1976).

Straw and organic matter incorporation are known to favor pesticide degradation in wetland soils. Currently, burning is the major method of handling rice straw. Environmental policies tending to restrict straw burning and to promote incorporation might be adopted more rapidly in temperate developed countries than in the tropics.

Alternate periods of flooding and drying, resulting in successions of aerobic and anaerobic microflora, favor extensive microbial decomposition of pesticides (Sethunathan 1972). In irrigated tropical ricefields, crop intensification might lead to long periods of continuous flooding. In temperate rice, with a single crop per year, dry fallow might ensure better decomposition of pesticide residues.

Effects on non photosynthetic microorganisms

General trends (Table 2, A)

The database tabulates 606 quantitative records of pesticide effects, mostly measured in the presence of soil (Table 1). Much more data refer to tropical rice (509) than to temperate rice (97). Effects were negative in 20% of the cases (tropical: 20%; temperate: 19%), not significant in 60 % of the cases (trop.: 58% ; temp.: 68%), and positive in 20% of the cases (trop.: 22% ; temp.: 13%). As the dataset on temperate rice is too small to allow comparisons, herafter we only discuss the whole dataset.

Experiments *in situ* showed a higher percentage of non significant effects (nse) (nse: 73 %) than small scale experiments (nse: 46 %), confirming that the last ones overestimate pesticide effects. Extreme effects (all negative or all positive) were also less frequent *in situ*. Pesticide effects were more marked in the bulk of soil (nse: 52 %) than in the rhizosphere (nse: 70 %), which is probably a more active and more resilient environment than the soil. Herbicides affected more microflora or its activities (nse: 30 %) than fungicides (nse: 50 %) and insecticides (nse: 68 %). Population densities were less affected by pesticides (nse: 58 %) than microbial activities (nse: 46 %) and soil enzymes (nse: 93 %). Fungi (nse: 80%) and actinomycetes (nse: 62 %) were less sensitive to pesticides than bacteria (nse: 52%).

Effects on nitrogen cycle (Table 2, B)

N_2-fixing microflora and BNF were more affected by pesticides (nse: 31 %) than other populations and activities of the N cycle (nse: 71 %). A high number of positive effects (45 %), was observed with all pesticides. With 25 % of negative effects and 45 % of positive effects, BNF seem quite versatile in their response to pesticides. Nayak and Rajaramamohan Rao (1980), using Benomyl, Carbofuran and gamma-BHC found both positive and negative effects on N_2 fixation. A single pesticide could exhibit a negative or positive effect depending on the soil type.

Nitrification was not affected in 60 % of cases. Negative effects (34 %) cannot be considered detrimental as they reduce N-losses by denitrification. Identifying efficient and economically feasible nitrification inhibitors has been an objective of research on microbial management in ricefields (Roger *et al.* 1992). Denitrification was not affected by pesticides in 87 % of cases, probably because the denitrifying microflora, being complex and very versatile, can metabolize or resist a wide range of substrates. As a result, high pesticide levels are needed to inhibit denitrification. Mitsui *et al.* (1964) found that 20 -100 ppm Dithiocarbamate was required to decrease denitrification.

In situ experiments (Table 2, C)

Pesticide effects were less often significant *in situ* than *in vitro* and were more often negative than positive, whereas the same percentage of positive and negative effects (20 %) was recorded with the whole dataset. However most trends observed with the whole dataset were also obseved *in situ*, namely: (1) more impacts of herbicides than of insecticides, (2) a higher sensitivitiy of bacteria to pesticides than of fungi, actinomycetes, or algae, (3) a higher sensitivity of microbial activities to pesticides than of population densities, and (4) a higher sensitivity of BNF to pesticides (nse: 39 %) than the average sensitivity observed with the whole set of data *in situ* (nse: 73 %).

