SOME MICROBIOLOGICAL AND HYDROBIOLOGICAL ENVIRONMENTAL EFFECTS OF NEW RICE TECHNOLOGY

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Contents

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1. INTRODUCTION

About 75% of the 143 M ha of rice land are lowlands (wetlands), where rice grows in flooded fields during part or all of the cropping period.

Flooding favours rice environments by : (1) bringing the soil pH near to neutrality; (2) increasing availability of nutrients, especially P and Fe, (3) maintaining soil N ; (4) stimulating N_2-fixation; (5) depressing soil-borne diseases; (6) supplying nutrients from irrigation water; (7) decreasing weed incidence, especially those of C_4 type, and (8) preventing water percolation and soil erosion.

So called "new technologies" in wetland rice cultivation are based on the utilization of fertilizer responsive rice varieties, fertilizers, and pesticides. These technologies have very significantly increased rice yield and production in most rice growing countries but their environmental impacts need to be assessed.

This paper, after summarizing the major effects of flooding on soil microflora and fauna, presents some of the microbiological and hydrobiological impacts of new rice technologies that have currently been observed in relation with soil microbiology studies. Aspects dealing with vector-borne diseases were recently covered in a workshop at IRRI (9-14 March 1987) and are therefore not included.

2. MICROBIOLOGICAL AND BIOLOGICAL EFFECTS OF FLOODING

21. Flooding diversifies environments in the rice field ecosystem and increases its fertility

Principal environmental characteristics of wetland rice fields are determined by flooding, the presence of rice plants, and agricultural practices. Flooding creates anaerobic conditions in the reduced layer, a few millimeters beneath the soil surface. This lead to the differentiation of five major environments differing by their physicochemical and trophic properties: floodwater, surface oxidized soil, reduced soil, rice plants (submerged parts and rhizosphere), and subsoil.

The reduced soil layer is a nonphotic anaerobic environment where Eh is predominantly negative, reduction processes predominate, and where microbial activity is concentrated in soil aggregates containing organic debris.

The oxidized soil layer is a photic aerobic environment with a positive redox potential, a few millimeters thick, where NO_3-, Fe^{+3}, SO_4^{-2}, and CO_2

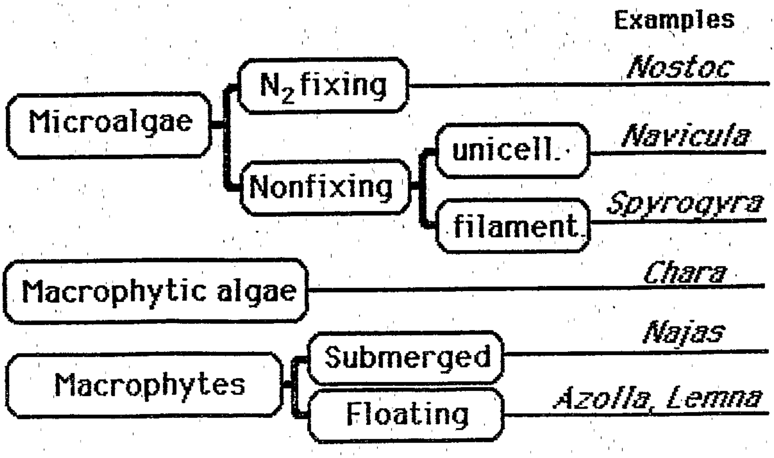
are stable and where algae and aerobic bacteria predominate.

The floodwater is a photic, aerobic environment where aquatic communities of producers (algae and aquatic weeds) and consumers (bacteria, zooplancton, invertebrates etc...) provide organic matter to the soil and recycle nutrients.

As a result of the differentiation of macro- and microenvironments that differ by redox state, physical properties, light status, and nutritional sources for the microflora, all major N_2-fixing organims can and do grow in the wetland rice field ecosystem. Foodwater, submerged plant biomass and aerobic soil layer are sites of photodependent N_2 fixation by blue-green algae (BGA). Heterotrophic N_2-fixation develops preferentially in the soil aggregates that contain organic debris, and the rhizosphere.

This results in a high fertility of wetland rice soils which has permitted, year after year, moderate but constant yield without utilization of Nfertilizer. Long term fertility experiments show that N balance between losses and inputs through BNF and other minor N sources range from 20 to 70 kg N/ha and per crop in plots receiving no N fertilizer (Watanabe et al 1981). Evaluation of photodependent BNF, compiled by Roger and Kulasooriya (1980), ranged from very little to 80 kg N/ha and per crop and averaged 27 kg N/ha per crop.

Table 1 : Components of the photosynthetic aquatic biomass in wetland rice fields



21. Flooding permits the establishment of an aquatic community preponderant in maintaining soil fertility.

2.1.1. Characteristics of the photosynthetic aquatic biomass

Ricefield floodwater is colonized by a photosynthetic aquatic biomass composed of planktonic, filamentous and macrophytic algae, and vascular macrophytes (Table 1). Their development depends on the availability of nutrients and light ; largest biomasses are recorded in fallow plots and in fertilized fields when the rice canopy has not become too dense. Biomass value is usually a few hundred kg d.w./ha and rarely exceeds 1 t d.w./ha (Table 2). Reported productivities of 50-60 g C/m^2 in 90 days (Saito and Watanabe, 1978), 70 g C/m2 in 144 days (Yamagishi et al., 1980), and 0.5 to 1 g C/ m^2 per day (Vaquer, 1984) correspond to 10-15% of that of the rice crop and are similar to productivity values reported in eutrophic lakes.

The average composition of aquatic macrophytes is about 8% dry matter, 2 to 3% N (d.w. basis), 0.2 to 0.3% P, and 2 to 3% K. Planktonic algae have a lower dry matter content (averaging 4%) , a higher N content (3 to 5%) and are also frequently P deficient (Roger and Watanabe, 1984 ; Roger et al., 1986). Planktonic algae and aquatic macrophytes usually have low dry matter content and high ash content.

Biomass measurements and data on the composition of algae and aquatic macrophytes indicate that the N content of spontaneously growing photosynthetic aquatic biomass in planted rice fields rarely exceeds 10-20 kg/ha but might attain 30-40 kg /ha in flooded fallow fields, when large populations of aquatic macrophytes develop.

Components of the photosynthetic aquatic biomass are primary producers contributing significantly to the fertility of the ecosystem. Their major characteristics and activities regarding the nitrogen cycle are : biological N_2 fixation (BNF) by free living BGA and Azolla , N immobilization, N recycling by grazing, N accumulation at the soil surface, N supply to the rice crop, and N losses by NH_3 volatilization (in relation to pH increase due to photosynthesis by the aquatic biomass) (Fig. 1).

Table 2 : Biomasses of algae and aquatic macrophytes in rice fields

Nature	Fresh weight (kg/ha)	Dry Weight (kg/ha)	Location	Reference
BGA	7500	375[a]	China	Acad. Sinica ... 1958[c]
Green algae	60/6000[a]	3/300	India	Mahapatra *et al.* 1971[c]
BGA	800[a]	32	India	Mahapatra *et al.* 1971[c]
Algal biomass	16000	640[a]	UzbSSR	Muzafarov, 1953[c]
Algal biomass	2/6000	0/240[a]	Senegal	Reynaud and Roger 1978[c]
BGA	2/2300	0/92[a]	Senegal	Reynaud and Roger 1978[c]
BGA	50/2850[a]	2/114	Philippines	Saito and Watanabe 1978[c]
BGA (*Aulosira*)	12000[a]	480	India	Singh 1976[c]
BGA	125/2625[a]	5/105	India	Srinivasan 1979[c]
BGA (*Gloeotrichia*)	24000	117	Philippines	Watanabe *et al.* 1977[c]
Chara sp.	9000/15000	720/1200[b]	India	Misra *et al.* 1976[d]
Chara, Nitella	5000/10000	400/800[b]	India	Mukherjy and Laha, 1969[d]
Najas, Chara	5000[b]	400	Philippines	Saito and Watanabe 1978[d]
Chara spp.	2500/7500[b]	200/600	France	Vaquer, 1984[d]
Marsilea	25000	2000[b]	India	Srinivasan, 1982[d]
Total biomass				
fallow field	1000/3000	80/240[b]	Philippines	Kulasooriya *et al.* 1981[d]
planted field	7500	600[b]	Philippines	Kulasooriya *et al.* 1981[d]
planted field	1250/2500[b]	100/200	Philippines	Inubushi and Watanabe
fallow field	1250/6250[b]	100/500	Philippines	1986.
Average	**6000**	**350**		

a : extrapolated on the basis of 4% dry weight ; b : extrapolated on the basis of 8% dry weight ; c : quoted in Roger & Kulasooriya, 1980 ; d : quoted in Roger & Watanabe, 1984

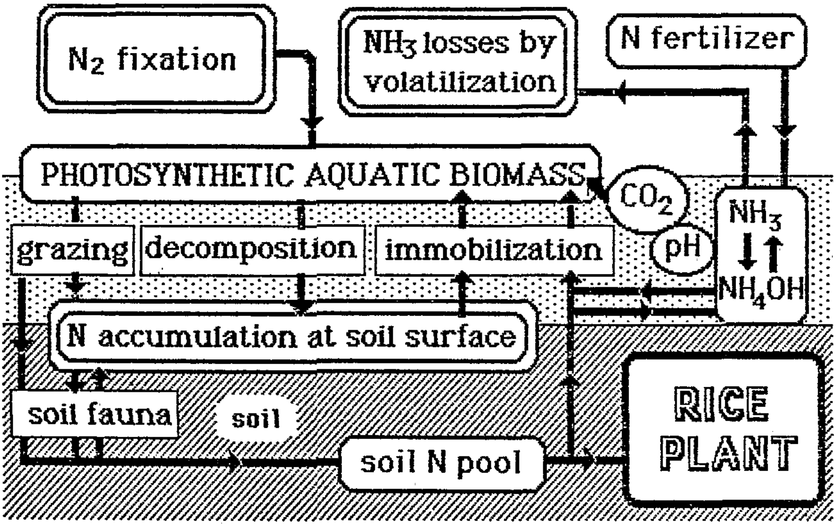


Figure 1 : Role of the photosynthetic aquatic biomass in nitrogen recycling in wetland rice fields (Roger, 1987).

2.1.2. The contribution of the aquatic biomass to the fertility of wetland rice soils

Rice is heavily dependent on N mineralized from soil organic matter but only a small fraction of total soil nitrogen is easily available to the crop. Total soil N is not an accurate index of soil fertility as indicated by low correlation coefficients between total soil N and mineralizable N as reported for soils from Japan (Shioiri 1948, $r = 0.52$) China (Zhu et al. 1984, $r = 0.56$) and South and Southeast Asia (Kawaguchi and Kyuma 1977, $r = 0.58$).

