APPENDIX A
ANNOTATED BIBLIOGRAPHY ON THE FATE OF PESTICIDES IN RICEFIELDS AND RICEFIELD SOILS

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This annotated bibliography of 136 references deals with the degradation/persistence of pesticides in ricefields and ricefield soils. Papers selected include:

- Papers reporting studies in ricefields, with ricefield soil, or with strains isolated from ricefields or known to be present in ricefields;
- Few papers of interest for methodological aspects or presenting data useful for comparison; and
- Bibliographic reviews including references on wetland soils.

The list is not exhaustive. About sixty additional annotated references on the topic can be found in the following report: D.G. Crosby and S. Mabury (1992), *Management of pesticide residues in ricefield tailwater*, A report to the Soil Conservation Service of U.S. Department of Agriculture, Department of Environmental Toxicology, University of California, Davis, CA 95616, USA. 57 pp.

The following code is used:

(NS)	(No summary) The original paper has no summary.
(NC)	(Not consulted) The paper was not available and is cited from another paper.

Abstract	The document cited is only an abstract, not a full paper.
Summary	The summary or abstract included in the original paper.
Notes	Short summary or comments by the author of this compilation.

Adhya, T.K., Sudhakar-Barik, Sethunathan N. (1981) Fate of fenitrothion, methyl parathion and parathion in anoxic sulfur-containing soil systems. *Pestic. Biochem. Physiol.* 16: 14. (NC)

Adhya, T.K., Sudhakar-Barik, Sethunathan N. (1981) Hydrolysis of selected organophosphorus insecticides by two bacteria isolated from flooded soils. *J. Appl. Bacteriol.* 50: 167. (NC)

Adhya, T.K., Sudhakar-Barik, Sethunathan N. (1981) Stability of commercial formulation of fenitrothion, methyl parathion and parathion in anaerobic soils. *J. Agric. Food Chem.* 29: 90–93.

Summary: The relative stability of formulated emulsifiable concentrates of fenitrothion, methyl parathion, and parathion in an anaerobic soil was studied by using two approaches. When the formulated pesticides were applied to ten-day preflooded soil, followed by continued incubation of soil samples under static flooded conditions, degradation of parathion proceeded essentially by nitro group reduction and of methyl parathion and fenitrothion by hydrolysis. In contrast, all three insecticides were degraded by nitro group reduction to their respective amino analogues in the second approach involving direct equilibration of the pesticide with the soil prereduced by flooding for different periods. Interestingly, rapid nitro group reduction of all organophosphates, parathion in particular, occurred within 5 s of their equilibration with a soil prereduced by incubation with rice straw under flooding. Sterilization of the prereduced soil by autoclaving prevented the rapid destruction of the pesticides by the prereduced soil.

Agnihotri, N.P. (1978) The degradation of pesticides in soil. Edwards C.A., Veeresh G.K., Krueger H.R. (eds.), Pages 343–356 in *Pesticide residues in the environment in India*. Proceedings of a symposium held on November 1978 at the University of Agricultural Sciences, Hebbal Bangalore India under the auspices of FAO/UNESCO/UNDP/ICAR/UAS. 524 p.

Notes: Laboratory and field experiment using flooded and nonflooded soils. Degradation of disulfon and phorate in soil alone was slightly slower when fertilizer was added, however, *in situ* degradation was faster when fertilizer was applied because of a better plant growth in the treated plots.

Aquino, G.B., Pathak, M.D. (1976) Enhanced absorption and persistence of carbofuran and chlordimeform in rice plant on root zone application under flooded conditions. *J. Econ. Entomol.* 69: 686–690. (NC)

Notes: cf. Pathak et al. (1974)

Arita, H., Kuwatsuka, S. (1991) Relationships between the degradation rate of the herbicide pyrazofen and soil properties. *J. of Pest. Sci.* 16(1): 71–76.

Summary: A comparison was made by laboratory experiments of the degradation rate of ^{14}C-labeled pyrazoxyfen in five paddy soils (collected from Tochigi, Ibaraki, Nagano, Anjo, (Aichi) and Fukuaoka) under simulated upland (moisture adjusted to 50 percent of the maximum water holding capacity) or flooding (covered with 1 cm of water) conditions. Pyrazoxyfen degraded faster in the mineral soils (Fukuaoka > Anjo > Nagano) than in the humic volcanic ashes (Ibaraki > Tochigi), exhibiting a half-life of 3–5 and 5–34 days in the respective soils. When compared in the same soil, degradation was generally faster under flooded than upland conditions (half life of < 10 and 3–34 days respectively). Pyrazoxyfen degradation rate was negatively correlated with soil cation exchange capacity, OM content, C/N ratio and water holding capacity.

Au, L.A. (1980) Pesticide interactions in the laboratory rice paddy model ecosystem. *Diss. Abstr. Int. B* 40: 3567–3568.

Notes: Model ecosystem (Microcosm) to study the impact of combinations of pesticides. Do not include microbiological measurements. Combination of methyl parathion with atrazine substantially decreased the degradation of both pesticides in the rots of rice and increased their persistence in the water and soil phase of the model.

Bardsley, C.E., Savage, K.E., Walker, J.C. (1968) Trifluralin behavior in soil: II Volatilization as influenced by concentration, time, soil moisture content, and placement. *Agron. J.* 60: 89–92.

Notes: Trifluralin can be extensively lost by volatilization depending upon concentration, mode of application and moisture content of the soil.

Brahmaprakash, G.P., Reddy, B.R., Sethunathan, N. (1985) Persistence of hexachloro-cyclohexane isomers in soil planted with rice and in rice rhizosphere soil suspensions. *Biol. Fert. Soils* 1: 103–109.

Summary: The relative persistence of alpha, beta and gamma-isomers of hexachlorocyclo hexane (HCH) was studied in a flooded soil with and without

rice seedlings under greenhouse conditions. Beta-HCH was more stable than alpha- and gamma-HCH in both planted and unplanted systems. Alpha- and gamma-HCH decreased to negligible levels (5.5 percent for the alpha-isomer and 2.4 percent for the gamma-isomer) after thirty days in planted and unplanted soils. During the same period, 30.9 percent of the added beta-HCH was recovered from planted soil and 50.6 percent from unplanted soil. Likewise, in anaerobically ($H_2 + CO_2$ atmosphere) incubated mineral salts solution inoculated with suspensions from rice rhizosphere and non-rhizosphere soils. Gamma-HCH decreased to low levels (< 15 percent) within five days. Most of the added beta-HCH was recovered from mineral solution inoculated with nonrhizosphere soil suspension even after thirty days while beta-HCH decreased to 53.6 percent of the original level in mineral solution inoculated with rice rhizosphere soil suspension. The data reveal that the degradation of anaerobically unstable HCH isomers is not retarded by the possible aeration of a flooded soil by rice roots.

Castro, T.F., Yoshida, T. (1971) Degradation of organochlorine insecticides in flooded soils in the Philippines. *J. Agric. Food Chem.* 19: 1168–1170.

Summary: The effect of organic matter in the biodegradation of the organochlorine insecticides DDT, endrin, heptachlor, and the four isomers of BHC was studied in two soils under submerged soil condition. The four insecticides were found to degrade biologically at a faster rate in nonsterilized than in sterilized soil. Adding organic matter to the soil seems to increase its organic chemical adsorption in the control soil. When the soil has a relatively high content of organic matter, addition of more organic matter seems to have no effect. When the soil has little organic matter, however, a more pronounced effect is obtained.

Chen, S.J., Hsu, Err-Lieh, Chen, Y.L. (1982) Fate of the herbicide benthiocarb (Thiobencarb) in a rice paddy model ecosystem. *J. Pest. Sci.* 7: 335–340.

Summary: The metabolic fate of benthiocarb (thiobencarb) was studied with ^{14}C-labeled compound by a rice paddy model ecosystem in the laboratory. In addition to rice plants, ten organisms including grasshopper, rice brown planthopper, mosquito larva, wolf spider, water flea, dragonfly naiad, giant duckweed, mosquito fish, alga, and paddy snail were involved in this ecosystem. The radioactivity extracted with n-hexane from water, sand and biota at the end of experiment (twenty-three days after the application of ^{14}C-benthiocarb) corresponded to 2.73 percent, 23.18 percent, and 0.31 percent of the initial radioactivity applied, respectively. Metabolic fate of benthiocarb in these organisms was studied. Some unknown metabolites were detected beside several known ones. From its low ecological magnification values on the aquatic organisms and high biodegradability indices for these biota, benthiocarb was found to be safe

from an environmental standpoint. This rice paddy model ecosystem seemed to be very effective and useful for studying the fate of pesticides in the environment, especially in paddy fields.

Notes: Sand is used instead of rice soil which might have biased the results.

Chen, Y.L. (1980) Degradation of butachlor in paddy fields. Pages 121–141 in *FFTC Book Series No. 20, Weeds and weed control in Asia.* Food and Fertilizer Technology Center, Taiwan. (NS)

Notes: Extensive experimental survey of all pathways of butachlor disparition from ricefields. Includes data on its effect on nitrification at different temperatures and pH. At 30°C and pH 6.8, 6 ppm butachlor simulated nitrification, soil respiration, had no significant effect on populations of fungi and actinomycetes but possibly increased total populations of bacteria for about two weeks.

Del Rosario, D.A., Yoshida, T. (1976) BHC and DDT residues of some rice crops and soils in the Philippines. *Soil Sci. Plant Nutr.* 22(1): 81–87.

Summary: Rice seed, plant, and soil samples from the provinces of lloilo, Bulacan, Nueva Ecija, and Mountain Province, and Palawan in the Philippines were analyzed for the presence of the four BHC isomers and of DDT. Low levels of the four BHC isomers were detected in all the samples. The plants generally had a higher BHC content than the soil. The amounts of BHC found in the grain and hull were below the tolerance limit set by the United States Food and Drug Administration. DDT and its metabolites were identified in Palawan and the Mountain Province. The presence of DDT in the samples could have been due to the contamination from the DDT sprayed for malaria control in the dwelling places where the rice was stored.

Deuel, L.E., Turner, F.T., Brown, K.W., Price, J.D. (1978) Persistence and factors affecting dissipation of molinate under flooded rice culture. *J. Environ. Qual.* 7(3): 373–377.