Results of field experiments usually indicate either an absence of pesticide effect or a transitory change of population densities followed by a recovery within two or three weeks. Two studies report a long lasting effect that was observed with rhizospheric BNF and probably resulted more from the effects on the rice plant than a direct effect on microflora (see Roger *et al.* 1992). The only field study conducted over several crop cycles in temperate conditions (Nishio and Kusano 1978) showed that nitrification and total bacterial populations in temperate soils having received insecticide for four consecutive years were not significantly different from those in the control; but counts of bacteria tolerant to organophosphate insecticides were 2-4 times higher in treated soils.

Field surveys in 32 farms of the Philippines, by the authors, showed no correlation between soil microbial biomass estimated at the beginning and the end of the crop cycle (to assess long-term effects of pesticides) and various expressions of the intensity of pesticide use (Roger *et al.* 1992).

Table 2. **Pesticide effects on non photodependant ricefield microflora at concentrations corresponding to the recommended level for field application (adapted from Roger *et al.* 1995).**

Groups	number of data	% of data for each effect * all negative	negative trend	no effect	positive trend	all positive
A: ALL DATA	606	8	12	60	11	9
Experimental design (606 data)						
Field experiments	309	5	17	73	4	1
Pot and flask expts.	283	10	8	46	18	19
Environment (590 data)						
Tropical soil	509	6	14	58	12	10
Temperate soil	97	18	1	68	6	7
Soil	347	7	12	52	16	14
Rhizosphere	243	8	13	70	5	5
Type of measurement (606 data)						
Microbial counts	249	10	10	58	13	9
Bacteria	175	13	9	52	15	11
Actinomycetes	37	3	19	62	8	8
Fungi	37	5	5	81	8	0
Microbial activities	225	8	18	46	13	15
Enzymatic activities	123	0	7	93	1	0
Pesticide group (600 data)						
Fungicides	58	5	0	50	24	21
Herbicides	102	13	23	30	21	14
Insecticides	440	6	11	68	7	8
B: N CYCLE	302	8	15	48	16	13
Data on BNF	176	2	23	31	26	19
In bulk of soil	95	1	12	25	37	25
In rhizosphere	81	2	36	38	12	11
Bacterial counts	69	4	3	52	23	17
BNF measurements	107	0	36	18	27	20
Fungicides	25	0	0	20	52	28
Herbicides	26	0	23	23	35	19
Insecticides	125	2	27	35	18	17
Other aspects of N cycle	126	16	6	71	3	5
Nitrification	54	30	4	61	0	6
Denitrification	47	6	4	87	2	0
Others	25	4	12	60	12	12
C: *IN SITU* MEASUREMENTS	351**	5	16	73	5	2
Herbicides	50	8	18	64	10	0
Insecticides	297	4	14	75	4	3
Bacteria	84	17	13	57	6	7
Actinomycetes	29	0	24	76	0	0
Fungi	29	0	7	86	7	0
(Algae and cyanobacteria)**	42	7	10	71	10	2
Microbial counts	184	9	13	68	6	4
Microbial activities	65	0	45	46	8	2
Heterotrophic BNF all data	93	2	32	39	15	12
Bacterial counts	35	6	6	63	3	23
BNF measurements	58	0	48	24	22	5

*Most experiments are bacterial counts and activity measurements performed several times after pesticide application. Each experiment was attributed a score of 1 within a 5 cases scale:
• no effect: no significant difference between treatment and control • all negative/positive: for all measurements the treatment was statistically lower/higher than the control • negative/positive trend: various effects were recorded, the balance was negative/positive,
** 42 data on microalgae and cyanobacteria are included for comparison

Table 3. Effect of 109 pesticides on ricefield cyanobacteria and microalgae at concentrations corresponding to the recommanded level for field application.