Utilization of the chloroform fumigation method (Jenkinson and Ladd 1981) has shown that microbial biomass is a major channel through which nutrients are transferred to crop plants. Marumoto (1984) found that in oven-dried and rewetted rice soils, 66% of the N mineralised during 28 days of incubation came from the newly killed (chloroform fumigated) microbial biomass.

Estimates of microbial biomass in wetland rice soils (Marumoto 1984; Hasebe et al. 1985) show higher ratios of microbial biomass C to total soil C (4-8%) than reported for upland arable lands (Jenkinson and Ladd 1981). Total microbial biomass may be larger during flooding because of the development of the aquatic microbial community, especially microalgae.

Early experiments in drums at IRRI showed that flood fallow promotes N accumulation. After 24 consecutive crops, the percentage of N in soils subjected to flood fallow was 0.183-0.185; that in dry fallow was 0.118-0.126. After 10 successive crops without Nfertilizer application rice grown on flood fallow yielded more (112-140 g/drum) than rice grown on dry fallow soils (77-93 g/drum) (IRRI Annual report for 1977).

Recent experiments have shown that, as a result of the activities of the photosynthetic aquatic biomass, the consumer populations, and the microbial communities, N accumulates at the soil surface. Such an accumulation was observed only when the soil was exposed to light. Reported values range from a few kg N/ha (App et al. 1984) to 35 kg N/ha per crop (Ono and Koga 1984). Chlorophyll-like substances accumulates at the soil surface in parallel with microbial biomass N (Watanabe and Inubushi 1986). A positive correlation between chlorophyll-type compounds and mineralisable N (Inubushi et al.,1982 ; Wada et al. , 1982), indicates that photosynthetic biomass contributes significant quantities of available N and has an important role to play in maintaining the fertility of wetland soils.

Watanabe and Inubushi (1986) observed that microbial biomass measured by chloroform fumigation increased at the soil surface and decreased in the puddled layer during flooding. The microbial biomass N in the upper 1 cm soil layer accounted for 10-20 % of that in the 0-15 cm layer. This indicates a significant direct or indirect contribution of the aquatic communities to the total microbial biomass.

Inubushi and Watanabe (1986) estimated the residence time of microbial biomass N (or available N) to be 33 days, which suggests that the turnover of microbial biomass is much faster in tropical-wetland soils than in temperate upland soils (Jenkinson and Ladd 1981).

It thus appeard that fertility of wetland soils results for a significant part from the activity of a photosynthetic aquatic biomass of a few hundred kg/ha which allows a rapid recycling of nutrients in the ecosystem through decomposition and/or grazing by the microfauna.

3. GENERAL EFFECTS OF CROP INTENSIFICATION

When considering reports on traditional utilization of the rice field a few decades ago it appears that crop intensification lead to a drastic diminution of the species diversity in general and in the number of outputs that a farmer obtains from his field.

3.1. Crop intensification provoques blooming of individual species

Traditional rice fields, cultivated for sometimes several hundred of years migt be considered as climax communities. In general, a disturbance to a stabilized ecosystem reduces the number of species while provoquing "blooms" of individual ones. Crop intensification, besides permitting blooming of the most important species (*Oriza sativa*) frequently lead to explosive developments of other species that might have directly or indirectly detrimental effects. Some examples are listed thereafter together with their possible detrimental effects:

- Blooms of green algae and diatoms observed at the beginning of the crop after fertilizer application (common in most of rice fields) ;

- Causes losses of N by volatilization;

- Development of very dense ostracods populations observed after Furadan application (observed in the IRRI farm);

- Inhibit the development of efficient N_2-fixing BGA blooms;

- Development of very dense populations of aquatic snails at the beginning of the crop (observed in the IRRI farm and in many fields in the Philippines);

- Vector of bilharziosis, damage to young rice seedlings (*Pomacea* spp);

- Blooms of some species of aquatic weeds such as Chara or Nitella;

- Reduces yield;

- Development of large populations of mosquito larvae in shallow water rice fields whereas such populations were absent in traditional rice fields due to deeper floodwater and the abundance of predators (Heckman, 1979);

- Vector of malaria, graze on N_2-fixing BGA;

Blooming of microalgae and aquatic invertebrates do not usually last long. Only mucilaginous BGA and aquatic macrophytes may develop long lasting large biomasses.

3.2. Crop intensification replaces food diversity by rice productivity.

An striking example is in the detailed study of the ecology of a rice field in 1975 by Heckman (1979) showing that rice fields in North Thailand were used to produce fish and to collect edible plants and invertebrates which were abundant. Aquatic plants were also collected as feed for livestock (pigs). Water bufalos were released in the rice field after harvest to graze on stubble, thus providing allochtonous source of nutrients. During the fallow period, a flock of domestic ducks was released in the field daily, feeding on a large variety of small aquatic animals and plants. Table 3 lists edible plants and animals harvested during 1975 in the studied field.

In this study, Heckman expressed his concern about crop intensification : " Because of great dependance of the local human population on the aquatic community for protein, the danger exist that projects designed to incrase rice production may reduce the fish producing capacity of the rice fields, thus depriving the local farmers from an important part of their diet. The same author quoted a study by Yunus and Lim (1971) showing that chemical treatment of rice fields in Malaysia had already significantly reduced their useful fauna.

Table 3 : Edible plants and animals harvested during 1975 in a Thai rice field (after Heckerman, 1979)

Oriza sativa	
Ipomea aquatica	Green vegetable
Pila pesmei	Large edible snail
Pila polita	Large edible snail
Macrobrachium lanchesteri	Small prawn
Somanniathelphusa sinensis	Crab
Lethocerus indicus	Large edible water bug
Channa stiata	Snakehead
Clarias batrachus	Walking catfish
Anabas testudineus	Climbing perch
Cyclocheilichthys apogon	Cyprinid
Puntius leiachantus	Cyprinid
P. stigmatosus	Cyprinid
Esomus metallicus	Cyprinid
Fluta alba	Swamp eel
Trichogaster pectoralis	Edible gourami
Macrognathus aculeatus	Spiny eel
Rana limnocharis	Frog

4. SPECIFIC ASPECTS OF CROP INTENSIFICATION

4.1. Nitrogen fertilization

4.1.1.Effects on biological nitrogen fixation

A general trend observed with cultures N_2-fixing microorganisms is the inhibition of their N_2-fixing activity by chemical sources of nitrogen. *In situ* this inhibition is not as clearly marked. Free-living phototrophs (BGA) seems to be more susceptible to inhibition by Nfertilizers than heterotrophs. Associative N_2 fixation is most active near heading stage, and at this stage, ammonium concentration at the rhizosphere is negligible, hence, the effect of N fertilizer on this process is minimum.

Surveys in long-term fertility plots showed N fertilizer application strongly depresses BGA population and their bloom (Watanabe et al 1977). More recent studies at IRRI confirm an inhibitory effect of surface application of nitrogen on photodependant ARA. Inhibition is never total but was observed when urea was applied basally (Fig. 2) as well as when it was applied later in the crop cycle (Fig. 3).

Deep placement of N fertilizer significantly reduces the inhibitory effect of N fertilizers on BGA in floodwater. Results from 3 cropping seasons show a quite large variability of the relative ARA (% of control without N) in plots where urea was deep-placed and an average value of 73 %.

Figure 2 : Dynamics of photodependant ARA in a field with split surface application of urea (Ns) and a control with no Nfertilizer applied (No) (Reddy and Roger unpub.).

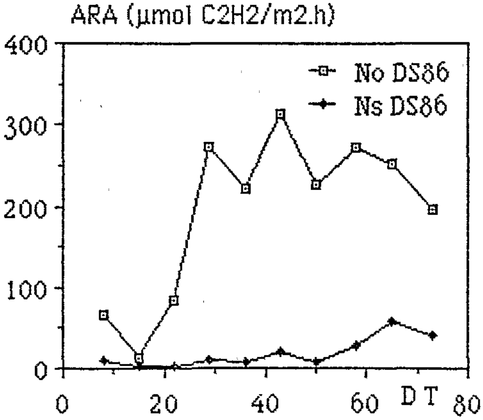


Figure 3 : Dynamics of photodependant ARA in plots with no basal application of Nfertilizer (Control 1), Nfertilizer basally broadcast (Control 2), basal straw incorporation, and basal surface application of straw. Urea was broadcasted in all plots at 55 DT (Roger et al. unpub.).

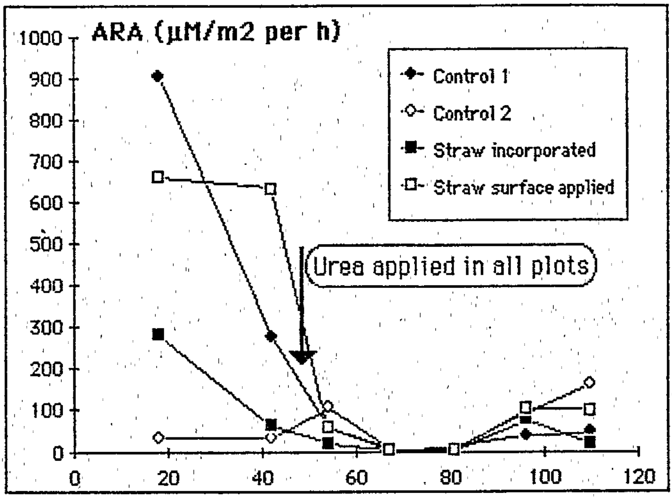
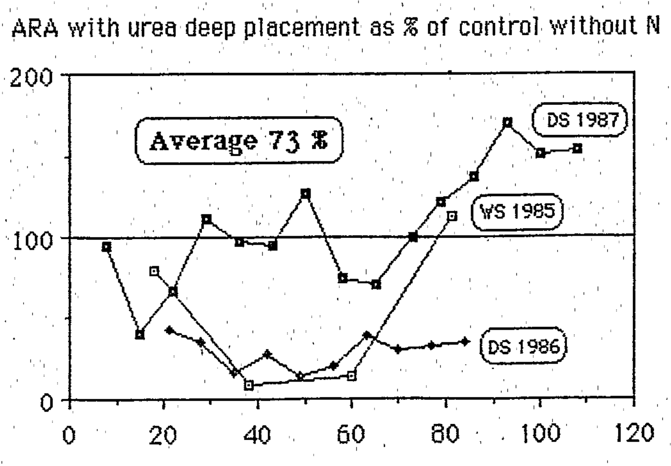


Figure 4 : Effect of Nfertilizer deep-placement on photodependant ARA as compared with a control without N.



Variability of the inhibition observed with deep-placed N might be related with N contamination of the floodwater during its placement. In 1987, when N was placed without standing water, average ARA was similar in the controls and in the plots where N was deep-placed (Fig. 4). Average inhibition over three crop cycles caused a decrease by about one third of the nitrogen fixing activity as compared with a control witout N applied.