Summary: Pesticides, essential for the economical production of rice (*Oryza sativa* L.), could pose a serious problem if transported to surface impoundments and estuaries along the Gulf Coast via the return flow associated with flooded rice culture. Field experiments were conducted under flooded rice cultivation to determine persistence and half-life of molinate (Sethyl-hexahydro-1-H-azepine 1–1carbothioate). Persistence and half-life were evaluated with respect to intermittent and continuous flow irrigation schemes at normal and excessive application rates of 3.4 and 11.2 kg/ha molinate, respectively. Persistence at statistically significant levels ranged from 96 to 384 hours following the application, and generally was more a function of the application rate than irrigation scheme. Half-life values averaged 96 ± 22 hours in intermittent flow plots, and 54 ± 17 hours in continuous flow plots over the three-year experiment. Application rate had little effect on half-life. Best fit analysis of field data to the first order biological decay equation and laboratory studies under flooded soil conditions suggested that biological degradation was the principle mode by which molinate was dissipated in the field experiment.

Fereria, J., Raghu, K. (1981) Decontamination of hexachlorocyclohexane isomers in soil by green manure application. *Environ. Tech. Lett.* 2: 357–364.

Summary: Application of green manure to flooded rice soils resulted in enhanced degradation of all four isomers of hexachlorocyclohexane (HCH) including the most persistent beta isomer. This suggest the possibility of using this agricultural practice for lowering the residue levels of HCH in soil.

Fox, J. L. (1983) Soil microbes pose problems for pesticides. *Science* 221: 1029–1031. (NS)

Notes: Short review on the problem of pesticide inactivation by adaptive soil microflora.

Funayama, S., Uchida, M., Kanno, H., Tsuchiya, K. (1986) Degradation of buprofezin in flooded and upland soils under laboratory conditions. *J. Pest. Sci.* 11: 605–610.

Notes: Buprofezin gradually decomposed in soils under flooded and upland conditions, with half lives of 104 and 80 days respectively. Degradation products were identified. Degradation was markedly reduced in sterile soil. The authors concluded that buprofezin seems to undergone complete mineralization by microorganisms in both submerged and non-submerged soils.

Gill, S.S., Yeoh, C.L. (1980) Degradation of carbaryl in three components of the paddy-field ecosystem of Malaysia. Pages 229–243 in *Agrochemical residue: Biota interactions in soil and aquatic ecosystems*. Proceedings of a Joint workshop, FAO/IAEA, IAEA, Vienna.

Summary: The degradation of carbaryl in soil, soil extract and the paddy-field *Trichogaster pectoralis* was studied. In Kundor soil, under flooded conditions, carbaryl had a half-life of about seven weeks. The formation of the major degradation product, 1-naphthol, correlated with the disappearance of carbaryl. 1-Naphthyl-N-hydroxymethylcarbamate, 4 and 5-hydrocarbaryl were also formed. The rate of degradation of carbaryl was dependent on the moisture level and the presence of microorganisms. Carbaryl was relatively more persistent in acid sulphate soils than normal (Kundor) paddy-field soil. Carbaryl underwent a similar degradation in water extracts of soil. Degradation of carbaryl by the liver of *T. pectoralis*, however, followed as slightly different pathway with 1-naphthyl-N-hydroxymethylcarbamate being the major product. The other products formed include 1-naphtol, 5-hydroxycarbaryl and three unidentified metabolites.

Gowda, T.K.S., Sethunathan, N. (1976) Persistence of endrin in Indian rice soils under flooded conditions. *J. Agric. Food Chem.* 24: 750–753.

Summary: A radiotracer study was conducted to determine the relative persistence of endrin-^{14}C under flooded conditions in eight Indian rice soils. Endrin decomposed rapidly and reached low levels within fifty-five days in all soils except in a sandy soil. Interestingly, most rapid degradation occurred in pokkali soil despite its high salt content. The decrease in the total radioactivity partitioned in the chloroform-diethyl ether fraction was less pronounced despite the rapid decline in endrin levels indicating the formation of stable metabolites. Radioautography reveals that endrin was converted to six stable metabolites in all soils except in sandy and kari soils; five compounds were detected in kari soil and three compounds in sandy soil. More rapid degradation of endrin occurred in nonautoclaved samples of three soil types than in autoclaved samples indicating microbial participation in its degradation. The addition of rice straw enhanced the degradation of endrin. Liming the acid soils had no effect on the degradation rate of endrin.

Gowda, T.K.S., Sethunathan, N. (1977) Endrin decomposition in soils as influenced by aerobic and anaerobic conditions. *Soil Sci.* 124: 5–9.

Summary: The relative persistence of endrin in soils as related to flooding and alternate "anaerobic" (flooded unstirred) and "aerobic" (flooded stirred) conditions was studied in three soils by radiotracer technique. More rapid degradation of endrin occurred in all three soils under flooded conditions than under nonflooded conditions. Autoradiography revealed the formation of six breakdown products in flooded soils as compared to four compound in nonflooded soils after twenty-five days of incubation. The breakdown products, detected at the end of twenty-five days of preincubation under flooded unstirred (predominantly anaerobic) conditions, decreased to low levels following incubation under unstirred conditions for another thirty days. By contrast, when the flooded soils were stirred for thirty days after twenty-five days of unstirred conditions, undecomposed endrin and some of its breakdown products detected at the end of unstirred conditions persisted and accumulated. The data demonstrated than aerobic conditions in

nonflooded soils and in flooded soils subjected to an unstirred-stirred cycle increased the persistence of endrin and its breakdown products.

Guenzi, W.D., Beard, W.E. (1976) The effects of temperature and soil and water on conversion of DDT to DDE in soil. *J. Environ. Qual.* 5: 243–246.

Notes: High temperature decreases adsorption and favor desorption of pesticides, which may result in higher quantities of pesticides dissolved in soil water and a faster disparition.

Heritage, A.D., MacRae, I.C. (1979) Degradation of hexachlorocyclohexane and structurally related substrates by *Clostridium sphenoides*. *Austr. J. Biol. Sci.* 32–493. (NC)

Notes: Demonstration of the ability of a strain isolated from an anaerobic soil to degrade HCH.

Higashi, R.M. (1987) Modelling the environmental fate of rice herbicides. Ph.D. Thesis. Agricultural and Environmental Chemistry. University of California, Davis. 109 p.

Summary: The California ricefield is a unique environment in which to study the chemistry of environmental fate. Under certain circumstances, the newly flooded rice paddy has well-defined physical and chemical characteristics due to relatively few biological interactions, static water, static soil-water, and the yearly application of large amounts of agrochemicals which can serve as study chemicals. These conditions limit the processes of dissipation from the water to soil adsorption, volatilization, and thermal/photochemical breakdown. In spite of the simplified situation, the ricefields are very dynamic with large diurnal variations forces such as pH, temperature, UV light, and dissolved oxygen. A dynamic approach to microcosm modeling aims to mimic the actual field profiles, thereby normalizing or otherwise accounting for the variable rates caused by the cycling of these forces. A physical-chemical microcosm with airflow, light and temperature under computer control was constructed and used to study the volatilization of molinate and the photodissipation of bentazon. Microcosm studies of dissipation under field-mimicking conditions corresponded much better to the field studies than under average, steady-state conditions. For molinate, the microcosm successfully reproduced field dissipation rates to within + 15 percent, whereas the conventional steady-state experiment yielded results that was fourfold too short, the discrepancy due to interaction between the granular formulation and the temperature profile. In the case of bentazon, the microcosm was able to mimic field dissipation from + 11 percent to + 113 percent, the greater discrep-

ancies using average temperature or laboratory water which consistently underestimated photodissipation rates as compared to varying temperature or field water. For one of the photoproducts of bentazon, diurnal and constant light gave results that drew opposite conclusions, namely that it does and does not accumulate, respectively. Again, the field-mimicking microcosm experiment (diurnal light) was closer to field observations. These findings point out the experimental conditions appropriate for the environment and dissipation mechanism(s) of the chemical-instead of standardized conditions—is crucial for estimations of persistence. Thus, dynamic microcosm studies, when are restricted to realistic field parameters, can converge on realistic estimations of persistence and fate of chemicals in the ever-changing environment.

Higashi, R.M., Crosby, D.G. (1987) A physical-chemical microcosm for ricefield environmental fate studies. Pages 445–448 in Greenhalgh R., Roberts T.R. (eds.), *Pesticide science and biotechnology.* Blackwell Scientific Publications, Oxford.

Summary: Physical-chemical microcosms can serve as a basis for prediction of persistence. The California flooded ricefield environment was modeled because of its well-defined history, relatively few biological interactions, and the large amounts of agrochemicals introduced into it yearly. We have constructed a computer-controlled aquatic microcosm to model volatilization and photolysis of the herbicides molinate and bentazon, respectively. Modeling was conducted with the dissipation forces (temperature and UV light) maintained both steady-state (field average) and profiled (diurnally varied as in a corresponding field study). Molinate dissipation in the steady-state microcosm (28°C, $t_{1/2}$ = 1.60 days) was in discordance with experiments under profiled temperatures (18–32°C, $t_{1/2}$ = 7.22 days), but the latter was similar to the field dissipation. This difference was attributed to an interaction of the profiled temperatures (16–28°C, $t_{1/2}$ = 3.00 days) matched the field dissipation rate ($t_{1/2}$ = 2.90 days) well, but was faster than the steady-state average temperature experiment (23.5°C, $t_{1/2}$ = 4.12 days). In addition, cycling the UV light diurnally resulted in the persistence of a major photochemical product, although it did not accumulate under constant UV. These results indicate that accurate representation of variable field forces is essential for the development of a realistic microcosm system.

Hill, I.R. (1978) Microbial transformation of pesticides. Pages 139–202 in Hill, I.R., Wright, S.J.L. (eds.), *Pesticide microbiology.* Academic Press, London. 844 p.

Notes: A review that covers mostly the chemistry of pesticide decomposition. 334 references. Only six references refer specifically to flooded soils.

Hill, I.R., Wright, S.J.L. (1978) The behavior and fate of pesticides in microbial environments. Pages 79–136 in Hill, I.R., Wright, S.J.L. (eds.), *Pesticide microbiology*. Academic Press, London. 844 p.

Notes: A review with about 280 references. References on freshwater and anaerobic ecosystems are useful for understanding pesticide fate in wetland rice soils.

Ide, A., Niki, Y., Sakamoto, F., Watanabe, I., Watanabe, H. (1972) Decomposition of pentachlorophenol in paddy soil. *Agric. Biol. Chem.* 36: 1937–1944. (NC)

Isensee, A.R., Kaufman, D.D., Jones, G.E. (1982) Fate of 3,4-Dichloroaniline in a rice (*Oryza sativa*)—paddy microecosystem. *Weed Sci.* 30: 608–613.