Nature of the data	No. of data	% of data corresponding to the above levels of inhibition				
		none	< 50%	50 %	> 50%	100%
All data	407	39	19	26	2	14
All data *in situ* or with soil	39	62	8	3	3	26
Algicides (3 tested)	33	3	0	67	0	30
Fungicides (22 tested)*	30	40	10	7	0	43
Herbicides (57 tested)	252	33	25	28	2	12
Herbicides, *in situ* or with soil	24	58	8	4	4	25
Insecticides (28 tested)	97	67	11	14	3	4
Insecticides, *in situ* or with soil	10	90	10	0	0	0

* several fungicides act also as algicides

Effects on photosynthetic microorganisms

The photosynthetic aquatic biomass in ricefield floodwater is composed of cyanobacteria, microalgae, macrophytic algae, and vascular macrophytes. Reported average primary production over a crop cycle range from 0.5 to 1 g C/m^2 /day. Standing crops range from 100 to 500 kg/ha dry weight.

Role of the photosynthetic aquatic biomass in ricefields

The photosynthetic aquatic biomass acts as a trap for C and N evolved from the soil and helps reduce nutrient losses when reincorporated into the soil. It affects the N fertility of ricefields through:

(1) photodependant biological N_2 fixation (BNF) by cyanobacteria, which provides 5-20 kg N/ha/crop depending on the method of N-fertilizer application (Roger *et al.* 1992);
(2) N immobilization and recycling in relation to weeding, death or grazing, followed by decomposition, N accumulation at soil surface, and translocation to deeper soil by soil fauna;
(3) Replenishment of the soil microbial biomass and available N, as shown by positive correlations between these variables and chlorophyll-type compounds (Watanabe and Inubushi 1986);
(4) Provision of N to the rice plant, which averages 30 % of the nitrogen of algae and aquatic plants incorporated into soil and 20 % of those decomposing at the soil surface; and
(5) Induction of N losses by NH_3 volatilisation (2 to 60% of N applied) which are partly due to algae, which deplete CO_2 in floodwater, thus increasing its pH and the concentration of volatile NH_3.

In transplanted rice, microalgae, and submerged and floating plants are rarely considered weeds of major economic importance. In direct seeded rice, microalgae and macrophytic algae are detrimental at germination because (1) they compete for light, (2) they form a membranous mat, restricting root penetration into the soil and the gaseous exchanges between soil and water, and (3) they have detrimental mechanical effects when their epiphytic growth either pulls seedlings down, or lifts them up and uproots them, when the water level varies (Noble and Happey-Wood 1987, Smith *et al.* 1977).

Impacts of pesticides on microalgae

Reported data are mostly percentages of inhibition estimated by measuring dry weight, N content, chlorophyll content, etc. on laboratory cultures. Table 3 analyses 407 records at RFLA. Pesticides had no effect in 39 % of all records and in 62 % of the records *in situ* or in the presence of soil. It confirms that pesticide effects are more marked *in vitro* than *in situ*. Herbicides were the most detrimental to phytoplankton, causing partial or total inhibition in 67% of the tests *in vitro* and in 42% of the tests *in situ* or performed with soil. Herbicides can inhibit photodependant BNF, as shown with Pentachloro- phenol (Ishizawa and Matsuguchi 1966). Some herbicides specifically affect the N_2-fixing ability of cyanobacteria: inhibition occured in N-free medium but not in the presence of inorganic N; as observed with Dichlone (fungicide/algicide) and Machete (Kashyap and Pandey 1982). With insecticides, no inhibition was observed for 67 % of all data and 90% of field data.

Field studies in temperate areas have shown various effects of pesticides on phytoplankton:

1. a decrease in phytoplankton abundance (Takamura and Yasuno 1986);
2. a decrease in phytoplankton biodiversity (Tomaselli *et al.* 1987);
3. a selective toxicity which affects the composition of the algal population. Many cyanobacteria (1) can tolerate pesticide levels higher than the RFLA, and (2) are more resistant to pesticides than eucaryotic algae, which results in selection in favor of cyanobacteria. This was observed with BHC (Ishizawa and Matsuguchi 1966), and PCP (Watanabe 1977); and
4. a growth promoting effect of insecticides due to inhibition of invertebrates that graze on algae, as observed with Carbofuran, Phorate, and Parathion (Hirano *et al.* 1955). However, insecticide application did not invariably increase photodependant BNF. Some inhibitory effect was reported for PCP *in situ* (Ishizawa and Matsuguchi 1966). Also, in the long term, insecticide use might become detrimental to phytoplankton by causing the proliferation of resistant grazers.