4.1.2 Effects on floodwater ecology

Nitrogen application in the floodwater at the beginning of the crop cycle causes the blooming of green algae and diatoms whose photosynthetic activity depletes CO_2 in the floodwater, increases pH and stimulates NH_3 volatilisation. A positive correlation exists between photosynthetic activity in the floodwater (O_2 concentration) and floodwater pH (Fig. 5).

Estimation of the photosynthetic biomass in fields where N losses were evaluated indicates that large algal populations are not required to increase floodwater pH to levels that promote rapid N losses (Fillery et al. 1986).

Suppression of algal growth by Cu^{++} (Mikkelsen et al. 1978) and deep-placement of N-fertilizer (Cao et al. 1984) decreases diurnal variation of pH and N losses. Figure 6 shows the influence of the method of application of N fertilizer on floodwater pH and thus N losses by volatilization.

Figure 5 : Correlation between O_2 concentration of the floodwater and pH in 5 flooded soil (Roger and Reddy unpub.)

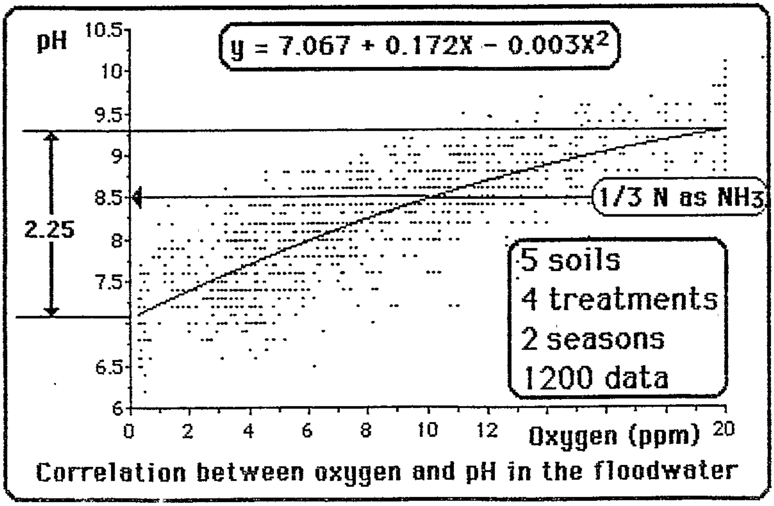
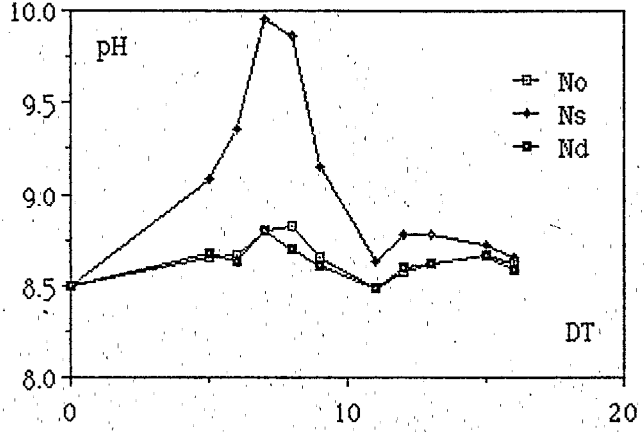


Figure 6 : Floodwater pH at noon in plot where 1) no N was applied (No), 2) urea was split broadcast, and 3) urea was deep-placed as supergranule (DS 1987, Roger et al unpub.)



The inhibitory effect of surface application of Nfertilizer on photodependant N_2-fixation might also be indirect. By favoring the growth of unicellular green algae early in the crop cycle, it then favors the development of populations of invertebrates that might further inhibit the growth of N_2-fixing BGA when the concentration of mineral nitrogen in the floodwater is not sufficient to inhibit them either directly or indirectly through competition with green algae (Fig. 7). Such an hypothesis has however not been fully demonstrated.

These results show that brodcasting fertilizer into the floodwater lead to a serie of effects wich contradict the goal of fertilization (enrichment of the environment in N nutrient available to the rice plant). These include losses of applied fertilizer by ammonia volatilization and direct and indirect inhibition of biological nitrogen fixation.

Environmental implications of ammonia volatilization are not known.

Photodependant BNF by free-living BGA has a potential impact of about 30 kg N on rice production where farmers cannot use chemical Nfertilizer. Its inhibition by chemical N fertilizer lead to the waste of a free natural input of about 20-30 kg N/ha but permit to increase very significantly grain yield. Recent experiments at IRRI shows a negative correlation between photodependant N_2-fixation and rice yield in plots where N was surface applied (Fig. 8) which confirm an inhibitory effect of N fertilizer on ARA and indicates that high ARA after N application is observed when N efficiency is poor, most probabely because of significant losses by ammonia volatilization.

Fig. 7 : Possible direct and indirect inhibitry effects of surface application of N fertilizer on N2-fixing BGA.

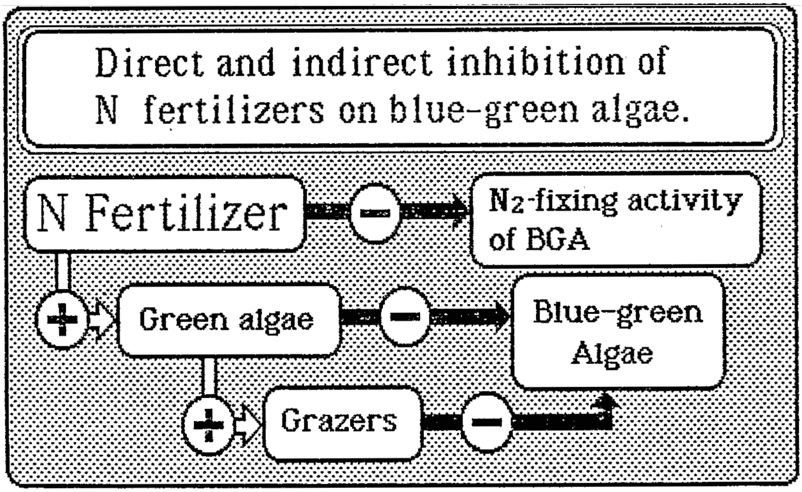
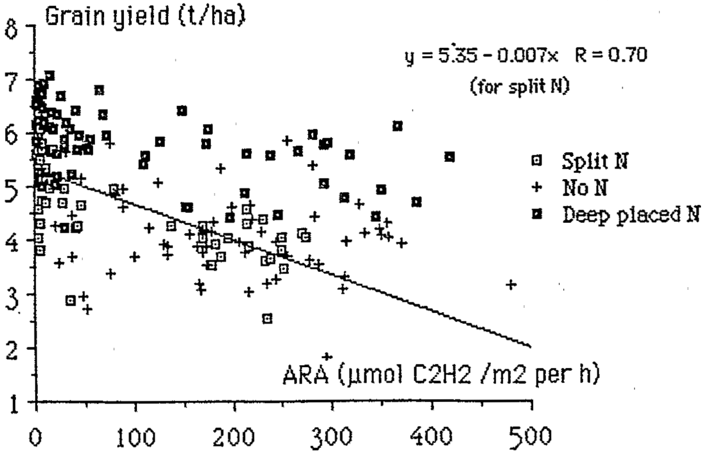


Figure 8 : Grain yield and average nitrogen fixing activity (ARA) during the crop cycle in plots according to the method of Nfertilizer application (WS 1985, DS 1986, DS 1987, Roger et al. unpub.)



Results also shows (Fig. 8) that 1) higher yieds are obtained with deep-placement of Nfertilizer, and 2) deep-placement allows the development of high N_2-fixing activities.

When inorganic Nfertilizer is used, soil N still remains the main source of N for the plant which remove about 60 kg soil N/ha /crop of rice. There are evidences that chemical Nfertilizer application increases subterranean and aquatic biomass and lead to a higher soil N fertility.

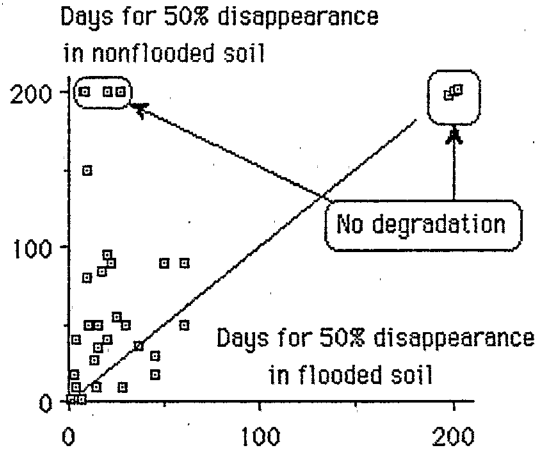
Long term-fertility experiment in flooded rice soils at Konosu, Saitama, Japan (from 1925 to 1979) showed higher total soil N and available N contents in plots where chemical fertilizer was applied than in nonfertilized plots (Kimura et al.,1980). At the end of experiment, rice was grown without fertilizer in all plots. Nitrogen absorbed by the crop was 48 kg N/ha in previously nonfertilized plots and 54 kg N/ha in previously fertilized plots. Kimura et al. (1980) concluded that a larger organic matter supply in fertilized plots due to a larger biomas production may explain the larger accumulation of total and available N in the fertilized plots than in the nonfertilized plots. This is in agreement with observations by Sayeki and Yamazaki (1978) who estimated the quantity of stubbles and root left after harvest of rice to be 1.4 t dry weight . ha^{-1} in fertilized plots and 1.0 t dry weight . ha^{-1} in nonfertilized plots. In addition to rice stubbles and roots, weed biomass, grown during the fallow period and incorporated before transplanting rice, was 0.16 t dry weight . ha^{-1} in nonfertilized plots and 1.3 t dry weight . ha^{-1} in fertilized plots. On the other hand, during rice cropping, weed biomass was larger in nonfertilized plots than in fertilized plots, presumably due to the weed depression by the larger rice biomass in fertilized plots. However, total weed biomass production in a year was larger in fertilized plots (Sayeki and Yamazaki, 1978).

4.2.Pesticides

4.2.1. Degradation of pesticides in wetland soils

Flooded rice soil is an ideal environment for rapid detoxication of certain pesticides known to persist in non flooded soils and other aerobic systems (Sethunathan and Siddaramapa, 1978). Pesticide degradation is favored by reducing conditions caused by submersion and further accelerated by organic matter incorporation, as well as a pH which , in most rice soils, stabilizes in a range favoring microbial activity (6.7 to 7.2) (Ponnamperuma. 1972).

Figure 9 : Relative stability of 30 pesticides in flooded and non flooded soils (drawn from data by Sethunathan & Siddaramappa, 1978).