Summary: The fate of 3,4-dichloroaniline (DCA), a major metabolite of the herbicide propanil (3',4'-dichloropropionanilide), in rice (*Oryza sativa* L.), soil, water and aquatic organisms was determined in rice-paddy microecosystems. Soil, treated with 10 ppm DCA, was placed in glass chambers, planted to rice, then flooded when the rice reached the two-leaf stage. After flooding, four species of aquatic organisms were added. The concentration of DCA and metabolites in soil, rice, water, and aquatic organisms was determined over a period of time. A maximum of 2.8 percent of the total radioactivity applied to soil desorbed or leached into water. DCA recovered from water decreased from 12 to 1 percent of the total radioactivity in water between 1 and 30 days after flooding. Between 10.5 and 18.5 percent of the radioactivity remaining in soil at the end of the experiments was extractable. Of the radioactivity recovered, between 5 and 11 percent was DCA, and up to 6 to 19 percent was 3,3', 4'4'—tetrachloroazobenzene (TCAB), these percentages being dependent on exposure time. Rice accumulated 0.5 percent or less of the total radioactivity in soil. Only 35 to 55 percent of the accumulated radioactivity was extractable. Very small amount of radioactivity were accumulated by aquatic organisms.

Ishikawa, K., Asano, U., Nakamura, Y., Akasaki, K. (1976) Behavior and disappearance of benthiocarb herbicide in water, soil and rice plant of paddy fields treated with its granular formulations. *Weed Res. Japan* 21: 16. (NC)

Kandasamy, D., Marimuthu, T., Rajukkannu, K., Raghuraj, R., Oblisami, G., Krishnamoorty, K.K., Subrahmaniam, T.R. (1975) A study on the relationship between the dissipation of insecticides and rhizosphere microflora of paddy. *Madras Agric J.* 62(4): 203–207.

Summary: A study on the interrelationship between the dissipation of two granular insecticides and different microbial populations in the rhizosphere soil of paddy corp indicated a positive correlation between the residues of phorate and actinomycete and *Azotobacter* populations. However, no such definite relationship could be recorded with carbofuran and various groups of microflora.

Kearney, P.C., Smith, R.J. Jr., Plimmer, J.R., Guardia, F.S. (1970) Propanil and TCAB residues in rice soils. *Weed Sci.* 18: 464–466.

Summary: We surveyed soils that produce rice (*Oryza sativa* L.) at the University of Arkansas Rice Branch Experiment Station at Stuttgart, Arkansas, to determine whether residues at 3,3',4,4'—tetrachloroazobenzene (hereinafter referred to as TCAB) accumulated with repeated applications of 3', 4' -dichloropropionanilide (propanil). We sampled Crowley silt loam with known histories of propanil application to determine the effect of depth, rate and time on TCAB formation. Propanil and TCAB were measured by electron capture gas chromatography. Low concentrations of TCAB (< 0.2 ppm) generally were detected in the surface 0 to 10.1-cm layer of soil receiving applications of propanil at rates of 6.7 kg/ha. Concentration and occurrence of TCAB decreased with increasing time and depth in soil.

Kirkpatrick, D., Biggs, S.R., Conway, B., Finn, C., Hawkins, D.R., Honda, T., Ishida, M., Powell, G.P. (1981) Metabolism of N-(2, 3-Dichlorophenyl)-3,4,5,6-tetrachlorophthalamic acid (Techlofthalam) in paddy soils and rice. *J. Agric. Food Chem.* 29: 1149–1153.

Summary: The metabolism of the bactericide N-(2, 3-dichlorophenyl)-3,4,5,6-tetrachlorophthalamic acid, techlofthalam, has been studied, under controlled conditions, in paddy soil and after application to rice plants by using the ^{14}C-labeled compound. Reductive dechlorination of the tetrachlorophthalamic acid moiety was shown to be the major degradative pathway in paddy soil stored in laboratory flasks. Monodechlorinated products were detected after two weeks of incubation, and after thirty-two weeks more than 90 percent of the extractable radioactivity, equivalent to about 30 percent of the applied radioactivity, was associated with two or possibly more monodechlorinated products. Nine percent of the applied radioactivity was converted to $^{14}CO_2$ during thirty-two weeks. The imide of techlofthalam was a minor metabolite in paddy soil but was the major transformation product detected in rice leaves treated with [^{14}C] techlofthalam.

Kuwatsuka, S. (1973) Degradation products of swep ad DCPA herbicides under flooded and upland conditions, in *Proc. Ann. Meet. Soc. Sci. Soil Manure, Japan* 19: 19. (NC)

Lee, H.K. (1981) Effect of rice straw amendment and repeated application of diazinon on the persistence of diazinon in submerged soils. *J. Korean Agric. Chem. Soc.* 24(1): 1–4. (NS)

Notes: Straw incorporation, which increases microbial activity and hastens the drop in redox potential in flooded soils, favors diazinon degradation.

Lichtenstein, E.P., Liang, T.T., Koeppe, M.K. (1983) Effect of soil mixing and flooding on the fate and metabolism of ^{14}C Fonotos and ^{14}C parathion in open and closed agricultural microcosm. *J. Econ. Entomol.* 76(2): 233–238.

Notes: One example of experimental design known as microcosm.

MacRae, I.C., Raghu, K., Bautista, E.M. (1969) Anaerobic degradation of the insecticide lindane by *Clostridium* sp. *Nature* (London) 221: 859. (NS)

MacRae, I.C., Raghu, K., Castro, T.F. (1967) Persistence and biodegradation of four common isomers of benzene hexachloride in submerged soils. *J. Agric. Food Chem.* 15: 911–914.

Summary: The persistence of the isomer of benzene hexachloride (lindane) when added to submerged tropical soils at a rate approximately three times that recommended for the protection of rice from stem borer infestation and of the alpha, beta and delta isomers of benzene hexachloride applied at similar rates was between seventy and ninety days. Losses of all four isomers from sterilized, flooded soil samples were much slower than from nonsterilized samples, indicating that the microflora of submerged soils is able to degrade benzene hexachloride. Microbial degradation of gamma-BHC was demonstrated by the release of $C_{14}O_2$ from submerged soils treated with C_{14}-labeled-BHC. An application of gamma-BHC at a rate approximately five times the usual field rate apparently inhibited CO_2 evolution from two tropical soils.

Mathur, S.P., Saha, J.G. (1975) Microbial degradation of lindane-^{14}C in a flooded sandy loam soil. *Soil Sci.* 120: 301–307.

Summary: Lindane-^{14}C degraded slowly (90 percent recovered) in a sandy loam soil, incubated for six weeks under flooded conditions. The degradation products were isolated and identified by gas chromatography and mass spectrometry. The major degradation product was—3,4,5,6-tetrachlorocyclohexane (> 5 percent), followed by -2,3,4,5,6-pentachlorocyclohex-1-ene (< 2 percent)

and small amounts of 1,2,4-trichlorobenzene, 1,2,3,5- and/or 1,2,4,5-tetrachlorobenzene, and 1,2,3,4-tetrachlorobenzene. Chlorophenolic metabolites of lindane, observed in plants, insects, and mammals were not detected in the soil.

Matsumura, F., Benezet, H.J. (1978) Microbial degradation of insecticides. Pages 623–667 in Hill, I.R., Wright, S.J.L. (eds.), *Pesticide Microbiology*. Academic Press, London. 844 pp. (NS)

Notes: A review with 133 references; ten references on submerged soils.

Matsumura, F., Krishna Murti, C.R. (1982) *Biodegradation of Pesticides*. Plenum Press, New York. 312 p.

Notes: A review with about 160 references; ten references on submerged soils.

Moon, Y.H., Kumatsuka, S. (1984) Properties and conditions of soils causing the dechlorination of the herbicide benthiocarb in flooded soil. *J. Pest. Sci.* 9: 745–754.

Notes: 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.

Mostafa, I.Y., El-Arab, A.E., Zayed, S.M.A.D. (1987) Fate of ^{14}C-lindane in a rice-fish model ecosystem. *J. Environ. Sci. Health* B 22(2): 235–243.

Summary: A model ecosystem has been used to evaluate the impact of ^{14}C-lindane on rice-fish agricultural system. The distribution of ^{14}C-residues among the constituents of the model ecosystem was studied over a period of 90 days. The insecticide was found to be readily absorbed by the roots and translocated to all parts of the rice plant. The peak level in the shoots (26 ppm) and roots (105 ppm) of plants was reached to within three weeks. Lindane was concentrated in fish and residues as high as 90 ppm could be detected after thirty days. The major part of the residues present in the different constituents of the ecosystem could be extracted with hexane and proved to contain solely the parent compound. The data obtained show that lindane possesses a relatively low biodegradability in fish and in rice plant. The insecticide accumulates in fish and rice plant to considerable extent.

Murthy, N.B.K., Kaufman, D.D. (1978) Degradation of pentachloronitrobenzene (PCNB) in anaerobic soils. *J. Agric. Food. Chem.* 26: 1151–1156. (NC)

Murthy, N.B.K., Kaufman, D.D., Fries, G.F. (1979) Degradation of pentachlorophenol (PCP) in aerobic and anaerobic soil. *J. Environ. Sci. Health* 14 B: 1–14.

Summary: Aerobic and anaerobic degradation of ^{14}C-labeled pentachlorophenol (PCP) was examined in nitrogen aerated, moist Hagerstown silty clay loam with or without cellulose amendments. In anaerobic soil, PCP reduced soil respiration in the presence of cellulose; volatilization losses accounted for only 0.5 percent of the PCP added to soil; no $^{14}CO_2$ was detected; and organic solvent extractable radioactivity was the same from all treatments. Gas and thin-layer chromatographic analysis of the soil extracts showed the presence of pentachloroanisole in both aerobic and anaerobic soils. 2,3,5,6- and 2,3,4,5-tetrachlorophenols and 2,3,6-trichlorophenol were also detected as degradation products by chromatography after methylation. Further degradation of the pentachloroanisole was examined in both aerobic and anaerobic soils.

Nakamura, Y., Ishikawa, K., Kuwatsuka, S. (1977) Degradation of benthiocarb in soils as affected by soil conditions. *J. Pest. Sci.* 2: 7–16.

Summary: Some factors affecting the degradation of ^{14}C-benthiocarb (S-4-chlorobenzyl N,N-diethylthiocarbamate) labeled at the benzene-ring in soils were studied. The degradation rates of ^{14}C-benthiocarb in three different soils under upland, oxidative flooded, and reducive flooded conditions were compared. ^{14}C-Benthiocarb was rapidly degraded under oxidative conditions, but slowly under reductive conditions. Very small differences in the degradation rates were observed among different soils. Under oxidative conditions ^{14}C-carbon dioxide was liberated remarkably with the degradation of ^{14}C-benthiocarb. The degradation was remarkably retarded by sterilizing the soils. The repeated application of benthiocarb, or its incorporation into the soil with simetryne, CNP or propanil had no significant effect on the degradation rate.