Specific aspects pertaining to temperate rice

Whereas in the tropics, studies of phytoplankton have focused on the use of N_2-fixing cyanobacteria as a biofertilizer, in temperate regions, studies deal mostly with it's detrimental effects.

Blooms of unicellular algae, which may cause problems at the beginning of the crop cycle in direct seeded rice, are most often controlled by copper-based algicides (Noble and Happey-Wood 1987). Copper use against algae in ricefields is documented mostly in the temperate areas of Russia (Kayumov 1963), Italy (Bisiach 1971), the USA (Dunigan and Hill 1978), and Australia (Noble and Happey-Wood 1987). As cyanobacteria are often more resistant to pesticides than eukaryotic algae, algicide application to control unicellular eukaryotic algae may cause blooming of cyanobacteria as observed in Italian ricefields (Bisiach 1970). It was also observed that blooms of unicellular algae may result from the utilization of insecticides applied against chironomid larvae, which might damage rice roots but are also algal grazers. After discontinuing insecticide application, little slime problem was encountered (Noble and Happey-Wood 1987).

Algicides tested for their potential to decrease N losses by NH_3 volatilization are copper sulfate (Muirhead *et al.* 1989), Simazine (Vlek *et al.* 1980), Diuron (IRRI 1977), and Terbutryne (Bowmer and Muirhead 1987). Simazine, Diuron, and Terbutryne reduced pH and increased NH_4^+ -N concentration in water, but data suggested that fertilizer saving was low. With Terbutryne, the estimated saving averaged 4.7- 9.6 kg N/ha when 90-150 kg N/ha was applied (Muirhead *et al.* 1990). Deep placement of N-fertilizers, which avoids algal blooming and prevents high concentration of NH_3 in water, seems a more efficient method to decrease N losses by volatilization (Roger *et al.* 1992). Floodwater pH is fairly stable under floating macrophytes such as *Azolla* and *Lemna* because they restrict light penetration in to the water. Herbicide application on such mats may increase photosynthetic activity in the floodwater by resistant microalgae and enhance N losses by volatilization.

Effects on invertebrates

Role of aquatic invertebrates in ricefields

Soil and water invertebrates dominant in ricefields are ostracods, copepods, cladocerans, rotifers, insect larvae, aquatic insects, molluscs, oligochaetes, and nematodes (Roger and Kurihara 1988). Representatives of all these groups are present in tropical and temperate ricefields where they have agricultural impacts as nutrient recyclers, rice pests, and rice pest predators; and environmental impacts as vectors of human and animal diseases.

Microcrustaceans, and larvae of mosquitoes and chironomids are ubiquitous primary consumers, which recycle nutrients from the photosynthetic aquatic biomass. They usually proliferate about two weeks after the peak of phytoplankton abundance (Kurasawa 1956) and may cause the disappearance of microalgae blooms within 1-2 weeks. Ostracods have the potential to recycle 20 kg N/ha/crop. Primary consumers that feed on cyanobacteria may inhibit photodependant BNF or cause the dominance of mucilaginous colonial forms that are less susceptible to grazing than noncolonial forms, but are less active in BNF (see Roger and Kurihara 1988). Large populations of microcrustaceans were recorded in Japan (Kurasawa 1956; Kikuchi *et al.* 1975). Species of Ostracods originating from Africa, Asia, South America, and Australia were recorded in Italian ricefields (Fox 1965; Ghetti 1973). Chironomids were reported to be to be the most numerous insects in the ricefields of Korea, and larvae up to 18,000/m^2 were recorded in California (Clement *et al.* 1977). Oligochaetes, especially tubificidae, are a major component of the zoobentos, that ensure nutrient exchange between soil and floodwater, and increase soil N uptake by rice plants. Populations reach up to 40,000 /m^2 (0- 700 kg/ha f. w.) in temperate (Kikuchi *et al.* 1975) and tropical ricefields (Simpson *et al.* 1992 a,b).