Anaerobic microorganisms are particularly implicated in these transformations but chemical transformations catalyzed by redox reactions such as the iron redox system may also be common. The alternate oxydation and reduction processes in non continuously flooded soils may assist in more extensive degradation of pesticides (Sethunathan and Siddaramapa, 1978).

The comparison of the relative stability of commonly used pesticides in wetland and upland conditions (Fig. 9) shows that most of the pesticides have much longer persistance in nonflooded soils than in flooded soils.

Repeated application of pesticide has been reported to enhance the growth of the related specific decomposing microorganisms. This causes the rapid inactivation of the pesticide but may also causes changes in the metabolic pattern of pesticide decomposition that lead to serious problems. For example, Benthiocarb is generally detoxified by hydrolysis, but its repeated application to flooded soil favoured the multiplication of anaerobic bacteria that decompose Benthiocarb by reductive dechlorination, resulting in the formation of a very phytotoxic compound (Moon and Kuwatsuka, 1984).

4.2.2. Effets on soil microflora and microbial activities

A non exhaustive compilation of the recorded effect of pesticides on microflora and microbial activities in wetland rice soils is annexed (Annex 1). Table 4 presents a summarized analysis of the results. As 82 % of the data refer to insecticides, the significance of the analysis is obviously limited by the imbalance of the nature of the pesticides tested.

In the phyllosphere, pesticides tested had most often an inhibitory effect on microbial activities.

When restricting the data to observations in soil and the rhizosphere, over 290 tests of the effect of a pesticide at on a microbial population or activity, an inhibitory effect was recorded in about 30 % of the cases, no effect was recorded in about 26 % of the cases, and a promoting effect was recorded in 44 % of the cases.

Total bacteral and actinomycetes counts in soil and rhizosphere seems to be little affected by pesticides. Populations of fungi seems to be more sensitive. However it has to be keept in mind that the relative abundance of actinomycetes and fungi is much lower in wetland soils than in upland soils.

Among microbial activities, nitrification and denitrification were most frequently recorded as sensitive to pesticide application.

Results regarding N_2 fixation are variable. In about 25% of the cases a negative effect of pesticides was recorded.

Effects on other microbial populations or activities concern only very restricted number of cases and do not therefore allow conclusions.

4.2.3. Effects on floodwater microflora and microfauna

4.2.3.1 Effects on BGA

Most of the information on the effects of pesticides on algae has come from laboratory experiments conducted with flask cultures. Among the 38 references cited by Roger and Kulasooriya (1980) on the effect of pesticides on rice field algae in general only 7 refer to field observations. In a more recent review on the effect of pesticides on BGA, Chinnaswamy and Patel (1984) list 87 case studies. Only 6 of them refer to field experiments.

Flasks experiments with algal cultures can give an index of the sensitivity of the strains to the pesticides, but such results can hardly be extrapolated to field conditions for the following reasons:

Table 4: Summarization of the effect of pesticides on microbial populations and microbial activities in wetland rice soils
(Complete data and references are in annex 1)

Nature of pesticides (a)			Population/ Activity	Effect (b)		
I	H	F		-	=	+
17	1	0	Actinomycetes in soil or rhizosphere	3	7	8
2	2	0	Aerobic bacteria	0	0	4
4	4	0	Ammonification and related bacteria	4	0	5
9	0	0	Amylase	2	3	4
5	0	0	Anaerobic N_2-fixers	3	0	2
5	0	0	Azospirillum	0	0	5
15	0	0	Azotobacter in soil or rhizosphere	4	2	10
21	1	0	Bacterial count in soil or rhizosphere	3	13	9
8	1	0	Cellulase or cellulose decomposers	2	2	5
0	5	0	CO_2 production	2	0	3
2	3	0	Dehydrogenase	0	2	3
3	10	1	Denitrification or denitrifying bacteria	12	1	1
7	0	0	Dextranase	2	3	2
17	1	0	Fungi in soil or rhizosphere	9	4	5
15	0	0	Invertase	2	9	4
51	9	1	N_2 fixation in soil and/or rhizosphere)	15	11	31
18	1	0	Nitrification	14	4	1
1	2	0	Nitrite oxidizers	1	2	0
17	2	0	Phosphatase or P solubilizing bacteria	3	8	9
1	1	0	Sulphate reducers	0	0	2
2	3	0	Urease	0	4	1
13	0	0	ß-glucosidase	8	0	5
3	4		Miscellanous	0	0	7
236	**50**	**2**	**TOTAL**	**89**	**75**	**126**
280	0	0	Populations and activities in phyllosphere	25	3	0
264	**50**	**2**	**TOTAL**	**114**	**78**	**126**

(a) Nature of the pesticide and n° of records (I = insecticide, H = herbicide, F = fungicide).
(b) Nature of effect and number of records (- : inhibitory effect, = : no effect, + : enhancement)

- Toxicity seems to be higher in flask cultures than in the field; for example. 5 ppm propanil prevented the growth of *Anabaena cylindrica, Tolypothrix tenuis*, and *Nostoc endophytum* in flask cultures, but the same concentration did not produce any inhibition in the presence of unsterilized or sterilized soil (Wright et al., 1977).
- The rate of degradation of pesticides in the fields is likely to be more rapid than in flask experiments.
- In the field, toxicity also depends on the initial microbial population, the nutrient status, and the mode of application of the pesticides: Pentachlorophenol incorporated in soil with lime stimulated N_2-fixing BGA; but if surface-applied, even at low levels, it was depressive with a long residual effect (Ishizawa and Matsuguchi, 1966).
- For nonpersistent pesticides, the rate of degradation and the toxicity of degradation products are important in considering the possible effects on algae. Laboratory experiments showed that metabolic products of Aldrin, Dieldrin, and Endrin are inhibitory to algal growth (Batterton et al., 1971). 3-4 Dichloroaniline, the primary product of Propanil degradation, is far less inhibitory than Propanil, but at the concentration of Propanil used in the field (12 ppm), the degradation product can still be inhibitory for some BGA (Wright et al., 1977).

Depending upon the nature of the chemical, its concentration, and the algal strain, the pesticide's effect on BGA could be inhibitory, selective, or even stimulatory.

From the bibliographic review on BGA and Rice by Roger and Kulasooriya (1980) following conclusions can be drawn :

- Resistance to pesticides varies widely with strain but most of the N_2-fixing BGA can tolerate high levels of pesticides, generally higher than the recommended application rate .
- BGA seems to be more resistant than other algae to pesticides, which may lead to a selective effect of pesticides on algal flora.
- A direct stimulatory effect of some herbicides and insecticides has been recorded at low concentrations.
- Insectides have been shown to have an indirect stimulatory effect on algal growth due to a decreasing population of algal grazers.
- In general, pesticides appear to have an initial depressive effect on N_2-fixation by BGA, followed by either an increase or decrease in activity . Inhibitory effects have been reported at concentrations recommended for field application of herbicides whereas insecticides generally had little effect.

4.2.3.2. Effect on micro fauna

A common observation in the IRRI farm is that at the beginning of the crop cycle, Furadan application, after an initial decrease of zooplancton populations is usually followed by the resurgence of ostracods that develop populations as high than 10.000 to 15.000 individuals/m^2. Such populations may cause the disappearance of algal bloooms in a few days. Their activity is easy to notice, the floodwater becoming muddy because of the scrapping action of these invertebrates at the soil surface.

A field study by Takamura and Yasuno (1986) also 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 probabely because of grazing by ostracods.

4.2.4. Conclusion for pesticides

Studies of the microbial degradation of pesticides and their influence on microflora and microbial activities in flooded rice soils, hitherto mostly restricted to laboratory conditions, must be performed under more realistic field conditions and cultural practices.

Effects of pesticides might be temporary or result in the removal or depression of components of the microbial community, thus leadind to a new microfora equilibrium. Little attention, has been paid to long term effects of pesticides application. The observation that repeated application of pesticides may result in detrimental changes in the pattern of their microbial decomposition (Moon and Kuwatsuka,1984) shows the need to study long-term effect of pesticide application to their metabolism *in situ*

4.3.Overcultivation : the rice garden

The rice garden was a high input continuous year-round rice production system divided into a number of small plots (13) equal to the rice crop duration expressed in weeks (Domingo, 1985). Each week, one plot was transplanted and another was harvested. During the wet season, urea (60kg N/ha) and superphosphate (30 kg P205/ha) was incorporated at the final harrowing; ammonium sulfate (30 kg N/ha) was topdressed 22 DT. During the dry season, 80kgN was applied as basal and 40 as topdressing. Five tons/ha of chicken manure was applied every 4 crops. Intensive weeding was performed and high levels of pesticides were used.

Yield records (Fig 10) show a tendancy of the productivity to decrease with time.

Figure 10 : Monthly grain yield in the rice garden from 1978 to 1983 (Drawn from data of Domingo, 1985).

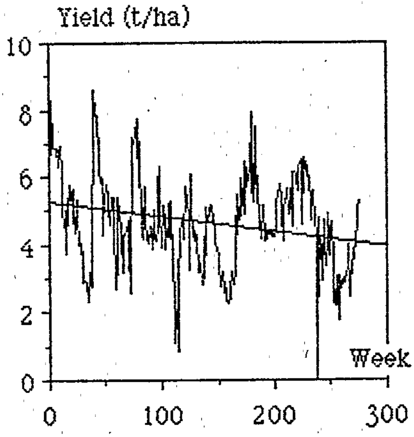
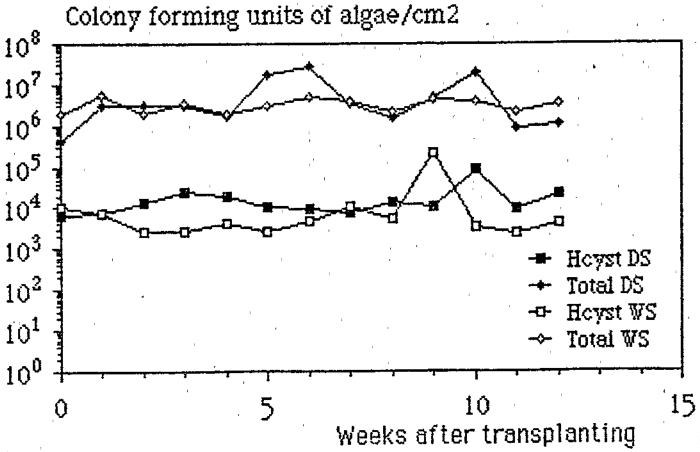


Figure 11 : Abundance of N2-fixig BGA (Hcyst) and total algae (Total) in the plots of the rice garden at IRRI as a funtion of the age of the crop during the wet and dry seasons 1985.



As a result of the continuous presence of a rice canopy, pesticide application, and intensive weeding, photosynthetic aquatic biomass was very low in the plots. Visual observations and estimation of total algae and N_2-fixing BGA by plating (Fig. 10) showed very limited algal growth in both the dry and wet season. In most cases, densities of algae did not significantly differed from the values measured in the soil collected just after plowing to estimate the abundance of spores present in the soil.