Ohisa, N., Yamaguchi, M. (1978a) Degradation of gamma-BHC in flooded soils enriched with peptone. *Agric. Biol. Chem.* 42: 1983. (NC)

Notes: The enrichment of soil populations of *Clostridium rectum*, a bacterium that degrades BHC by a cometabolic process, was not caused by BHC application but by peptone addition.

Ohisa, N., Yamaguchi, M. (1978b) Gamma-BHC degradation accompanied by the growth of *Clostridium rectum* isolated from paddy field soil. *Agric. Biol. Chem.* 42: 1819–1823.

Summary: A BHC decomposer isolated from a ricefield soil was identified as *Clostridium rectum*. The most dominant degradation intermediate from gamma-BHC was identified to be remarkably reduced in the resting state, e.g., spore-formed cell or washed cell suspension. The growth and the BHC decomposing ability of *C. rectum* were inhibited simultaneously by oxygen, chloramphenicol, streptomycin, and pentachlorophenol. BHC degradation is discussed in relation to the cometabolism.

Parr, J.E., Smith, S. (1973) Degradation of trifluralin laboratory conditions and soil anaerobiosis. *Soil Sci.* 115: 55–63.

Summary: The rate and extent of photodecomposition of trifluralin in n-hexane solutions exposed to laboratory light were concentration-dependent. Trifluralin degraded very slowly in either the dark or light at a concentration of 200 ppm. However, rapid decomposition occurred at concentrations of 1.0 and 0.1 ppm in the light, but a considerably slower rate in the dark. Trifluralin degrades in soil by two principal pathways, the aerobic pathway involving sequential dealkylation of propyl groups, and the anaerobic pathway involving initial reduction of the nitro groups. Ultimately, polar products are probably formed during the latter stage of degradation. Degradation of trifluralin was more rapid and extensive in substrate-amended soil under anaerobic (N_2) conditions compared with well-aerated (CO_2-free air) systems, and followed the order of moist (1/3 bar) anaerobic > flooded anaerobic > moist aerobic. Degradation in these environments after 20 days was 99, 45, and 15 percent, respectively. More trifluralin volatilized from the moist aerobic soil compared with moist anaerobic systems because degradation was more extensive in the latter environment. Volatilization was effectively retarded in the flooded anaerobic environment. Evidence for microbiological involvement in the initial degradation of trifluralin under soil anaerobiosis was obtained, including (1) enhanced degradation in the presence of an organic substrate, (2) lack of trifluralin degradation in moist anaerobic environments after autoclaving, (3) resumption of respiratory activity in autoclaved systems after reinoculation, which corresponded with increased degradative activity, and (4) a temporary lag period or suppression of respiratory activity and trifluralin degradation from the presence of KN_3 as a biological inhibitor, with simultaneous resumption of respiration and degradation soon after chemical dissipation of KN_3.

Parr, J.F., Smith, S. (1974) Degradation of DDT in an everglades muck as affected by lime, ferrous ion and anaerobiosis. *Soil Sci.* 118: 45–52.

Notes: Liming flooded/anaerobic acid soils was reported to cause a rapid conversion of DDT to DDE.

Parr, J.F., Smith, S. (1976) Degradation of toxaphene in selected anaerobic soil environments. *Soil Sci.* 121: 52–57. (NC)

Notes: A low or negative redox potential favored the degradation of Toxaphene.

Pathak, M.C., Encarnacion, D., Dupo, H. (1974) Application of insecticides in the root zone of rice plants. *Indian J. of Plant Protection* 1(2): 1–16.

Notes: A better efficiency of several insecticides when placed in the vicinity of the root was demonstrated indicating that application could be reduced as compared with floodwater application.

Pinhero, R.G., George, T.U., Tomy, P.J. (1988) Residual toxicity of granular insecticides to fishes and prawns in the pokkali fields. *Agric. Res. Kerala* 26(2): 263–265.

Summary: Among the granular insecticide tested, none of the insecticides was found to be completely safe for use in pokkali fields.

Raghu, K., MacRae, I.C. (1966) Biodegradation of the gamma isomer of benzene hexachloride in submerged soils. *Science* 154: 263–364.

Summary: Determination of the residual gamma isomer of benzene hexachloride (gamma-BHC) by gas chromatography showed that the insecticide persisted longer in sterilized flooded soils than in nonsterilized flooded soils. A second addition of gamma-BHC to one of the nonsterilized soils (fifty-five days after the first application) disappeared more rapidly than the first addition. These results strongly indicate biodegradation of gamma-BHC in flooded soils.

Notes: Half-life in nonsterilized soil was about eighteen days at the first application and twelve days at the second application.

Rajagopal, B.S., Brahmaprakash, G.P., Sethunathan, N. (1983) Degradation of carbofuran by enrichment cultures and pure cultures of bacteria from flooded soils. *Rice Res. News.* 4(1–2), CRRI. ICAR, India. (NS)

Notes: Enrichment cultures from soil repeatedly treated with pesticide have been used to isolate carbofuran degrading bacteria but even enrichment cultures showed a lag in the degradation of carbofuran.

Rajagopal, B.S., Brahmaprakash, G.P, Sethunathan, N. (1984) Degradation of carbofuran by enrichment cultures and pure cultures of bacteria from flooded soils. *Environ. Pollut.* (Series A) 36: 61–73.

Notes: Test tube experiment showing a built-up of the microflora degrading carbofuran by comparing inocula origination from fields previously treated with carbofuran with inocula originating from non-treated fields.

Rajagopal, B.S., Chendrayan, K., Reddy, B.R., Sethunathan, N. (1983) Persistence of carbaryl in flooded soils and its degradation by soil enrichment cultures. *Plant Soil* 73: 35–45.

Notes: The addition of ammonium nitrogen to a mineral medium retarded the degradation of the nitrogenous pesticide carbaryl by soil enrichment cultures.

Rajagopal, B.S., Rao, V.R., Najendrappa, G., Sethunathan, N. (1984) Metabolism of carbaryl and carbofuran by soil enrichment and bacterial cultures. *Can. J. Microbiol.* 30: 1458–1466.

Notes: Test tube experiment with 20 g soil showing a shift in dominant microbial populations when carbaryl (*Bacillus* dominant) was replaced with carbofuran (*Arthrobacter* dominant). Degradation steps are described.

Rajagopal, B.S., Sethunathan, N. (1984) Influence of nitrogen fertilizers on the persistence of carbaryl and carbofuran in flooded soils. *Pest. Sci.* 15: 591–599.

Summary: Ammonium sulphate and urea but not potassium sulphate, increased the persistence of carbaryl in a flooded laterite soil with a low nitrogen content (0.04 percent), but not in an alluvial soil with a higher nitrogen content (0.11 percent). Consequently, after forty days, more than 50 percent of the ^{14}C in a ^{14}C carbaryl and ^{14}C carbofuran remained in the soils as hydrolysis product plus soil bound residues.

Notes: Test tube experiment with 20 g soil.

Rajaram, K.P., Rao, Y.R., Sethunathan, N. (1978) Inhibition of biological hydrolysis of parathion in rice straw-amended flooded soil and its reversal by nitrogen compounds and aerobic conditions. *Pest. Sci.* 9: 155–160.

Summary: The effect of nitrogen compounds and moisture regimes on the inhibition of the biological hydrolysis of parathion in rice straw-amended soil under flooded conditions was studied. Single applications of rice straw, potassium nitrate or ammonium sulphate to the flooded soil, inoculated with parathion-hydrolysing enrichment culture, inhibited the hydrolysis of the insecticide; the inhibition was reversed, however, in combined applications of rice straw with potassium nitrate or with ammonium sulphate. Aqueous extracts of rice straw-amended soils incubated under flooded undisturbed conditions as well as at 100 percent moisture inhibited the hydrolysis. The inhibitory factor was not formed in rice straw-amended flooded soils incubated at 50 and 75 percent moisture levels.

Rajaram, K.P., Sethunathan, N. (1975a) Effect of organic sources on the degradation of parathion in flooded alluvial soil. *Soil Sci.* 119: 296–300. (NC)

Rajaram, K.P., Sethunathan, N. (1975b) Persistence and biodegradation of hinosan in soil. *Bull. Environ. Contam. Toxicol.* 16: 709–715. (NC)

Notes: Comparison of persistence under upland and flooded conditions. Cited from Sethunathan and Siddaramappa (1978).

Rajasekhar Reddy, B., Sethunathan, N. (1983a) Mineralization of parathion in the rice rhizosphere. *Appl. Environ Microbiol.* 45(3): 826–829.

Notes: $^{14}CO_2$ evolution from ring labelled parathion was studied in the rhizosphere of rice seedlings. Results suggest that soil planted with rice permits significant ring cleavage, especially under flooded conditions. 5.5 percent of ^{14}C was evolved as $^{14}CO_2$ in unplanted nonflooded soil whereas 22.6 percent was evolved in planted and flooded soil.

Rajasekhar Reddy, B., Sethunathan, N. (1983b) Mineralization of parathion in the rhizosphere of rice and pearl millet. *J. Agric. Food Chem.* 31: 1379–1381.

Notes: Mineralization of Parathion in the rhizosphere of rice was more pronounced at the seedling stage than at the maximum tillering and panicle initiation stage. The degree of rhizosphere effect also depended on the rice variety. The rhizosphere effect was related to the root oxydase activity in rice but not necessarily to the biomass of the plant. Pearl millet, a C4 plant, exerted a more pronounced rhizosphere effect on ring clivage of parathion than rice, a C3 plant.

Rao, A.V., Sethunathan, N. (1974) Degradation of parathion by *Penicillum waksmani* Zaleski isolated from flooded acid sulphate soil. *Arch. Microbiol.* 97: 203–208. (NC)

Rao, Y.R., Sethunathan, N. (1979) Effect of ferrous sulfate on the degradation of parathion in flooded soil. *J. Environ. Sci. Health* 14B: 335. (NC)

Read, D.C. (1987) Greatly accelerated microbial degradation of aldicarb in retreated field soil, in flooded soil, and in water. *J. Econ. Entomol.* 80: 156–163.

Summary: The successive application of aldicarb as sub-surface band-in-row soil treatment at 4 kg ai in the same field resulted in development of strains of microorganisms that rapidly broke down aldicarb in acid mineral soils of pH above ca. 6. Rate of accelerated microbial degradation depended on pH and moisture content of the soil, amount applied per treatment, number of treatments, and time period between treatments.

Ross, L.J., Sava, R.J. (1986) Fate of thiobencarb and molinate in ricefields. *J. Environ. Qual.* 15(3): 220–225.