Invertebrates have also detrimental effects. Mosquitoes are vectors of diseases including malaria, and Japanese encephalitis. Chironomids and ostracods feed on rice seedling roots, but this effect is limited in time and space (Clement *et al.* 1977; Barrion and Litsinger 1984). Large species of snails that graze on rice seedlings have been recognized as an important rice pest in tropical countries and Japan. Other species (*Bilinus* spp., *Biomphalaria* spp., *Limnea* spp. ...) are detrimental as vectors of bilharziosis.

Impact of pesticides

Methodological aspects: Field experiments using farmer practices and pesticide rates corresponding to RFLA are scarce. Those testing pesticides with no fertilizer application are of limited value because such a situation is uncommon in farmers' fields and zooplankton are more affected by fertilizer than by pesticides (Simpson *et al.* 1993 b). Only few records of floodwater biota dynamics during a crop cycle and under a range of agricultural practices are available for temperate (Kurasawa 1956; Ishibaschi and Itoh 1981; Takamura and Yasuno 1986)) and tropical ricefields (Simpson *et al.* 1993 ab, 1994 ab).

In vitro effects of pesticides applied in ricefields on soil and water fauna include acute toxicity, alteration of filtration and assimilation, and inhibition of growth and egg production. Insecticides are the most active pesticides on floodwater invertebrates. Herbicides and fungicides appear to possess limited toxicity to invertebrates at field concentrations (Georghiou 1987).

Zooplankton: The major reported effects of insecticide application on zooplankton are (1) a transient decrease of the total population, (2) a decrease in species diversity and, (3) the blooming of individual species, especially ostracods, mosquito larvae, and molluscs (Roger and Kurihara 1988). A field study by Takamura and Yasuno (1986) reports the development of large populations of chironomids and ostracods in herbicide and insecticide treated fields. Simultaneously, the number of natural predators of chironomids and ostracods decreased. Benthic algae decreased in herbicide treated plots and did not increase in insecticide treated plots, probably because of grazing by ostracods. Lim and Wong (1986) attributed the dominance of ostracods in treated fields to their resistance to pesticides and the large number of eggs produced parthenologically. In Japan, Takaku *et al.* (1979) observed that the application of Fenitrothion by helicopter heavily reduced the abundance of *Moina* spp. in floodwater. Whereas insecticides appears to favor ostracods, an almost complete inhibition of ostracods for the whole crop cycle, by herbicide Benthiocard application, was observed by Ishibashi and Itoh (1981) in Japan. There are also reports indicating a limited effect of pesticides on zooplankton. In a two year field study of the effects of carbofuran at high levels of N-fertilizer, Simpson *et al.* (1993b) concluded that aquatic invertebrates were not strongly affected.

Vectors: Most agricultural insecticides are nonspecific; they affect rice pests as well as vectors on which they have three major effects: they (1) temporarily decrease their incidence, (2) cause resurgence of resistant strains, and (3) have adverse effects on their predators and competitors (see Roger and Bhuiyan 1991). Marked reduction of malaria and Japanese encephalitis in Japan, since 1945, results at least partly from the extensive use of organophosphorus and carbamate insecticides. The decrease of *C. tritaeniorhynchus* after 1970 in Japan might partly result from the increase of its natural predators by the switch from chlorinated hydrocarbons to carbamates, less toxic to vector predators (Mogi 1987). In Korea, agricultural pesticide application reduced the density of *Culex tritaeniorhyncus* , the vector of Japanese encephalitis, in rice-growing areas, but had no effect on the malaria vector *Anopheles sinensis*. Mosquito populations are particularly adapted at evolving resistant strains: in 1987, 50 malaria vectors resistant to one or more pesticides were recorded in the world (Bown 1987).