The absence of data on soil chemistry and microbial biomass in this experiment do not permit to draw definite conclusions, however observations made show the need for long term experiments to study the effects of intensive continuous cropping on the photosynthetic aquatic biomass, the microbial biomass and the available N.

5. CONCLUSIONS AND SUMMARY

Flooding maintains biological and chemical fertility of the rice field ecosystem through the diversification of microbial environments and the establishment of an aquatic community preponderant in recycling nutrients and providing available N into the ecosystem.

Crop intensification provoques blooming of individual species and replaces the diversity of food production observed in traditional rice fields by rice productivity. An important issue might be how to increase rice yield while preserving the ability of the rice field ecosystem to produce additional sources of protein (Rice-fish ; Rice-Azolla-fish (Liu ChungChu, 1986).

Among possible environmental effects of crop intensification on soil and floodwater populations, the effect of Nfertilizer and pesticides application have been mostly studied.

Chemical Nfertilizer application increases rice biomass as well as subterranean and aquatic biomass, and lead to a higher soil N fertility. However, brodcasting Nfertilizer into the floodwater causes direct and indirect inhibition of biological nitrogen fixation and losses of applied fertilizer by ammonia volatilization. This lead to the wastage of a free natural N input of 20-30 kg N/ha per crop and a significant part of fertilizer. Both losses can be significantly reduced by deep-placement or incorporation of Nfertilizer. A better understanding of the floodwater ecology will help in decreasing N wastage due to a non optimized management of the photosynthetic biomass.

Flooded rice soil is an ideal environment for rapid detoxication of many pesticides. Degradation is usually faster in flooded soils than in non flooded soils and other aerobic systems. In 290 tests of the effect of a pesticide on a microbial population or activity in wetland soils or in rice rhizosphere, an inhibitory effect was recorded in about 30 % of the cases, no effect was recorded in about 26 % of the cases, and a promoting effect was recorded in 44 % of the cases.

Study of the effects of pesticides, hitherto mostly restricted to short term laboratory conditions, must be performed under more realistic field conditions and cultural practices. Pesticides might have only temporary effects but, when applied repetitively, lead to the disparition or strong depression of several components of the microbial community, thus leading to a new equilibrium and detrimental changes in the pattern of their microbial decomposition. Therefore, attention has to be paid to long term effects of pesticide application. With regard to the major role of the microfauna in recycling N in the rice field ecosystem, attention should also be paid to the effect of pesticides on invertebrates populations.

Maximum crop intensification by continuous rice cultivation with high chemical inputs and little fallow period lead to a significant decrease of the photosynthetic aquatic biomass and might result in a decrease of soil fertility.

A major issue is the study of long term effects of the factors of crop intensification (cropping intensity, Nfertilizer, and pesticides) on microbiological properties of soil. Principal aspects are the effects on the ecology of the photic zone (floodwater and surface soil) in relation with N cycling and the effects on soil microbial biomass in relation with N availability.

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Annex 1 Effect of pesticides on microbial populations in wetland rice soils.

PESTICIDE		Concentration range	Population/ Activity	At field rate			At higher rates			REFERENCE
				-	=	+	-	=	+	
Phorate	I	1.25 kg a.i./ha	Actinomycetes			1				Kandasamy et al., 1975
Carbofuran	I	1.25 kg a.i./ha	Actinomycetes		1					Kandasamy et al., 1975
Carbaryl + lindane	I	1.5 kg a.i./ha	Actinomycetes			1				Purushothman et al., 1976
Carbofuran	I	1.5 kg a.i./ha	Actinomycetes		1					Purushothman et al., 1976
Cytrolane	I	1.5 kg a.i./ha	Actinomycetes		1					Purushothman et al., 1976
Diazinone	I	1.5 kg a.i./ha	Actinomycetes		1					Purushothman et al., 1976
Dursban	I	1.8 L/acre	Actinomycetes			1				Sivasithamparam, 1970
Dursban	I	1.5 kg a.i./ha	Actinomycetes		1					Purushothman et al., 1976
Linuron	H	1 Lb./acre	Actinomycetes			1				Sivasithamparam, 1970
Quinalphos	I	1.5 kg a.i./ha	Actinomycetes		1					Purushothman et al., 1976
mephosfolan	I	0.75 to 1.0 kg a.i./ha	Actinomycetes *	1			1			Sivaraj & Venugopal, 1979
AC 92100	I	1.0 kg a.i./ha	Actinomycetes in rhizosphere	1						Jayachandran & Chandramohan, 1977
Carbofuran	I	1.0 kg a.i./ha	Actinomycetes in rhizosphere		1					Jayachandran & Chandramohan, 1977
Chlorfenvinphos	I	1.0 kg a.i./ha	Actinomycetes in rhizosphere			1				Jayachandran & Chandramohan, 1977
Chlorodimeform	I	1.0 kg a.i./ha	Actinomycetes in rhizosphere			1				Jayachandran & Chandramohan, 1977
Diazinon	I	1.0 kg a.i./ha	Actinomycetes in rhizosphere			1				Jayachandran & Chandramohan, 1977
Mephosfolan	I	1.0 kg a.i./ha	Actinomycetes in rhizosphere	1						Jayachandran & Chandramohan, 1977
Quinalphos	I	1.0 kg a.i./ha	Actinomycetes in rhizosphere			1				Jayachandran & Chandramohan, 1977
			COUNTS	3	7	8	1	0	0	
Dursban	I	1.8 L/acre	Aerobic bacteria			1				Sivasithamparam, 1970
Linuron	H	1 Lb./acre	Aerobic bacteria			1				Sivasithamparam, 1970
Dursban	I	1.8 L/acre	Aerobic N fixers			1				Sivasithamparam, 1970
Linuron	H	1 Lb./acre	Aerobic N fixers			1				Sivasithamparam, 1970
			COUNTS	0	0	4	0	0	0	
Dursban	I	1.8 L/acre	Ammonifiers			1				Sivasithamparam, 1970
Linuron	H	1 Lb./acre	Ammonifiers			1				Sivasithamparam, 1970
benthiocarb	H	r. r.	Ammonifying bacteria			1				Sato, 1987.
Dursban	I	1.8 L/acre	Ammonium oxidizers	1						Sivasithamparam, 1970
Linuron	H	1 Lb./acre	Ammonium oxidizers	1						Sivasithamparam, 1970
benthiocarb	H	10 x r. r.	Ammonium-N				1			Sato, 1987.
Dithane A-40		8 to 15 kg/ha	Ammonium-N availability			2			2	Russo, 1970
Ordram		55 to 80 kg/ha	Ammonium-N availability	1				1		Russo, 1970
potassium azide		4 to 10 kg/ha	Ammonium-N availability			1			1	Russo, 1970

Annex 1 Effect of pesticides on microbial populations in wetland rice soils.

PESTICIDE		Concentration range	Population/ Activity	At field rate			At higher rates			
				-	=	+	-	=	+	REFERENCE
benthiocarb	H	r.r.	Ammonium-oxidizing bacteria	1						Sato, 1987.
			COUNTS	4	0	5	1	1	2	
AC 92100	I	1.0 kg a.i./ha	Amylase	1						Jayachandran & Chandramohan,1977
Basalin 48 EC		2 to 10 ppm	Amylase		1		2			Palaniappan & Balasubramanian,1985
Carbofuran	I	1.0 kg a.i./ha	Amylase	1						Jayachandran & Chandramohan,1977
Chlorfenvinphos	I	1.0 kg a.i./ha	Amylase			1				Jayachandran & Chandramohan,1977
Chlorodimeform	I	1.0 kg a.i./ha	Amylase		1					Jayachandran & Chandramohan,1977
Diazinon	I	1.0 kg a.i./ha	Amylase			1				Jayachandran & Chandramohan,1977
Furadan 3G	I	2 to 10 ppm	Amylase			1			2	Palaniappan & Balasubramanian,1985
Mephosfolan	I	1.0 kg a.i./ha	Amylase		1					Jayachandran & Chandramohan,1977
Quinalphos	I	1.0 kg a.i./ha	Amylase			1				Jayachandran & Chandramohan,1977
			COUNTS	2	3	4	1	0	1	
Carbofuran	I	1.0 kg a.i./ha	Anaerobic N2-fixers	1						Rao et al., 1983
Carbofuran	I	1.0 kg a.i./ha	Anaerobic N2-fixers			1				Rao et al., 1983
SAN-155	I	1.0 kg a.i./ha	Anaerobic N2-fixers	1						Rao et al., 1983
SAN-155	I	0.02 % a.i.	Anaerobic N2-fixers	1						Rao et al., 1983
SAN-155	I	1.0 kg a.i./ha	Anaerobic N2-fixers			1				Rao et al., 1983
			COUNTS	3	0	2	0	0	0	
Carbofuran	I	1.0 kg a.i./ha	Azospirillum			1				Rao et al., 1983
Carbofuran	I	1.0 kg a.i./ha	Azospirillum			1				Rao et al., 1983
SAN-155	I	1.0 kg a.i./ha	Azospirillum			1				Rao et al., 1983
SAN-155	I	1.0 kg a.i./ha	Azospirillum			1				Rao et al., 1983
SAN-155	I	0.02 % a.i.	Azospirillum			1				Rao et al., 1983
			COUNTS	0	0	5	0	0	0	
Carbofuran	I	1.0 kg a.i./ha	Azotobacter			1				Rao et al., 1983
Carbofuran	I	1.0 kg a.i./ha	Azotobacter			1				Rao et al., 1983
SAN-155	I	1.0 kg a.i./ha	Azotobacter		1					Rao et al., 1983
SAN-155	I	1.0 kg a.i./ha	Azotobacter			1				Rao et al., 1983
SAN-155	I	0.02 % a.i.	Azotobacter	1						Rao et al., 1983
AC 92100	I	1.0 kg a.i./ha	Azotobacter in rhizosphere	1						Jayachandran & Chandramohan,1977
Carbofuran	I	1.0 kg a.i./ha	Azotobacter in rhizosphere			1				Jayachandran & Chandramohan,1977
Chlorfenvinphos	I	1.0 kg a.i./ha	Azotobacter in rhizosphere			1				Jayachandran & Chandramohan,1977
Chlorodimeform	I	1.0 kg a.i./ha	Azotobacter in rhizosphere			1				Jayachandran & Chandramohan,1977