Summary: The fate of thiobencarb (S-[4-chlorobenzyl] N, N-diethylthiolcarbamate) and molinate (S-ethyl hexahydro-1 H-azepine-1-carbothioate) in air, water, soil, and vegetation of rice (*Oryza sativa* L.) fields was documented for thirty-two days following application. Analysis of variance was used to determine if holding periods facilitated herbicide dissipation in water prior to release to drainage canals. Maximum thiobencarb concentrations in air, water, soil, and vegetation were 1.4 µg/cum, 576 µg/L, 3,860 µg/kg, and 1,750 µg/kg, respectively. During the six-day holding period, thiobencarb concentrations in water did not decline significantly, indicating that this period was not sufficient to facilitate dissipation. The mass balance budget indicated that thiobencarb was predominantly distributed between water (34 percent) and soil (43 percent) and < 1 percent was located in air and vegetation. Maximum molinate concentrations in air, water, soil, and vegetation were 48 g/m^3, 3,430 g/li, 2,210 g/kg, and 918 g/kg, respectively. Molinate concentrations in water declined significantly during the holding period, indicating that this water management practice facilitated dissipation of molinate. The mass balance budget indicated that as much 81 percent of the molinate applied was dissolved in water followed by soil (10 percent), air (9 percent), and vegetation (< 1 percent). Partitioning of these herbicides in the field was closely related to their physicochemical properties.

Seiber, J.N., Heinrichs, E.A., Aquino, G.B., Valencia, S.L., Andrade, P., Argente, A.M. (1978) *Residues of carbofuran applied as a systemic insecticide in irrigated wetland rice: Implications for insect control.* IRPS no 17, 28 pp., International Rice Research Institute, Manila, Philippines.

Notes: Persistence of pesticides depends on the method of application. Carbofuran placed in gelatin capsules in the root zone persisted for about sixty days. Soil incorporation provided a persistence of about sixty days. A much faster dissipation was observed when seedling roots were soaked in carbofuran solution.

Seiber, J.N., McChesney, M.M., Sanders, P.F., Woodrow, J.E. (1986) Models for assessing the volatilization of herbicides applied to flooded ricefields. *Chemosphere* 15(2): 127–138.

Summary: Volatilization rates of MCPA, thiobencarb, and molinate from water were calculated using the EXAMS aquatic fate computer model, and measured in a laboratory chamber and in flooded ricefields. A fair to good correlation was obtained between EXAMS-calculated and chamber measured rates for all three herbicides. Field-measured values correlated well with chamber measured rates for thiobencarb and molinate. For MCPA, field-measured values were much higher than expected for volatilization from water alone. In this case, the presence of plant and other surface residues in the field made the major contribution to observed volatilization. For MCPA, 4-chloro-o-cresol flux was comparable to that of the parent herbicide.

Sethunathan, N. (1971) Biodegradation of diazinon in paddy fields as a cause of its inefficiency for controlling brown planthoppers in ricefields. *PANS* 17(1): 18–19. (NS)

Sethunathan, N. (1972) Diazinon degradation in submerged soil and rice-paddy water. *Adv. Chem. Ser.* 111: 244–255.

Summary: Diazinon persisted for about fifteen days in a flooded soil (pH 6.6) that had been treated previously with the insecticide; but in a flooded soil that had never been exposed to diazinon, it persisted for about sixty days. Similarly, water from a diazinon-treated ricefield inactivated the insecticide within five days after incubation. Microorganisms that developed in response to insecticide application accelerated its hydrolysis and subsequent mineralization of the hydrolysis product, 2-isopropyl-6-methyl-4-hydroxy pyrimidine, to CO_2. A *Flavobacterium* sp., isolated from water of a treated ricefield, had exceptionally high capability to metabolize diazinon as sole carbon source. This provides unequivocal evidence that microbes are involved in the rapid inactivation of diazinon in ricefields.

Sethunathan, N. (1973a) Degradation of parathion in flooded acid soils. *J. Agric. Food Chem.* 21: 602–604.

Notes: In the acid rice soils in Kerala, India, Parathion degraded faster in the soil that had a higher organic matter content.

Sethunathan, N. (1973b) Microbial degradation of insecticides in flooded soil and in anaerobic cultures. *Res. Rev.* 47: 143–165.

Notes: A review with sixty-three references.

Sethunathan, N. (1973c) Organic matter and parathion degradation in flooded soil. *Soil Biol. Biochem.* 5: 641–644.

Summary: The effect of rice straw on parathion degradation in a flooded alluvial soils was investigated. In soils inoculated with an enrichment culture which exhibited an exceptionally high ability to hydrolyze parathion, rice straw amendments inhibited parathion hydrolysis to p-nitrophenol and diethyl thiophosphoric acid. On the other hand, in uninoculated soils amended with rice straw, aminoparathion and an unidentified metabolite evidently possessing a P = S bond were detected. Thus, the influence of organic matter on the persistence of parathion in flooded soil is governed by the metabolic pathway involved in the degradation.

Sethunathan, N. (1984a) Biodegradation of pesticides in tropical rice ecosystem. Paper presented at the Ecotoxicology Project Meeting (SCOPE) held at Brussels Belgium, July 5–6, 1984. 34 pp. (NC)

Sethunathan, N. (1984b) *Pesticide degradation in tropical rice soil environment.* Project report. 56 pp. CRRI, Cuttack, India. (NC)

Notes: A technical report to the Department of Environment of India. Reported results were then published in scientific journals.

Sethunathan, N., Adhya, T.K., Raghu, K. (1982) Microbial degradation of pesticides in tropical soils. Pages 91–115 in Matsumura, F., Krishna Murty, C.R. (eds.), *Biodegradation of Pesticides.* (NS)

Notes: A review with 98 references.

Sethunathan, N., Bautista, E.M., Yoshida, T. (1969) Degradation of benzene hexachloride by a soil bacterium. *Can. J. Microbiol.* 15: 1349–1354.

Summary: Attempts to characterize the breakdown product formed during the anaerobic degradation of the gamma isomer of benzene hexachloride (gamma-BHC, $C_6H_6C_{16}$) by the *Clostridium* sp. were made. Analysis by gas chromatography and thin-layer chromatography indicated that the degradation product of gamma-BHC and alpha-BHC differed from gamma-pentachlorocyclohexene ($C_6H_5C_{15}$), a direct product of dehydrochlorination of gamma-BHC. The ability of the bacterium to convert DDT to DDD by reductive dechlorination suggested that a similar mechanism might degrade gamma-BHC to gamma-pentachlo-

rocyclohexane ($C_6H_7C_{15}$). Potassium nitrate inhibited the bacterial degradation of gamma-BHC whereas potassium sulfate and potassium chloride enhanced it.

Sethunathan, N., MacRae, I.C. (1969) Persistence and biodegradation of diazinon in submerged soils. *J. Agric. Food Chem.* 17: 221–225.

Summary: Only 2 to 6 percent of the originally applied diazinon [0,0-diethyl 0-(2-isopropyl-4-methyl-6-pyrimidinyl) phosphorothioate] remained in the soils between 50 and 70 days after application when added to three submerged tropical soils at a rate about seven times that recommended for protecting rice plants from stem borer infestation and certain virus-transmitting leaf hoppers. Losses of the insecticide from sterilized samples of two of the soils were much slower than from nonsterilized samples, indicating microbial participation in diazinon degradation in these two soils. Diazinon disappeared rapidly in sterilized samples of the third soil, an acid clay of pH 4.7, apparently because of its instability under acid conditions. Microbial degradation of the pyrimidine ring of the diazinon labeled at the two positions of the pyrimidine ring. *Streptomyces* sp. isolated from diazinon-treated submerged soil could degrade diazinon in shake cultures, but only in the presence of glucose. Diazinon at 2–20 kg/ha caused a large increase in populations of actinomycetes.

Sethunathan, N., Pathak, M.D. (1971) Development of diazinon-degrading bacterium in paddy water after repeated applications of diazinon. *Can. J. Microbiol.* 17: 699–702.

Summary: A decline in the brown planthopper control effectivity of diazinon was noticed after its continuous application to rice paddies for three one or two years at the International Rice Research Institute. In a study undertaken to determine the factor involved in this decline, rapid inactivation of diazinon was recorded within three to five days of its incubation with water from ricefield that had received several applications of diazinon. During the same period, its degradation in water from an untreated ricefield was non-significant. This indicated the development of a degrading agent in paddy water following diazinon treatments. The inactivation of diazinon on incubation with water from treated fields was retarded if the incubation mixture was sterilized or kept anaerobically. Release of $^{14}CO_2$ from ^{14}C-diazinon was rapid from water of treated fields, but was inhibited when streptomycin was added to the system. A lag of two or three days, followed by a rapid degradation, was generally evident. Thus these data established the fact that aerobic biological agents, capable of degrading diazinon in paddy water, develop after diazinon application. A bacterium, *Arthrobacter* sp., capable of metabolizing diazinon in the presence of ethyl alcohol or glucose was isolated from paddy water of treated fields.

Sethunathan, N., Pathak, M.D. (1972) Increased biological hydrolysis of diazinon after repeated application in rice paddies. *J. Agric. Food Chem.* 20(3): 586–589.

Notes: Repeated application of diazinon caused a rapid degradation which was of microbial nature. The addition of streptomycin to the incubation mixture prevented breakdown of diazinon.

Sethunathan, N., Rajaram, K.P., Siddaramappa, R. (1975) Persistence and microbial degradation of parathion in Indian rice soils under flooded conditions. In *Origin and fate of chemical residues in food*, Agriculture and Fisheries Communication 1.2: 9–18, International Atomic Energy Agency, Vienna Austria.

Notes: Presents data on (1) the effects of repeated application and native and applied organic matter on parathion degradation, and (2) bacterial degradation of Lindane.

Sethunathan, N., Ramakrishna, C., Barik, S., Venkateswarlu, K., Raghu, K. (1978) Microbial degradation of pesticides in tropical soils: A review of work in India. Pages 471–481 in Edwards, C.A., Veeresh, G.K., Krueger, H.R. (eds.), *Pesticide residues in the environment in India.* FAO/UNESCO/UNDP/ICAR/UAS pub. 524 pp. (NS)

Notes: A review with 32 references.

Sethunathan, N., Siddaramappa, R. (1978) Microbial degradation of pesticides in rice soils. Pages 479–497 in *Soils and Rice.* IRRI, Manila, Philippines.

Notes: A review with 93 references.

Sethunathan, N., Siddaramappa, R., Siddarame Gowda, T.K., Rajaram, K.P., Barik, S., Rao, V.R. (1976) Pesticide-soil microflora interactions in flooded rice soils. Pages 27–36 in *Trace contaminants of agriculture, fisheries and food in developing countries.* Pesticide-Soil Microflora.