Aquatic oligochaetes: A few data indicate that aquatic oligochaetes are sensitive to pesticides but they are not numerous enough to draw definite conclusions. In Japan, the apparition of significant densities of tubificids in an experimental ricefield studied for 9 years was attributed to (1) the replacement of PCP by Benthiocarb and (2) the pollution of the irrigation water by domestic sewage. Simultaneously, grain yield increased by 0.9t/ha (Kurihara and Kikuchi 1988). In the Philippines, Carbofuran, Butachlor, and triphenyl tin hydroxide applied together at the beginning of the crop reduced average populations over the crop cycle from 1760 to 200/m^2 (Roger *et al.*1993). In a two year study, Carbofuran application decreased aquatic oligochaetes during the first crop cycle, but not during the second year, when the same treatment was applied (Simpson *et al.* 1992a). Ishibaschi and Itoh (1981) found no significant effect of herbicide Benthicarb on average populations of saprophitic and parasitic nematodes enumerated at 14 occasions during a crop cycle.

Molluscs: Snails are usually not affected by conventional rice pesticides but their populations may increase because of reduced competition for energy sources. After harvest, Ishibashi and Itoh (1981) observed larger snail populations in fields previously treated with the herbicide Benthiocarb than in the untreated control. Simpson *et al.* (1993c) found limited evidence suggesting that snails were favored by Carbofuran or Butachlor application.

Conclusions

Many papers on pesticide fate and impacts in wetland rice were published between 1970 and 1985. The number has decreased tremendously during the last five years. Studies have dealt mostly with tropical environments and focus on the effects of (1) insecticides on heterotrophic microflora and invertebrates and (2) herbicides on cyanobacteria. Information on pesticide impacts in temperate rice is limited and extrapolation from data obtained in the tropics should be done with caution because (1) the dominant class of pesticides used in rice culture is insecticide in tropical areas and herbicide in temperate areas, and (2) chemicals and formulations currently used partly differ from those studied in the tropics in 1970-85.

It is recognized that tropical flooded soil is an environment favorable for rapid detoxication of many pesticides. In temperate ricefields, a lower temperature might slow down decomposition during the crop cycle, whereas the dry fallow might favor residue mineralization.

Field and laboratory studies showed that pesticides applied on soil at recommended levels rarely had a detrimental effect on microbial populations or their activities. When significant changes were observed, a recovery of populations or activities was usually observed after 1 to 3 weeks. This seems to partly confirm the common belief that pesticides applied at recommended levels and intervals are seldom deleterious to the beneficial microorganisms and their activities (Wainright 1978).

Invertebrate populations seem to be more sensitive to pesticides than microflora. In the case of floodwater invertebrates, pesticide use can lead to the blooming of individual species (especially primary consumers) that might be detrimental. Reports in temperate and tropical ricfields indicate that aquatic oligochaetes in soil are at least partly inhibited by pesticide use.

However, it is important to emphasize that impacts of pesticides on the soil-floodwater ecosystem can be significant without being detrimental. For example, a shift in algal community structure may not affect soil fertility, provided that aquatic primary production is unchanged. Impacts should be considered in the context of the ecosystem equilibrium and not in isolation. Except for vectors and major rice pests, many invertebrates have both beneficial and detrimental effects. For example, chironomid larvae are detrimental when they feed on rice roots and N_2-fixing cyanobacteria, but they are useful because they recycle nutrients and serve as an alternative food for predators of rice pests and thus help in conserving them (Yatsumatsu *et al.* 1979).

The available information raises several concerns regarding long term impacts of pesticides on (1) soil fertility, (2) the microbial metabolism of pesticides, and (3) the preservation of a biological equilibrium in the floodwater that avoids proliferation of detrimental invertebrates.