PESTICIDE		Concentration range	Population/ Activity	At field rate			At higher rates			
				-	=	+	-	=	+	REFERENCE
Diazinon	I	1.0 kg a.i./ha	Azotobacter in rhizosphere			1				Jayachandran & Chandramohan,1977
Mephosfolan	I	1.0 kg a.i./ha	Azotobacter in rhizosphere	1						Jayachandran & Chandramohan,1977
Quinalphos	I	1.0 kg a.i./ha	Azotobacter in rhizosphere			1				Jayachandran & Chandramohan,1977
Phorate	I	1.25 kg a.i./ha	Azotobacter population			1				Kandasamy et al., 1975
Carbofuran	I	1.25 kg a.i./ha	Azotobacter population		1					Kandasamy et al., 1975
mephosfolan	I	0.75 to 1.0 kg a.i./ha	Azotobacter population *	1		2				Sivaraj & Venugopal,1979
			COUNTS	4	2	10	0	0	0	
AC 92100	I	1.0 kg a.i./ha	Bacteria in rhizosphere	1						Jayachandran & Chandramohan,1977
Carbofuran	I	1.0 kg a.i./ha	Bacteria in rhizosphere			1				Jayachandran & Chandramohan,1977
Chlorfenvinphos	I	1.0 kg a.i./ha	Bacteria in rhizosphere			1				Jayachandran & Chandramohan,1977
Chlorodimeform	I	1.0 kg a.i./ha	Bacteria in rhizosphere			1				Jayachandran & Chandramohan,1977
Diazinon	I	1.0 kg a.i./ha	Bacteria in rhizosphere			1				Jayachandran & Chandramohan,1977
Mephosfolan	I	1.0 kg a.i./ha	Bacteria in rhizosphere	1						Jayachandran & Chandramohan,1977
Quinalphos	I	1.0 kg a.i./ha	Bacteria in rhizosphere			1				Jayachandran & Chandramohan,1977
Carbofuran	I	1.5 kg a.i./ha	Bacterial count		1					Purushothman et al., 1976
Cytrolane	I	1.5 kg a.i./ha	Bacterial count		1					Purushothman et al., 1976
Diazinone	I	1.5 kg a.i./ha	Bacterial count		1					Purushothman et al., 1976
Dursban	I	1.5 kg a.i./ha	Bacterial count		1					Purushothman et al., 1976
Quinalphos	I	1.5 kg a.i./ha	Bacterial count		1					Purushothman et al., 1976
Carbaryl + lindane	I	1.5 kg a.i./ha	Bacterial count		1					Purushothman et al., 1976
EPN	I	10 to 90 ppm	Bacterial count			1			2	Nishio & Kusano,1978
fenitrothion	I	10 to 90 ppm	Bacterial count		1			1		Nishio & Kusano,1978
malathion	I	10 to 90 ppm	Bacterial count			1			2	Nishio & Kusano,1978
Carbofuran	I	1.25 kg a.i./ha	Bacterial count		1					Kandasamy et al., 1975
Phorate	I	1.25 kg a.i./ha	Bacterial count		1					Kandasamy et al., 1975
mephosfolan	I	0.75 to 1.0 kg a.i./ha	Bacterial count*	1	1	1	1		1	Sivaraj & Venugopal,1979
benthiocarb	H	r.r.	Bacterial count			1				Sato, 1987.
Endrin	I	0.45 to 2.25 kg a.i./ha	Bacterial count		1					Nair et al., 1974
gamma-BHC	I	0.45 to 2.25 kg a.i./ha	Bacterial count		1					Nair et al., 1974
Sevidol	I	0.45 to 2.25 kg a.i./ha	Bacterial count		1					Nair et al., 1974
			COUNTS	3	13	9	1	1	3	
AC 92100	I	1.0 kg a.i./ha	Cellulase	1						Jayachandran & Chandramohan,1977
Carbofuran	I	1.0 kg a.i./ha	Cellulase			1				Jayachandran & Chandramohan,1977

Annex 1 Effect of pesticides on microbial populations in wetland rice soils.

PESTICIDE		Concentration range	Population/ Activity	At field rate			At higher rates			REFERENCE
				-	=	+	-	=	+	
Chlorfenvinphos	I	1.0 kg a.i./ha	Cellulase			1				Jayachandran & Chandramohan,1977
Chlorodimeform	I	1.0 kg a.i./ha	Cellulase		1					Jayachandran & Chandramohan,1977
Diazinon	I	1.0 kg a.i./ha	Cellulase			1				Jayachandran & Chandramohan,1977
Mephosfolan	I	1.0 kg a.i./ha	Cellulase	1						Jayachandran & Chandramohan,1977
Quinalphos	I	1.0 kg a.i./ha	Cellulase		1					Jayachandran & Chandramohan,1977
Dursban	I	1.8 L/acre	Cellulose decomposers			1				Sivasithamparam, 1970
Linuron	H	1 Lb./acre	Cellulose decomposers			1				Sivasithamparam, 1970
			COUNTS	2	2	5	0	0	0	
2,4-D	H	19.76 kg/ha	CO2 production			2				Baruah & Mishra, 1986
butachlor	H	2.47 l/ha	CO2 production			2				Baruah & Mishra, 1986
oxyfluorfen	H	1.54 l/ha	CO2 production			2				Baruah & Mishra, 1986
Tribunil	H	0.5 to 5 ppm	CO2 production	1			1			Chopra & Magu, 1986
Isoproturon	H	0.35 to 3.50 ppm	CO2 production	1			1			Chopra & Magu, 1986
			COUNTS	2	0	3	2	0	0	
2,4-D	H	19.76 kg/ha	Dehydrogenase			2				Baruah & Mishra, 1986
Basalin 48 EC		2 to 10 ppm	Dehydrogenase		1		2			Palaniappan & Balasubramanian,1985
butachlor	H	2.47 l/ha	Dehydrogenase			2				Baruah & Mishra, 1986
Furadan 3G	I	2 to 10 ppm	Dehydrogenase		1		1			Palaniappan & Balasubramanian,1985
oxyfluorfen	H	1.54 l/ha	Dehydrogenase			2				Baruah & Mishra, 1986
			COUNTS	0	2	3	2	0	0	
Dicyandiamide		100 ppm	Denitrification					1		Mitsui et al.,1964
DIECA		100 ppm	Denitrification		1					Mitsui et al.,1964
Dithane	F	500 mg/pot	Denitrification	1						Mitsui et al.,1964
gamma BHC	I	100 mg/pot	Denitrification				1			Mitsui et al.,1964
N-Serve		14 ppm	Denitrification	1						Mitsui et al.,1964
Nabam		50 to 100 ppm	Denitrification	1						Mitsui et al.,1964
PCP-Na	H	20 mg/pot	Denitrification				1			Mitsui et al.,1964
Sodium azide		10 to 30 ppm	Denitrification	2						Mitsui et al.,1964
Sodium chlorate		50 to 100 ppm	Denitrification				1			Mitsui et al.,1964
Na monoiodoacetate		50 ppm	Denitrification	2						Mitsui et al.,1964
Thiuram		50 to 100 ppm	Denitrification	1						Mitsui et al.,1964
Vapam		20 ppm	Denitrification	2						Mitsui et al.,1964
Ziram		50 to 100 ppm	Denitrification	1						Mitsui et al.,1964

PESTICIDE		Concentration range	Population/ Activity	At field rate			At higher rates			
				-	=	+	-	=	+	REFERENCE
Ferbam		50 to 100 ppm	Denitrification	1						Mitsui et al.,1964
Maneb		50 to 100 ppm	Denitrification	1						Mitsui et al.,1964
Dursban	I	1.8 L/acre	Denitrifiers	2						Sivasithamparam, 1970
Linuron	H	1 Lb./acre	Denitrifiers	2						Sivasithamparam, 1970
benthiocarb	H	r.r.	Denitrifying bacteria			1				Sato, 1987.
			COUNTS	12	1	1	3	1	0	
AC 92100	I	1.0 kg a.i./ha	Dextranase	1						Jayachandran & Chandramohan,1977
Carbofuran	I	1.0 kg a.i./ha	Dextranase		1					Jayachandran & Chandramohan,1977
Chlorfenvinphos	I	1.0 kg a.i./ha	Dextranase			1				Jayachandran & Chandramohan,1977
Chlorodimeform	I	1.0 kg a.i./ha	Dextranase		1					Jayachandran & Chandramohan,1977
Diazinon	I	1.0 kg a.i./ha	Dextranase		1					Jayachandran & Chandramohan,1977
Mephosfolan	I	1.0 kg a.i./ha	Dextranase	1						Jayachandran & Chandramohan,1977
Quinalphos	I	1.0 kg a.i./ha	Dextranase			1				Jayachandran & Chandramohan,1977
			COUNTS	2	3	2	0	0	0	
Carbofuran	I	1.25 kg a.i./ha	Fungal population		1					Kandasamy et al., 1975
Phorate	I	1.25 kg a.i./ha	Fungal population		1					Kandasamy et al., 1975
Carbofuran	I	1.5 kg a.i./ha	Fungal population	1						Purushothman et al., 1976
Cytrolane	I	1.5 kg a.i./ha	Fungal population	1						Purushothman et al., 1976
Diazinone	I	1.5 kg a.i./ha	Fungal population	1						Purushothman et al., 1976
Dursban	I	1.5 kg a.i./ha	Fungal population	1						Purushothman et al., 1976
Quinalphos	I	1.5 kg a.i./ha	Fungal population	1						Purushothman et al., 1976
Carbaryl + lindane	I	1.5 kg a.i./ha	Fungal population	1						Purushothman et al., 1976
mephosfolan	I	0.75 to 1.0 kg a.i./ha	Fungal population *	1			1			Sivaraj & Venugopal,1979
Dursban	I	1.8 L/acre	Fungal population		1					Sivasithamparam, 1970
Linuron	H	1 Lb./acre	Fungal population			1				Sivasithamparam, 1970
AC 92100	I	1.0 kg a.i./ha	Fungi in rhizosphere	1						Jayachandran & Chandramohan,1977
Carbofuran	I	1.0 kg a.i./ha	Fungi in rhizosphere		1					Jayachandran & Chandramohan,1977
Chlorfenvinphos	I	1.0 kg a.i./ha	Fungi in rhizosphere			1				Jayachandran & Chandramohan,1977
Chlorodimeform	I	1.0 kg a.i./ha	Fungi in rhizosphere			1				Jayachandran & Chandramohan,1977
Diazinon	I	1.0 kg a.i./ha	Fungi in rhizosphere			1				Jayachandran & Chandramohan,1977
Mephosfolan	I	1.0 kg a.i./ha	Fungi in rhizosphere	1						Jayachandran & Chandramohan,1977
Quinalphos	I	1.0 kg a.i./ha	Fungi in rhizosphere			1				Jayachandran & Chandramohan,1977
			COUNTS	9	4	5	1	0	0	

Annex 1 Effect of pesticides on microbial populations in wetland rice soils.