Summary: Isotope studies revealed that gamma and beta isomers of HCH (hexachlorocyclohexane) decomposed rapidly in nonsterile soils capable of attaining redox potentials of −40 to −100 mV within 20 days after flooding. Degradation was slow, however, in soils low in organic matter and in soils with extremely low pH and positive potentials, even after several weeks of flooding. Under flooded conditions, endrin decomposed to six metabolites in most soils. There is evidence that biological hydrolysis of parathion is more widespread than hitherto believed, particularly under flooded soils conditions. Applications

of benomyl (fungicide) to a simulated-oxidized zone of flooded soils favoured nitrification.

Sethunathan, N., Sudhakar-Barik, Venkateswarlu, K., Wahid, P.A., Ramakrishna, C., Pal, S.S., Ray, R.C., Chendrayan, K., Rao, Y.R., Rao, V.R., Adhya, T.K. (1980) Effect of combined pesticides application on their persistence in flooded rice soils. Pages 259–281 in *Agrochemical-biota interactions in soil and aquatic ecosystems*. Panel proceedings series, I.A.E.A. Vienna.

Summary: Pesticide-microflora interactions were studied with special reference to flooded soils. The principal metabolic pathway for the insecticide parathion shifted from nitro group reduction to hydrolysis upon the repeated additions of parathion or its hydrolysis product, p-nitrophenol, to a flooded soil. Both nitro group reduction and hydrolysis are cometabolic reactions; the tremendous build-up of parathion-hydrolysing micro-organisms after parathion additions occurred at the expense of the product of the primary cometabolic hydrolysis, p-nitrophenol. The fungicide benomyl significantly increased the persistence of generally short-lived parathion in flooded soil by inhibiting nitro group reduction and hydrolysis. Benomyl inhibited nitrification, iron reduction and drop in the redox potential in a flooded soil. Aerobically incubated flooded soil liberated more $^{14}CO_2$ from the ^{14}C in p-nitrophenol than anaerobically incubated flooded soil. The lag of about twenty days in the degradation of carbofuran and its high water solubility may raise problems of carbofuran residues in the run-off waters from carbofuran-treated ricefields, particularly in areas comprised of soils capable of remaining acidic even under flooded conditions. Interestingly, during forty-day flooding, $^{14}CO_2$ evolution from ring-^{14}C-carbofuran was virtually negligible whereas 16–27 percent of carbonyl-^{14}C was converted to $^{14}CO_2$. Evidence suggests that redox potential, reducing capacity and certain reduction reactions, assayed for example in terms of nitrate disappeared or reduced iron formed, could be used as simple and suitable indicators of the pesticide-degrading capacity of anaerobic systems. Dehydrogenase activity is well pronounced in predominantly anaerobic flooded soil and may have the obvious advantage over the $^{14}CO_2$ evolution technique as an assay for the pesticide-degrading capacity of anaerobic systems.

Sethunathan, N., Yoshida, T. (1973a) A *Flavobacterium* sp. that degrades diazinon and parathion. *Can. J. Microbiol.* 19: 973–875.

Summary: A *Flavobacterium* sp., isolated from paddy water by enrichment culture technique, decomposed diazinon in a mineral medium as sole carbon source. The bacterium readily hydrolyzed diazinon to 2-isopropyl-6-methyl-4-hydroxy-pyrimidine which was then converted to carbon dioxide. The bacterium

also converted parathion to p-nitrophenol. The enzyme involved in the hydrolysis was constitutive.

Sethunathan, N., Yoshida, T. (1973b) Degradation of chlorinated hydrocarbons by *Clostridium* sp. isolated from lindane-amended flooded soil. *Plant Soil* 38: 663–666.

Summary: A *Clostridium* sp., isolated from flooded soil amended with lindane (-BHC), decomposed methoxychlor, -BHC and hetachlor in that order under anaerobic condition. During the bacterial degradation of ring-labeled ^{14}C-BHC there was a net loss of radioactivity from the reaction mixture. Release of $^{14}CO_2$ during the degradation of ^{14}C-BHC was negligible. Methane was not detected as an end product of -BHC breakdown.

Sethunathan, N., Yoshida, T. (1973c) Parathion degradation in submerged rice soils in the Philippines. *J. Agric. Food Chem.* 21: 504–506.

Summary: The persistence of parathion (0,0-diethyl 0-p-nitrophenyl phosphorothioate) in four Philippine rice soils was investigated in submerged and upland conditions. The parathion in the soils after incubation at 300 was extracted with a hexaneacetone mixture and the amount was determined by gas chromatography. The insecticide disappeared more rapidly from submerged soils than from upland soils. In submerged soils parathion was reduced to aminoparathion (0,0-diethyl 0-p-aminophenyl phosphorothiate). Autoclaving of the soils increased the persistence of parathion under submerged conditions, indicating microbial participation in its degradation. Parathion degraded faster in flooded soil inoculated with parathion-hydrolyzing *Flavobacterium* sp. than in uninoculated soil.

Siddaramappa, R. (1975) Biodegradation of insecticides in rice soils. Ph.D. thesis (Agricultural chemistry), Orissa University of Agricultural and Technology, Bhubaneswar, CRRI Cuttack. 127 pp.

Notes: A study of the degradation of parathion and its related nitrophenols and BHC in soils and by microorganisms.

Siddaramappa, R. (1978) *Fate of carbofuran in flooded soil and in rice plants.* A terminal report submitted to the International Rice Research Institute, Los Baños, Philippines. December 3, 1976–November 29, 1978. 65 pp. (NS)

Siddaramappa, R., Rajaram, K.P., Sethunathan, N. (1973) Degradation of parathion by bacteria isolated from flooded soil. *Appl. Microbiol.* 26: 846–849.

Summary: Two bacteria, *Bacillus* sp. and *Pseudomonas* sp., were isolated from parathion-amended flooded alluvial soil which exhibited parathion-hydrolyzing ability. *Bacillus* sp. readily liberated nitrite from the hydrolysis product, p-nitrophenol, but not from intact parathion. *Pseudomonas* sp. hydrolyzed parathion and then released nitrite from p-nitrophenol. These studies establish bacterial degradation of parathion past the p-nitrophenol stage to the end product, nitrite.

Siddaramappa, R., Seiber, J.M. (1979) Persistence of carbofuran in flooded rice soils and water. *Prog. Water Technol.* 11: 103–111.

Summary: The persistence of carbofuran (2,3-dihydro-2,2 dimethyl-7-benzofuranyl methyl carbamate) in soil and water samples collected from different rice growing areas in the Philippines was studied under laboratory conditions. After extraction, carbofuran was estimated by gas-liquid chromatography. Beside, studies with ^{14}C-labelled carbofuran were also conducted in some experiments. Rapid degradation of carbofuran occurred in two out of three sets of irrigation and paddy water samples. Degradation of carbofuran in water was mainly by non-biological process(es); but in soil, it was associated with microbial activities as well. The rate of degradation of carbofuran in water was related to the initial pH and that repeated application to paddy water did not result in a "build-up effect". Application carbofuran to a depth of about 3 cm from the surface of flooded soil reduced the concentrations in standing water but increased the persistence in soil significantly. Furthermore, addition of various nitrogenous fertilizers such as ammonium sulfate or urea along with carbofuran influenced the duration of the insecticide's activity in soil and water.

Siddaramappa, R., Sethunathan, N. (1975) Persistence of gamma-BHC and beta-BHC in Indian rice soils under flooded conditions. *Pest. Sci.* 6: 395–403. (NS)

Siddaramappa, R., Sethunathan, N. (1976) Volatilization of lindane from water in soil-free and flooded soil systems. *J. Environ. Sci. Health* 11B. 119. (NC)

Siddaramappa, R., Tirol, A., Watanabe, I. (1979) Persistence in soil and absorption and movement of carbofuran in rice plants. *J. Pest. Sci.* 4: 473–479.

Summary: The persistence of carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methyl carbamate) applied to paddy water or the root zone of flooded soil and its influence on absorption and translocation in rice plants were studied under greenhouse conditions. Also the degradation of carbofuran as affected by soil types and the effect of repeated root zone treatments was investigated under laboratory conditions without rice plants by gas-liquid chromatography, thin-layer chromatography, and the isotape technique. Placement of

carbofuran at the root zone of rice resulted in a significant increase in persistence in soil as compared with paddy water application. The absorption and translocation rates of carbofuran in rice plants were more rapid in paddy water application, however, while in the root zone placement those rates increased gradually. Most of the carbofuran absorbed by rice accumulated in the leaves, particularly, the tip portions. A consistently lower concentration was present in the stem portion of the plant. Microbial degradation of carbofuran in three soils was studied; degradation was slowest in soil with the lowest pH.

Siddaramappa, R., Tirol, A.C., Seiber, J.N., Heinrich, E.A., Watanabe, I. (1978) The degradation of carbofuran in paddy water and flooded soil of untreated and retreated ricefields. *J. Environ. Sci. Health* 13B: 369–380.

Summary: Loss of carbofuran from paddy water and in flooded soil was studied in the laboratory and under field conditions. Carbofuran was rapidly hydrolyzed to carbofuran phenol in just five days after its application to paddy water. Hydrolysis of carbofuran appeared to be primarily due to chemical, but degradation of carbofuran phenol was biological. Previous applications of carbofuran to paddy water had no appreciable effect on the rate of degradation of the insecticide. However, in soil from the carbofuran-treated plot, a more rapid degradation of carbofuran occurred only after three weeks of incubation under laboratory conditions. Incubating paddy water under light or dark conditions revealed that photo-decomposition of carbofuran may not be occurring. The data furnished no evidence that microbial acclimatization plays a major role in the dissipation of carbofuran applied as granules to paddy water.

Siddaramappa, R., Tirol, A.C., Watanabe, I. (1977) Fate of carbofuran under flooded soil conditions. IRRI Saturday Seminar, October 8, 1977. 17 pp. (NS)

Siddaramappa, R., Watanabe, I. (1978) Fate of carbofuran in flooded soil and in rice plants. *International Rice Research Newsl.* 3(6): 15. (NS)

Notes: The authors conclude that the rice plant may lose appreciable quantities of carbofuran through vaporization.

Siddaramappa, R., Watanabe, I. (1979) Evidence for vapor loss of ^{14}C-carbofuran from rice plants. *Bull. Environ. Contam. Toxicol.* 23: 544–551. (NS)

Notes: The authors conclude that the rice plant may lose appreciable quantities of carbofuran through vaporization.

Soderquist, C.J., Bowers, J.B., Crosby, D.G. (1977) Dissipation of molinate in a ricefield. *J. Agric. Food Chem.* 25(4): 940–945.