There are reports of significant direct or indirect effects of pesticides on microorganisms, primary producers, and floodwater invertebrates of importance to soil fertility. Long term possible impacts are largely unknown. Several long-term experiments have shown a yield decline with time (Cassman and Pingali, in press). Reasons are imperfectly understood, but one factor might be the combination of weeding/herbicide use and a dense rice canopy, which restricts the growth of the photosynthetic aquatic biomass and, in turn, its contribution to the replenishment of soil microbial biomass and N-fertility. Insecticides are possibly also involved by decreasing populations of aquatic oligochaetes and the translocation of the nutrients accumulating at the soil surface to the deeper soil layer. Currently little data are available to substantiate this hypothesis, but experiments at IRRI have shown that totally restricting photosynthetic activity in the floodwater of planted fields with black cloth coverage reduced soil microbial biomass by 22% after two years.

Pesticides might have only temporary effects but, when applied repeatedly, could lead to the promotion, depression, or disappearance of components of the microbial community, thus leading to a new equilibrium and changes in the rate or pattern of their microbial decomposition that might be detrimental.

A better understanding of the floodwater ecology is needed to develop agricultural practices that maintain a biological equilibrium in the ricefield ecosystem; in particular, practices that decrease pesticide use and conserve the natural predators of rice pests and vectors. Even if it is not envisaged that invertebrate predators can be exploited as biological control agents, cultural practices favoring their conservation--which is a major component of integrated pest and vector management--should be encouraged.

It would be as unwise to under or overestimate the significance of pesticide impacts on microflora and non-target invertebrates in wetland soil. Underestimation could cause avoidable ecological damage. Overestimation could restrict the judicious use of pesticides when appropriate. Current knowledge of impacts in temperate ricefields is very fragmentary and needs further investigation. Study of the fate and effects of pesticides, hitherto mostly restricted to short term laboratory conditions, must be performed under more realistic field conditions and cultural practices, and on a long-term basis.

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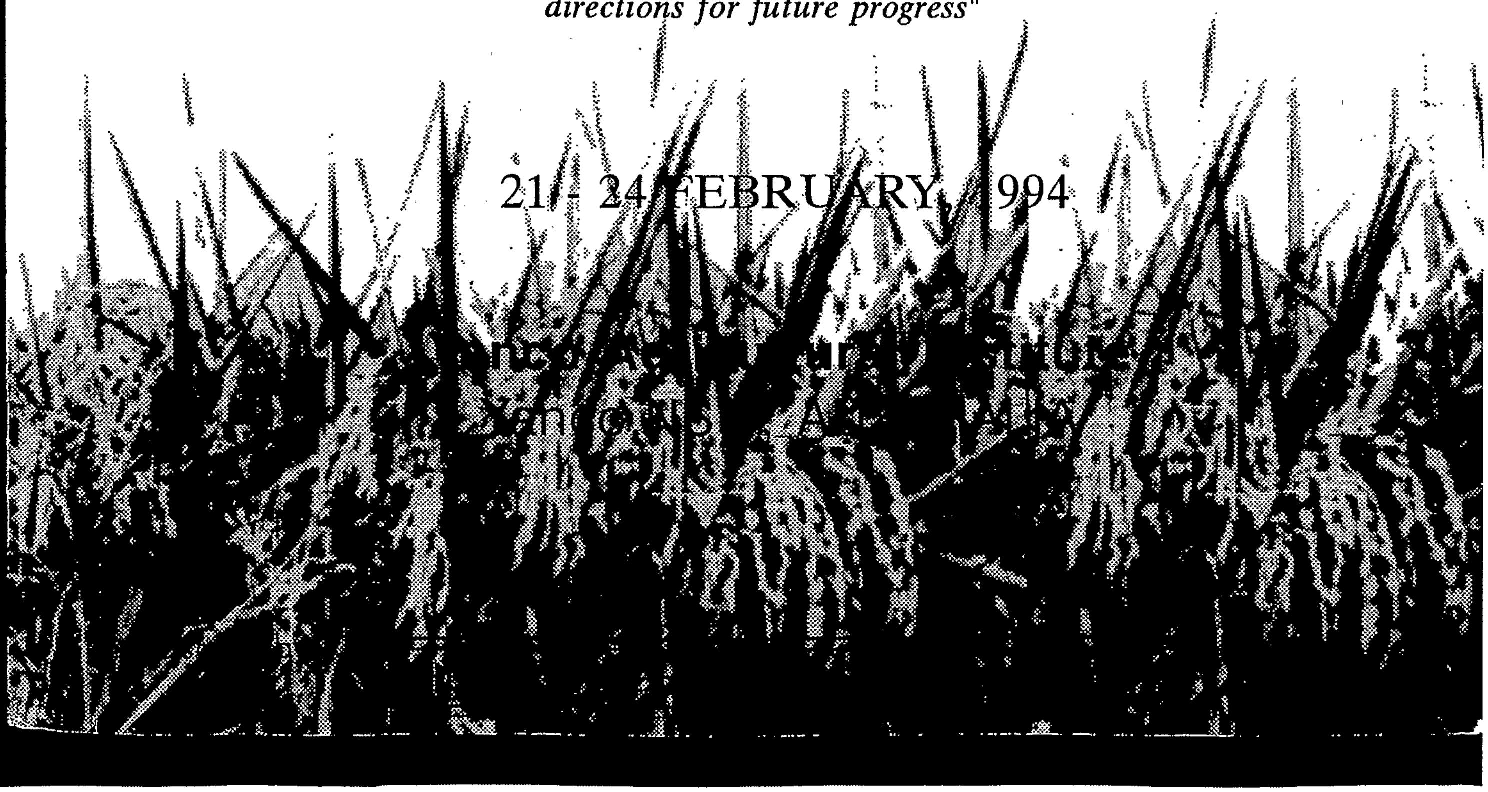