PESTICIDE		Concentration range	Population/ Activity	At field rate			At higher rates			
				-	=	+	-	=	+	REFERENCE
benthiocarb	H	r.r.	Gram-negative bacteria			1				Sato, 1987.
Basalin 48 EC		2 to 10 ppm	Invertase		1		2			Palaniappan & Balasubramanian,1985
Furadan 3G	I	2 to 10 ppm	Invertase		1		1			Palaniappan & Balasubramanian,1985
AC 92100	I	1.0 kg a.i./ha	Invertase	1						Jayachandran & Chandramohan,1977
Carbaryl + lindane	I	1.5 kg a.i./ha	Invertase		1					Purushothman et al., 1976
Carbofuran	I	1.0 kg a.i./ha	Invertase		1					Jayachandran & Chandramohan,1977
Carbofuran	I	1.5 kg a.i./ha	Invertase		1					Purushothman et al., 1976
Chlorfenvinphos	I	1.0 kg a.i./ha	Invertase			1				Jayachandran & Chandramohan,1977
Chlorodimeform	I	1.0 kg a.i./ha	Invertase			1				Jayachandran & Chandramohan,1977
Cytrolane	I	1.5 kg a.i./ha	Invertase		1					Purushothman et al., 1976
Diazinon	I	1.0 kg a.i./ha	Invertase			1				Jayachandran & Chandramohan,1977
Diazinone	I	1.5 kg a.i./ha	Invertase		1					Purushothman et al., 1976
Dursban	I	1.5 kg a.i./ha	Invertase		1					Purushothman et al., 1976
Mephosfolan	I	1.0 kg a.i./ha	Invertase	1						Jayachandran & Chandramohan,1977
Quinalphos	I	1.0 kg a.i./ha	Invertase			1				Jayachandran & Chandramohan,1977
Quinalphos	I	1.5 kg a.i./ha	Invertase		1					Purushothman et al., 1976
			COUNTS	2	9	4	2	0	0	
Dursban	I	1.8 L/acre	Iron precipitators			1				Sivasithamparam, 1970
Linuron	H	1 Lb./acre	Iron precipitators			1				Sivasithamparam, 1970
			COUNTS	0	0	2	0	0	0	
Dithane A-40		8 to 15 kg/ha	K solubility			1			1	Russo, 1970
Ordram		55 to 80 kg/ha	K solubility			1			1	Russo, 1970
potassium azide		4 to 10 kg/ha	K solubility			1			1	Russo, 1970
			COUNTS	0	0	3	0	0	3	
Carbofuran	I	4 µg/g soil	N2 fixation (flooded soil)			2				Jena & Rajaramamohan Rao, 1986
oxadiazone	H	1 to 5 µg/g soil	N2 fixation (flooded soil)			2		x		Jena & Rajaramamohan Rao, 1986
Oxadiazone+Furadan	H+I	1 : 4 µg/g soil	N2 fixation (flooded soil)			2				Jena & Rajaramamohan Rao, 1986
Oxadiazone+Furadan	H+I	5 : 4 µg/g soil	N2 fixation (flooded soil)			1				Jena & Rajaramamohan Rao, 1986
thiobencarb	H	4 µg/g soil	N2 fixation (flooded soil)		1					Jena & Rajaramamohan Rao, 1986
Thiobencarb+Furadan	H+I	4 : 4 µg/g soil	N2 fixation (flooded soil)			1				Jena & Rajaramamohan Rao, 1986
Carbofuran	I	4 µg/g soil	N2 fixation (nonflooded soil)			2				Jena & Rajaramamohan Rao, 1986
thiobencarb	H	4 µg/g soil	N2 fixation (nonflooded soil)		1					Jena & Rajaramamohan Rao, 1986

Annex 1 Effect of pesticides on microbial populations in wetland rice soils.

PESTICIDE		Concentration range	Population/ Activity	At field rate			At higher rates			
				-	=	+	-	=	+	REFERENCE
Thiobencarb+Furadan	H+I	4 : 4 µg/g soil	N2 fixation (nonflooded soil)			2				Jena & Rajaramamohan Rao, 1986
butachlor	H	2 µg/g soil	N2 fixation (nonflooded soil)			2				Jena & Rajaramamohan Rao, 1986
Butachlor+Furadan	H+I	2 : 4 µg/g soil	N2 fixation (nonflooded soil)			2				Jena & Rajaramamohan Rao, 1986
BPMC	I	0.02 % a.i.	N2-ase (soil+rhizosphere)			1				Rao et al., 1983
benomyl	F	5 ppm	N2 fixation (heterotrophic) *			2				Nayak & Rajaramamohan Rao, 1980.
Carbofuran	I	5 ppm	N2 fixation (heterotrophic) *			1				Nayak & Rajaramamohan Rao, 1980.
gamma-BHC	I	5 ppm	N2 fixation (heterotrophic) *	2		1				Nayak & Rajaramamohan Rao, 1980.
			COUNTS	1	2	13	0	0	0	
benthiocarb	H	r.r.	Nitrate-reducing bacteria			1				Sato, 1987.
EPN	I	10 to 90 ppm	Nitrification		1			1		Nishio & Kusano,1978
Benomyl	I	10 to 100 ppm	Nitrification	1			2			Ramakrishna & Sethunathan,1982
HCH	I	10 to 100 ppm	Nitrification	2			2			Ramakrishna & Sethunathan,1982
butachlor	H	1.5 kg a.i./ha	Nitrification	1						Sathasivan et al., 1982
Carbaryl	I	10 to 100 ppm	Nitrification	1			2			Ramakrishna & Sethunathan,1982
Carbofuran	I	0.75 kg a.i./ha	Nitrification		1					Sathasivan et al., 1982
Carbofuran	I	10 to 100 ppm	Nitrification			2			2	Ramakrishna & Sethunathan,1982
fenitrothion	I	10 to 90 ppm	Nitrification	1			2			Nishio & Kusano,1978
FMC 35001	I	0.75 kg a.i./ha	Nitrification		1					Sathasivan et al., 1982
lindane	I	1.5 kg a.i./ha	Nitrification	1						Sathasivan et al., 1982
malathion	I	10 to 90 ppm	Nitrification	1			1			Nishio & Kusano,1978
Sevidol	I	0.5 to 2 kg a.i./ha	Nitrification		1				1	Singh et al., 1986
bifenox		3.36 kg/ha	Nitrification *	2			1			Turner, 1979.
Carbofuran	I	0.56 kg/ha	Nitrification *	1			1			Turner, 1979.
molinate		3.36 kg/ha	Nitrification *	1			1			Turner, 1979.
nitrapyrin		5.60 kg/ha	Nitrification *	2			2			Turner, 1979.
propanil		3.36 kg/ha	Nitrification *	1			2			Turner, 1979.
sodium azide		5.60 kg/ha	Nitrification *	2			2			Turner, 1979.
terrazole		5.60 kg/ha	Nitrification *	2			2			Turner, 1979.
			COUNTS	14	4	1	12	1	2	
Dursban	I	1.8 L/acre	Nitrite oxidizers		1					Sivasithamparam, 1970
Linuron	H	1 Lb./acre	Nitrite oxidizers		1					Sivasithamparam, 1970
benthiocarb	H	r.r.	Nitrite oxidizers	1						Sato, 1987.

Annex 1 Effect of pesticides on microbial populations in wetland rice soils.

PESTICIDE		Concentration range	Population/ Activity	At field rate			At higher rates			
				-	=	+	-	=	+	REFERENCE
			COUNTS	1	2	0	0	0	0	
Allitin	I	0.5%	Nitrogenase (Azospirillum)			1				Nayak et al., 1980.
neem extract	I	1%	Nitrogenase (Azospirillum)		1					Nayak et al., 1980.
neem oil	I	1%	Nitrogenase (Azospirillum)		1					Nayak et al., 1980.
Phosalone	I	0.5 kg/ha	Nitrogenase (Azospirillum)			1				Nayak et al., 1980.
pyrethrum	I	0.005%	Nitrogenase (Azospirillum)			1				Nayak et al., 1980.
Quinalphos	I	0.5 kg/ha	Nitrogenase (Azospirillum)			1				Nayak et al., 1980.
Carbofuran	I	2 kg a.i./ha	Nitrogenase (rhizosphere)			1				Rao et al., 1984
metham sodium	I	500 l/ha	Nitrogenase (rhizosphere)			1				Rao et al., 1984
Phosalone	I	0.5 kg/ha	Nitrogenase (rhizosphere)	2						Nayak et al., 1980.
prophos	I	2 kg a.i./ha	Nitrogenase (rhizosphere)			2				Rao et al., 1984
pyrethrum	I	0.005%	Nitrogenase (rhizosphere)	2						Nayak et al., 1980.
Allitin	I	0.5%	Nitrogenase (rhizosphere)	2						Nayak et al., 1980.
neem extract	I	1%	Nitrogenase (rhizosphere)	1						Nayak et al., 1980.
neem oil	I	1%	Nitrogenase (rhizosphere)	2						Nayak et al., 1980.
Chlorpyriphos	I	0.02 % a.i.	Nitrogenase (soil+rhizosphere	2						Rao et al., 1983
Carbaryl	I	0.02 % a.i.	Nitrogenase (soil+rhizosphere)		1					Rao et al., 1983
Carbofuran	I	1.0 kg a.i./ha	Nitrogenase (soil+rhizosphere)			1				Rao et al., 1983
Carbofuran	I	1.0 kg a.i./ha	Nitrogenase (soil+rhizosphere)			1				Rao et al., 1983
Diazinon	I	1.0 kg a.i./ha	Nitrogenase (soil+rhizosphere)		1	1				Rao et al., 1983
Quinalphos	I	0.5 kg/ha	Nitrogenase in rhizosphere	2						Nayak et al., 1980.
Chlorfenvinphos	I	0.02 % a.i.	Nitrogenase(soil+rhizosphere)	2						Rao et al., 1983
Endosulfan	I	1.0 kg a.i./ha	Nitrogenase(soil+rhizosphere)		1	1				Rao et al., 1983
Endosulfan	I	0.02 % a.i.	Nitrogenase(soil+rhizosphere)			1				Rao et al., 1983
Endosulfan	I	1.0 kg a.i./ha	Nitrogenase(soil+rhizosphere)	2						Rao et al., 1983
FMC-35001	I	0.02 % a.i.	Nitrogenase(soil+rhizosphere)	2						Rao et al., 1983
HCH	I	1.0 kg a.i./ha	Nitrogenase(soil+rhizosphere)	1						Rao et al., 1983
HCH	I	1.0 kg a.i./ha	Nitrogenase(soil+rhizosphere)			2				Rao et al., 1983
Isofenphos	I	1.0 kg a.i./ha	Nitrogenase(soil+rhizosphere)			1				Rao et al., 1983
Isofenphos	I	0.02 % a.i.	Nitrogenase(soil+rhizosphere)			2				Rao et al., 1983
Isofenphos	I	1.0 kg a.i./ha	Nitrogenase(soil+rhizosphere)			1				Rao et al., 1983
MIPC	I	0.02 % a.i.	Nitrogenase(soil+rhizosphere)		1					Rao et al., 1983
Monocrotophos	I	0.02 % a.i.	Nitrogenase(soil+rhizosphere)	2						Rao et al., 1983

Annex 1 Effect of pesticides on microbial populations in wetland rice soils.