Summary: The dissipation of the herbicide molinate (S-ethyl hexahydro-1H-azepine-1carbothioate) in a California ricefield was investigated. Laboratory experiments indicated that while dilute aqueous solutions of molinate were stable in sunlight, irradiations in the presence of tryphophan resulted in decomposition primarily to 1 [(ethylsulfinyl)carbonyl]hexahydro-1H-azepine, S-ethyl hexahydro-2-oxo-1H-azepine-1-carbothioate, and hexamethyleneimine. Analysis for molinate and its degradation products at sub-ppm levels in water, soil, and air samples collected from a commercially treated field, together with laboratory studies, showed that volatilization of molinate from water was the primary mode of dissipation, although photodecomposition products were present in field water.

Soderquist, C.J., Crosby, D.G. (1975) Dissipation of 4-Chloro-2-mehtylphenoxyacetic acid (MCPA) in a ricefield. *Pestic. Sci.* 6: 17–33. (NC)

Sudhakar-Barik, Wahid, P.A., Ramakrishna, C., Sethunathan, N. (1979) A change in the degradation pathway of parathion after repeated application to flooded soil. *J. Agric. Food. Chem.* 27: 1391–1392.

Summary: The degradation pathway of parathion shifted to hydrolysis from reduction after repeated applications of parathion or its hydrolysis product, p-nitrophenol, to a flooded soil. This shift occurred as a result of the proliferation of parathion-hydrolyzing microorganisms that utilized p-nitrophenol as the energy source. This is probably the first report of the enrichment of a population capable of degrading a parent molecule upon application of the primary product of its metabolism.

Sudhakar-Barik, Sethunathan, N. (1978a) Biological hydrolysis of parathion in natural ecosystems. *J. Environ. Qual.* 7: 346–348. (NC)

Sudhakar-Barik, Sethunathan, N. (1978b) Metabolism of nitrophenols in flooded soils. *J. Environ. Qual.* 7: 349–352.

Summary: Nitrophenols (p-, o-, and m-isomers and 2,4-dinitrophenol) disappeared fairly rapidly from flooded alluvial and organic matter-rice acid sulfate (pokkali) soils inoculated with parathion (0,0-diethyl 0,p-nitrophenyl phosphorothioate)-enrichment cultures from the respective soils. Nitrite, one of the reported end-products of nitrophenol (0,0-dimethyl 0,p-nitrophenyl phosphorothioate) metabolism, accumulated only in inoculated alluvial soil, irrespective of the type of nitrophenol added. In an isotope study, ring cleavage of p-nitrophenol leading to carbon dioxide was demonstrated in flooded soils inoculated with parathion-enrichment culture, particularly under stirred conditions.

Nitrophenols decomposed also in uninoculated samples of both soil types, though slowly as compared to inoculated soils; but nitrite and carbon dioxide were not formed. Resting cells of a bacterium, *Pseudomonas* sp. ATCC 29353, readily hydrolyzed parathion and then liberated nitrite from p-nitrophenol. In cell-free suspension, the reaction ceased at the p-nitrophenol stage. In bacterial cultures, parathion was hydrolyzed without proliferation while subsequent degradation of p-nitrophenol involved metabolism leading to bacterial enrichment.

Sudhakar-Barik, Sethunathan, N. (1979) Persistence of parathion increased by benomyl in flooded soil. *Prog. Water Technol.* 11: 113–119.

Summary: In a study on the persistence of pesticides under the impact of pesticide combinations, the addition of benomyl to a flooded soil even at close to field application rate of 5 ppm level significantly increased the persistence of generally less persistent parathion. This increased persistence was a direct consequence of the striking inhibition of biologically mediated nitro-group reduction and hydrolysis of parathion by benomyl. The addition of rice straw hastened nitro-group reduction; but the effect of benomyl in increasing the persistence of parathion was pronounced even in the presence of added rice straw. These studies demonstrate that long term persistence of parathion can occur in situations where it is applied in combination with other pesticides such as benomyl, rasing problems of contamination of water resources and inland fisheries.

Sudhakar-Barik, Siddaramappa, R., Sethunathan, N. (1976) Metabolism of nitrophenols by bacteria isolated from parathion-amended flooded soil. *Antonie van Leeuvenhoek* 42: 461–470.

Summary: Two bacterial isolates from parathion-amended flooded soil, *Pseudomonas* sp. and *Bacillus* sp., were examined for their ability to decompose nitrophenols. Uniformly labelled ^{14}C-p-nitrophenol was metabolized by both bacteria, $^{14}CO_2$ and nitrite being end products. A substantial portion (23 percent for *Pseudomonas* sp. and 80 percent for *Bacillus* sp.) of radioactivity applied as p-nitrophenol was accounted for as $^{14}CO_2$ at the end of a 72-h period; 8 to 16 percent remained in the water phase after solvent extraction. *Pseudomonas* sp. produced nitrite also from 2,4-dinitrophenol, but only after a lag, and not from o-and m-nitrophenols. Interestingly, m-nitrophenol, known for its resistance to biodegradation because of meta substitution, was decomposed by *Bacillus* sp., resulting in the formation of nitrite and phenol; o-nitrophenol and 2,4-dinitrophenol resisted degradation by this bacterium.

Suzuki, T. (1983a) Metabolism of pentachlorophenol (PCP) by soil microorganisms. *Bull. Nat. Inst. Agric. Sci. (Japan)* Serie C 38: 69–120.

Notes: in Japanese

Suzuki, T. (1983b) Methylation and hydroxylation of pentachlorophenol (PCP) by *Mycobacterium* sp. isolated from soil. *Bull. Nat. Inst. Agric. Sci. (Japan)* Serie C 8: 419–428.

Notes: The major pathways of PCP degradation by *Mycobacterium* are determined.

Tomizawa, C. (1975) Degradation of organophosphorus pesticides in soils with special reference to anaerobic conditions, in *Environmental quality and safety*, Coulston, F., Albany, N.Y., Korte, F. (eds.), Academic Press, New York. 117–127 pp. (NC)

Tomizawa, C. (1980) Biological accumulation of pesticides in an ecosystem: Evaluation of biodegradability and ecological magnification of rice pesticides by a model ecosystem. *JARQ* 14(3): 143–149. (NS)

Notes: Description of microosm where the fate of BHC is followed in water, algae, snail, fish, rice and cucumber.

Tomizawa, C., Kazano, H. (1979) Environmental fate of rice paddy pesticides in a model ecosystem. *J Environ. Sci. Health* 14B: 121–152.

Summary: The distribution and metabolic fate of several rice paddy pesticides were evaluated in a modified model ecosystem. Among the three BHC isomers, beta-isomer was the most stable and bioconcentrated in all of the organisms. Alpha- and gamma-isomers were moderately persistent and degraded to some extent during the thirty-three-day period. Disulfoton was relatively persistent due to the transformation to its oxidation products. Pyridaphenthion was fairly biodegradable. N-Phenyl maleic hydrazide derived from the hydrolysis of pyridaphenthion was not detected in the organism though it was found in the aquarium water after thirty-three days. Cartap and edifenphos were considerably biodegradable, and the ratio of the conversion to water soluble metabolites was very high. There was a distinct different in the persistence of Kitazin P and edifenphos in the aquarium water. It appeared that the hydrolysis rate of the pesticides affected their fate in the organisms. PCP appeared to be moderately biodegradable. CNP was considerably stable and stored in the organisms though the concentration in aquarium water was relatively low. The persistence and distribution of the pesticides in the model ecosystem were dependent on their chemical structures. In spite of the limitation derived from short experimental period, the model ecosystem may be applicable for predicting the environmental fate of pesticides.

Notes: The model uses sand instead of soil.

Tsukano, Y., Kobayashi, A. (1972) Formation of gamma-BTC in flooded rice soils treated with gamma-BHC. *Agric. Biol. Chem.* 36: 166–167. (NS)

Notes: Gamma BHC in upland soils is degraded into gamma PCCH while, in wetland conditions, gamma BTC is formed which disappears much faster and is therefore difficult to detect.

Venkateswarlu, K. (1979) Microbial degradation of carbamate insecticides in rice soils. Ph.D. thesis, Utkal University, Bhusbaneswar. (NC)

Venkateswarlu, K., Gowda, T.K.S., Sethunathan, N. (1977) Persistence and biodegradation of carbofuran in flooded soils. *J. Agric. Food Chem.* 25: 533–536.

Summary: The persistence of carbofuran (2,3,-dihydro-2,2-dimethyl-7-benzofuranyl methyl carbamate) in four soils was studied in the laboratory with special reference to flooded conditions. After thin-layer chromatographic separation of residues, carbofuran in the soil samples was converted to its phenol by alkaline hydrolysis and then assayed colorimetrically following diazotization. More rapid degradation of carbofuran occurred in soils under flooded conditions than under nonflooded conditions. Carbofuran degraded rapidly between twenty and forty days after flooding in most soils including an acid sulfate saline soil, Pokkali, capable of attaining near neutral pH upon flooding; but the insecticide persisted in another acid sulfate saline soil, Kari, perhaps due to its exceedingly low pH of 4.2, even after several weeks of flooding. Heat treatment of soils prior to incubation increased the persistence of carbofuran under flooded conditions. Moreover, a bacterium isolated from flooded soil by an enrichment technique, decomposed carbofuran in a mineral salts medium. These studies indicate that microorganisms are involved in the degradation of carbofuran in flooded soils.

Notes: Between 60 and 70 percent of carbofuran added to three soils was recovered immediately after mixing the pesticide with the soil.

Venkateswarlu, K., Sethunathan, N. (1978) Degradation of carbofuran in rice soils as influence by repeated application and exposure to aerobic conditions following anaerobiosis. *J. Agric. Food Chem.* 26: 1148–1151.

Summary: The persistence of carbofuran (2,3,-dihydro-2,2-dimethyl-7-benzo furanyl N-methylcarbamate) in flooded rice soils was studied after its repeated application. Repeated applications of carbofuran to flooded rice soils at rates close to field applications do not seem to favor rapid buildup of the microorganisms capable of decomposing carbofuran. An isotope study showed that degradation of carbofuran in flooded soils was more rapid under undisturbed conditions than under aerobic conditions provided by shaking. Under continued anaerobiosis of undisturbed flooded soils, the hydrolysis products, carbofuran phenol (2,3-dihydro-2,2-dimethyl-7-hydroxy benzofuran) in particular, accumulated; but when the undisturbed soil was returned to aerobic conditions, the hydrolysis products decreased rapidly.

Venkateswarlu, K., Sethunathan, N. (1979) Metabolism of carbofuran in rice straw-amended and unamended rice soils. *J. Environ. Qual.* 8: 365–368.