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FOREWORD

The **Temperate Rice Conference, Yanco 1994** was by any measure, a great success.

The Conference theme *"Temperate Rice – achievements and potential"* aptly describes the situation that exists throughout the temperate rice world – many achievements and much potential. The Conference objective, to *"review recent achievements in the production technology of temperate ricegrowing and to explore the potential and directions for future progress"* describes what we did throughout the four days of the Conference.

Those of us from the New South Wales rice industry are truly proud that this, the first international Temperate Rice Conference was held here in Australia. During the Conference 169 delegates from 14 countries, including 53 overseas delegates from north America, south America, Asia and Europe, joined together in the presentation of 75 papers and 12 posters covering the full range of rice production technology. Further informal sessions during the Conference provided the basis for stronger contacts in the future through the development of informal networks between rice workers in the temperate zones of the world.

The real success of the Conference can only be measured in the future. I believe, however, that the Conference will contribute significantly to the achievement of progress in three areas:–

* Sustaining the productivity gains of the last decade.
* Increasing the yield potential of rice by 20 to 30%.
* Improving management to utilise the higher potential.

The achievements of this Conference are the outcome of the efforts of many people before, during and after the event. To all those who helped, the Activity/ Session Co–ordinators and their many assistants, the Chairmen, and the staff at the various functions, we owe a debt of gratitude.

These Conference Proceedings will provide a lasting record of our contributions to the Conference. These papers represent much past effort which will contribute most significantly to our future progress. I sincerely thank and congratulate the Chief Conference Editor Liz Humphreys and her assistants Elaine Murray and Glenys Harrison for a difficult job well done.

The support and foresight of the Trustees of the McCaughey Memorial Institute are gratefully acknowledged. Without their sponsorship the Conference would not have achieved the results we recorded.

Thanks to my colleagues on the Organising Committee for their support and cooperation. I started with an idea, as one we put together a successful and professional Conference.

Time was a major challenge during the Conference. The full program would not have worked without the co–operation and support of all delegates.

Finally, what of the future? What of the opportunities for rice workers in temperate environments to get together and share knowledge, perspectives, experiences and common goals in resolving the challenges of the future? At the conclusion of the Conference there was general agreement that a future conference, to follow on the gains of Yanco, 1994, should be held in three to four years time and America was a possible venue. I am pleased to say that the U.S. Rice Technical Working Group has agreed to investigate the possibility of holding such a conference in conjunction with their 1998 meeting in California.

Warwick S. Clampett
Conference Convenor.

August, 1994