PESTICIDE		Concentration range	Population/ Activity	At field rate			At higher rates			
				-	=	+	-	=	+	REFERENCE
Phosphamidon	I	0.02 % a.i.	Nitrogenase(soil+rhizosphere)			1				Rao et al., 1983
Quinalphos	I	1.0 kg a.i./ha	Nitrogenase(soil+rhizosphere)		1					Rao et al., 1983
Quinalphos	I	1.0 kg a.i./ha	Nitrogenase(soil+rhizosphere)			1				Rao et al., 1983
Quinalphos)	I	0.02 % a.i.	Nitrogenase(soil+rhizosphere)	2						Rao et al., 1983
SAN-155	I	1.0 kg a.i./ha	Nitrogenase(soil+rhizosphere)		1					Rao et al., 1983
SAN-155	I	1.0 kg a.i./ha	Nitrogenase(soil+rhizosphere)		1					Rao et al., 1983
SAN-155	I	0.02 % a.i.	Nitrogenase(soil+rhizosphere)	1						Rao et al., 1983
			COUNTS	14	9	18	0	0	0	
Dithane A-40		8 to 15 kg/ha	Organic matter decomposition		1			1		Russo, 1970
Ordram		55 to 80 kg/ha	Organic matter decomposition		1			1		Russo, 1970
potassium azide		4 to 10 kg/ha	Organic matter decomposition		1			1		Russo, 1970
			COUNTS	0	3	0	0	3	0	
Dithane A-40		8 to 15 kg/ha	P availability			1		1		Russo, 1970
Ordram		55 to 80 kg/ha	P availability			1			2	Russo, 1970
potassium azide		4 to 10 kg/ha	P availability			1			2	Russo, 1970
AC 92100	I	1.0 kg a.i./ha	Phosphatase	1						Jayachandran & Chandramohan,1977
Carbaryl + lindane	I	1.5 kg a.i./ha	Phosphatase		1					Purushothman et al., 1976
Carbofuran	I	1.0 kg a.i./ha	Phosphatase			1				Jayachandran & Chandramohan,1977
Carbofuran	I	1.5 kg a.i./ha	Phosphatase		1					Purushothman et al., 1976
Chlorfenvinphos	I	1.0 kg a.i./ha	Phosphatase			1				Jayachandran & Chandramohan,1977
Chlorodimeform	I	1.0 kg a.i./ha	Phosphatase			1				Jayachandran & Chandramohan,1977
Cytrolane	I	1.5 kg a.i./ha	Phosphatase		1					Purushothman et al., 1976
Diazinon	I	1.0 kg a.i./ha	Phosphatase			1				Jayachandran & Chandramohan,1977
Diazinone	I	1.5 kg a.i./ha	Phosphatase		1					Purushothman et al., 1976
Dursban	I	1.5 kg a.i./ha	Phosphatase		1					Purushothman et al., 1976
Mephosfolan	I	1.0 kg a.i./ha	Phosphatase	1						Jayachandran & Chandramohan,1977
Quinalphos	I	1.0 kg a.i./ha	Phosphatase			1				Jayachandran & Chandramohan,1977
Quinalphos	I	1.5 kg a.i./ha	Phosphatase		1					Purushothman et al., 1976
Dursban	I	1.8 L/acre	Anaerobic P dissolvers			1				Sivasithamparam, 1970
Linuron	H	1 Lb./acre	Anaerobic P dissolvers	1						Sivasithamparam, 1970
Dursban	I	1.8 L/acre	Aerobic P dissolvers		1					Sivasithamparam, 1970
Linuron	H	1 Lb./acre	Aerobic P dissolvers		1					Sivasithamparam, 1970
			COUNTS	3	8	9	0	1	2	

Annex 1 Effect of pesticides on microbial populations in wetland rice soils.

PESTICIDE		Concentration range	Population/ Activity	At field rate			At higher rates			
				-	=	+	-	=	+	REFERENCE
Dursban	I	1.8 L/acre	Sulphate reducers			2				Sivasithamparam, 1970
Linuron	H	1 Lb./acre	Sulphate reducers			2				Sivasithamparam, 1970
			COUNTS	0	0	2	0	0	0	
2,4-D	H	19.76 kg/ha	Urease		1					Baruah & Mishra, 1986
Basalin 48 EC		2 to 10 ppm	Urease		1		2			Palaniappan & Balasubramanian,1985
butachlor	H	2.47 l/ha	Urease		1					Baruah & Mishra, 1986
Furadan 3G	I	2 to 10 ppm	Urease			1	2			Palaniappan & Balasubramanian,1985
oxyfluorfen	H	1.54 l/ha	Urease		1					Baruah & Mishra, 1986
			COUNTS	0	4	1	2	0	0	
Carbaryl + lindane	I	1.5 kg a.i./ha	β-glucosidase	2						Purushothman et al., 1976
Carbofuran	I	1.5 kg a.i./ha	β-glucosidase	2						Purushothman et al., 1976
Cytrolane	I	1.5 kg a.i./ha	β-glucosidase	2						Purushothman et al., 1976
Diazinone	I	1.5 kg a.i./ha	β-glucosidase	2						Purushothman et al., 1976
Dursban	I	1.5 kg a.i./ha	β-glucosidase	2						Purushothman et al., 1976
Quinalphos	I	1.5 kg a.i./ha	β-glucosidase	2						Purushothman et al., 1976
AC 92100	I	1.0 kg a.i./ha	β-glucosidase	1						Jayachandran & Chandramohan,1977
Carbofuran	I	1.0 kg a.i./ha	β-glucosidase			1				Jayachandran & Chandramohan,1977
Chlorfenvinphos	I	1.0 kg a.i./ha	β-glucosidase			1				Jayachandran & Chandramohan,1977
Chlorodimeform	I	1.0 kg a.i./ha	β-glucosidase			1				Jayachandran & Chandramohan,1977
Diazinon	I	1.0 kg a.i./ha	β-glucosidase			1				Jayachandran & Chandramohan,1977
Mephosfolan	I	1.0 kg a.i./ha	β-glucosidase	1						Jayachandran & Chandramohan,1977
Quinalphos	I	1.0 kg a.i./ha	β-glucosidase			1				Jayachandran & Chandramohan,1977
			COUNTS	8	0	5	0	0	0	
Phyllosphere										
AC 92100	I	1.0 kg a.i./ha	Actinomycetes in phyllosphere	1						Jayachandran & Chandramohan,1977
Carbofuran	I	1.0 kg a.i./ha	Actinomycetes in phyllosphere	1						Jayachandran & Chandramohan,1977
Chlorfenvinphos	I	1.0 kg a.i./ha	Actinomycetes in phyllosphere		1					Jayachandran & Chandramohan,1977
Chlorodimeform	I	1.0 kg a.i./ha	Actinomycetes in phyllosphere	1						Jayachandran & Chandramohan,1977
Diazinon	I	1.0 kg a.i./ha	Actinomycetes in phyllosphere	1						Jayachandran & Chandramohan,1977
Mephosfolan	I	1.0 kg a.i./ha	Actinomycetes in phyllosphere	1						Jayachandran & Chandramohan,1977
Quinalphos	I	1.0 kg a.i./ha	Actinomycetes in phyllosphere	1						Jayachandran & Chandramohan,1977
AC 92100	I	1.0 kg a.i./ha	Azotobacter in phyllosphere	1						Jayachandran & Chandramohan,1977
Carbofuran	I	1.0 kg a.i./ha	Azotobacter in phyllosphere	1						Jayachandran & Chandramohan,1977

Annex 1 Effect of pesticides on microbial populations in wetland rice soils.

PESTICIDE		Concentration range	Population/ Activity	At field rate			At higher rates			REFERENCE
				-	=	+	-	=	+	
Chlorfenvinphos	I	1.0 kg a.i./ha	Azotobacter in phyllosphere		1					Jayachandran & Chandramohan,1977
Chlorodimeform	I	1.0 kg a.i./ha	Azotobacter in phyllosphere	1						Jayachandran & Chandramohan,1977
Diazinon	I	1.0 kg a.i./ha	Azotobacter in phyllosphere	1						Jayachandran & Chandramohan,1977
Mephosfolan	I	1.0 kg a.i./ha	Azotobacter in phyllosphere	1						Jayachandran & Chandramohan,1977
Quinalphos	I	1.0 kg a.i./ha	Azotobacter in phyllosphere	1						Jayachandran & Chandramohan,1977
AC 92100	I	1.0 kg a.i./ha	Bacteria in phyllosphere	1						Jayachandran & Chandramohan,1977
Carbofuran	I	1.0 kg a.i./ha	Bacteria in phyllosphere	1						Jayachandran & Chandramohan,1977
Chlorfenvinphos	I	1.0 kg a.i./ha	Bacteria in phyllosphere	1						Jayachandran & Chandramohan,1977
Chlorodimeform	I	1.0 kg a.i./ha	Bacteria in phyllosphere	1						Jayachandran & Chandramohan,1977
Diazinon	I	1.0 kg a.i./ha	Bacteria in phyllosphere	1						Jayachandran & Chandramohan,1977
Mephosfolan	I	1.0 kg a.i./ha	Bacteria in phyllosphere	1						Jayachandran & Chandramohan,1977
Quinalphos	I	1.0 kg a.i./ha	Bacteria in phyllosphere	1						Jayachandran & Chandramohan,1977
Carbofuran	I	1.0 kg a.i./ha	Fungi in phyllosphere	1						Jayachandran & Chandramohan,1977
Chlorfenvinphos	I	1.0 kg a.i./ha	Fungi in phyllosphere		1					Jayachandran & Chandramohan,1977
Chlorodimeform	I	1.0 kg a.i./ha	Fungi in phyllosphere	1						Jayachandran & Chandramohan,1977
Diazinon	I	1.0 kg a.i./ha	Fungi in phyllosphere	1						Jayachandran & Chandramohan,1977
Mephosfolan	I	1.0 kg a.i./ha	Fungi in phyllosphere	1						Jayachandran & Chandramohan,1977
Quinalphos	I	1.0 kg a.i./ha	Fungi in phyllosphere	1						Jayachandran & Chandramohan,1977
AC 92100	I	1.0 kg a.i./ha	Fungi in rice phyllosphere	1						Jayachandran & Chandramohan,1977
			COUNTS	25	3	0	0	0	0	

* : Response varied with soil type

1 : Slight or non lasting response

2 : Marked or long lasting response