Summary: Degradation of carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl N-methylcarbamate) in rice straw-amended flooded soil under alternate anaerobic-aerobic conditions and $^{14}CO_2$ evolution from ring- and carbonyl-labeled ^{14}C-carbofuran in flooded soil were studied. The addition of rice straw accelerated the hydrolysis of carbofuran to carbofuran phenol (2,3-dihydro-2,2-dimethyl-7-hydroxy benzofuran) in predominantly anaerobic flooded soil. Carbofuran phenol appeared to accumulate under continued anaerobiosis and was readily decomposed with the significant formation of unextractable ("soil bound") residues when the system was returned to aerobic conditions. Interestingly, $^{14}CO_2$ evolution from the aromatic ring in carbofuran was almost negligible, accounting for < 0.3 percent of ring-^{14}C even after 40 days of flooding as compared to 27 percent released from carbonyl-^{14}C.

Venkateswarlu, K., Sethunathan, N. (1984) Fate of ^{14}C carbofuran in a flooded acid sulphate saline soil. *Current science* 53(17): 925–927. (NS)

Notes: Test tube experiment showing that carbofuran degradation in an acid saline soil was rapid under flooded conditions, after a lag of about twenty days.

Wahid, P.A., Sethunathan, N. (1978) Sorption-desorption of parathion in soils. *J. Agric. Food Chem.* 26: 101–105. (NS)

Wahid, P.A., Sethunathan, N. (1979) Involvement of hydrogen sulfide in the degradation of parthion in flooded acid sulphate soil. *Nature* (London) 282: 401. (NS)

Notes: Hydrogen sulfide formed in flooded soils was at least partly responsible for the formation of the dealkylation product from parathion through aminoparathion.

Wahid, P.A., Sethunathan, N. (1980) Instantaneous degradation of parathion in anaerobic soils. *J. Environ. Qual.* 9: 127–130.

Summary: In flooded rice (*Oryza sativa* L.) culture, the pesticides are applied to ricefields after several days of submergence when the soil is already in a reduced state. Parathion (0,0-diethyl O,p-nitrophenyl phosphorothioate) was, therefore, equilibrated with soils previously reduced by flooding with water and then analyzed by isotope technique or by gas-liquid chromatography. Instantaneous surface-catalyzed degradation of parathion occurred when the insecticide was shaken for as little as 5 sec with soils prereduced by flooding. Aminoparathion was the major product of this reaction. The interaction of parathion with prereduced soil appeared to be mediated by soil enzymes and/or other heat-labile substances produced by soil anaerobiosis.

Walter-Echols, G., Lichtenstein, E.P. (1978) Movements and metabolism of ^{14}C-phorate in a flooded soil system. *J. Agric. Food Chem.* 26: 599–604.

Summary: Experiments were conducted to study the effects of soil flooding on the fate and metabolism of [^{14}C]phorate in an agricultural loam soil, on the movement and metabolism of the insecticide in a soil-water-plant system, and factors affecting these phenomena. [^{14}C]Phorate residues were readily released from submerged soils into water, amounting to 45 percent of applied radiocarbon during the first three days after flooding. After a two-week incubation period as much as one-half of the radiocarbon applied to the soil was recovered from the water. Phorate was much more persistent under flooded than under nonflooded conditions. It was the principle compound recovered from submerged soils where it accounted for approximately 70 percent of the total residues recovered. Phorate sulfoxide was the major metabolite, only traces of it were detected in the flooded system. However, when *Elodea* plants were introduced into the system, phorate sulfone amounted after fourteen days to 30 percent of all benzene-extractable ^{14}C residues recovered, phorate sulfoxide to 44 percent, and phorate to 27 percent. At that time soils, water, and plants contained 32, 39, and 17 percent of the applied radiocarbon, respectively. While more lipid-soluble volatile metabolites were recovered from nonflooded soils, more $^{14}CO_2$ was evolved from the flooded soil. The production of $^{14}CO_2$ was a function of microbiological activity. When [^{14}C]phorate-treated soil was flooded with increasing amounts of water, the amounts of radiocarbon residues in the water increased. However, amounts of ^{14}C residues in the water decreased when increasing amounts of soil were used.

Wang, C.H., Broadbent, F.E. (1973) Effect of soil treatment on losses of two chloro-nitrobenzene fungicides. *J Environ. Qual.* 2: 511–515. (NS)

Notes: Comparison of persistence under upland and flooded conditions. Cited from Sethunathan and Siddaramappa, 1978.

Watanable, I. (1973a) Decomposition of pesticides by soil microorganisms: Special emphasis on the flooded soil condition. *JARQ Japan Agricultural Research Quarterly* 7(1): 15–18.

Notes: Short review with twenty references

Watanabe, I. (1973b) Isolation of pentachlorophenol decomposing bacteria from soil. *Soil Sci. Plat Nutr.* (Tokyo) 19: 109–116.

Notes: *Pseudomonas* or closely related strains able to degrade PCP, using it as sole C source, were isolated from a ricefield soil.

Watanabe, I. (1977) Pentachlorophenol-decomposing and PCP-tolerant bacteria in field soil treated with PCP. *Soil Biol. Biochem.* 9: 99–103.

Watanabe, I. (1978) Pentachlorophenol (PCP) decomposing activity of field soils treated annually with PCP. *Soil Biol. Biochem.* 10: 71–75.

Summary: Soil from field plots (Hokkaido Agricultural Experiment Station, Memuro, Japan) that had been treated once a year with pentachlorophenol (PCP) and from untreated plots was tested for PCP-decomposing activity in the laboratory. When PCP as an aqueous solution of pentachlorophenolate was added to both sets of soil samples, no significant difference was noticeable in the PCP-decomposing activity, despite a 1,000-fold difference in the number of PCP-decomposing microorganisms. When PCP was added as a PCP-celite mixture—to ensure that PCP was thoroughly mixed with the soil—PCP-decomposing activity was related to the history of the plot's treatment. The activity of the soil from PCP field plots was consistently higher than that from non-treated plots. When PCP was added to the untreated soil and incubated, the number of PCP-decomposing microorganisms increased, reaching the same order as that of PCP-treated soil plots after three to four weeks.

Watanabe, I., Hyashi, S. (1972) Degradation of PCP (Pentachlorophenol) in soil. I. Microbial depletion of PCP under dark and submerged conditions. *J. Sci. Soil Manure Japan* 43: 119–122 [in Japanese]. (NC)

Willis, G.H., Wanter, R.C., Southwick, L.M. (1974) Degradation of trifluralin in soil suspension as related to redox potentials. *J. Environ Qual.* 3: 262–265.

Summary: A system for controlling redox potential in soil suspensions was used to investigate the relationship between oxidation-reduction potential (Eh) and the rate of trifluralin (a-a-a-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine) degradation. Redox potentials of +450, +250, +150, +50, 0, and –50 mV were

imposed on trifluralin-amended (1 ppm oven-dry weight soil basis) soil suspensions (100 g soil in 300 ml H2O) for 21 days. Results indicated that exclusion of O_2 by soil flooding initiated rapid trifluralin degradation only when the Eh decreased below a critical range between +150 and +5 -mV. There was no clear-cut relationship between trifluralin degradation and microbiological respiratory activity (CO_2 evolution). If soil flooding is to be a practical cultural technique for accelerating the rate of degradation of persistent pesticides, steps may have to be taken to ensure that soil Eh decreases below a critical value for some required period of time. This may include soil incorporation of a readily available carbon or energy source to stimulate an active soil microbial population to enhance lowering of the soil Eh.

Yamada, T. (1976) Residues of nitrofen and CNP in paddy fields. Pages 217–222 in *Proceedings of the Fifth Asian-Pacific Weed Science Socelty Conference*, Tokyo.

Summary: The residue of herbicide, CNP (P-nitrophenyl 2,4,6-trichlorophenyl ether), and its derivatives: p-aminophenyl 2,4,6-trichlorophenyl ether, 2,4-dichlorophenyl p-nitrophenyl ether (NIP; nitrofen), and p-aminophenyl 2,4-dichlorophenyl ether in paddy field soils were determined. In the paddy field soil sprayed with CNP-granules about ten months ago, large quantities of these amino compounds which combined chemically with the soil organic matters were left over, and they were altered to the free amino compounds by the strong alkaline treatment of the soil samples. The survey of the residues of CNP and NIP, including respective amino derivative, in the paddy field soils in Japan revealed considerably heavy pollution by them, especially in the northern districts.

Yamada, T., Suzuki, S. (1983) Occurrence of reducive dechlorination products in the paddy field soil treated with CPN (Chlornitrofen) *J. Pest. Sci.* (Japan) 8: 437–443.

Notes: Dwarf symptoms of rice plant was generated with dechlorinated thiobencarb formed in soil when herbicide thiobencarb was applied at high rate in a field where rice straw had been incorporated. The decomposition of the dechlorinated compound was slower than that of the parent compound.

Yoshida, T. (1975) Pesticide residues in upland rice soils, Pages 200–216 in *Major research in upland rice,* International Rice Research Institute, Los Baños, Philippines. (NC)

Notes: A review of the work conducted by IRRI scientists with Philippine soils.

Yoshida, T., Castro, T.F. (1970) Degradation of gamma-BHC in rice soils. *Soil Sci. Soc. Am. Proc.* 34: 440–442.

Summary: The biodegradation of the organochlorine insecticide, gamma-BHC (gamma-isomer of 1,2,3,4,5,6-hexachlorocyclohexane) was evaluated for four Philippine rice soils: Casiguran sandy loam, Luisiana clay, Maahas clay and Pila clay loam. Rapid degradation of the insecticide was observed under flooded soil conditions. The rate of degradation for gamma-BHC was highest in Casiguran sandy loam; none of the parent insecticide remained in the soil after one month of incubation at 30°C. Organic matter levels were related directly to rate of decomposition. Molecular oxygen, nitrate, and manganic oxide retarded the rate of gamma-BHC degradation. Increased temperature increased the rate of gamma-BHC degradation, and it appears that gamma-BHC residues are unlikely to be a problem in the tropical rice-growing areas.

Yoshida, T., Castro, T.F. (1975) Degradation of 2,4-D, 2,4,5-T and picloram in two Philippine soils. *Soil. Sci. Plant Nutr.* (Tokyo) 21: 397–404.

Summary: The degradation of 2,4-D, 2,4,5-T, and picloram in two Philippine soils was investigated under upland and flooded (submerged) conditions. These herbicides degraded in both upland and flooded Maahas clay and Luisiana clay soils. The rate of degradation of the herbicides was more rapid in the Maahas clay soil than in the Luisiana clay soil. Among the three herbicides, 2,4-D was the least persistent and picloram was the most persistent in both soils under both submerged and upland conditions. 2,4,5-T degraded more actively in the two Philippine soils in this study than studies previously reported in the available literature. The fact that both the 2,4-D and 2,4,5-T did not degrade in sterilized soils during the incubation period suggests that the degradation is due to the microbial activity in the soils.