IMPACT OF AGROCHEMICALS ON SOIL AND WATER QUALITY

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ABSTRACT

Agrochemical pesticides are still very important in crop protection in the Philippines. Intensive use of pesticides over the years may result in some environmental problems, such as contamination of soil and groundwater with these chemicals. When pesticides are applied to protect crops from pests and diseases, only around 15% of the preparation hits the target. The rest is distributed in the soil and air.

The soil is the main matrix for pesticide disposition. However, the bulk of pesticide residues in soil are generally confined to the upper 5 cm of the topsoil. Agrochemicals in soil can move from the surface when they are dissolved in runoff water, or when they percolate down through the soil. Those that have infiltrated the soil will eventually reach the groundwater (FAO 2000).

Characteristics that may influence the leaching of pesticides into groundwater include the amount of rainfall, soil drainage, the depth of the groundwater below the soil surface, and the mobility of the pesticide and its degradation process, as well as agronomic factors such as timing, rate and method of the pesticide application, and the use of irrigation and cover crops (FAO 2000, Wyman et al. 1985, Helling and Gish 1986).

RICE ECOSYSTEM

In the Philippines, rice production can be considered a major contributor to pesticide contamination of the environment. It is a common practice for water to be drained from treated paddy fields into irrigation canals about 40 days before the rice is harvested.

Percolation and runoff are two important physical processes determining the fate of pesticides that are in solution in the water in rice fields. Percolation is the vertical movement of water through the soil profile. It allows pesticides which are in solution or absorbed by sediments to move downward through the soil profile, finally reaching the groundwater.

Runoff allows lateral movement of the chemicals away from the rice field when it is deliberately drained, or when excess rainfall and irrigation water flow causes the field bunds to overflow. In a rice irrigation system, all runoff from rice fields is collected in the main drainage system. This ultimately discharges the effluent into a large water body such as a river or lake, or the sea.

GROUNDWATER CONTAMINATION BY AGROCHEMICALS

The amount and rate of pesticide residue movement through the soil profile and into the groundwater are governed by the interaction of several processes (Fig. 1).

The residues of pesticides used in rice production (Table 1) were monitored by collecting groundwater from tube wells adjacent to rice fields in both irrigated and rainfed areas in Laguna and Nueva Ecija. Both these provinces are in Luzon, the northernmost large

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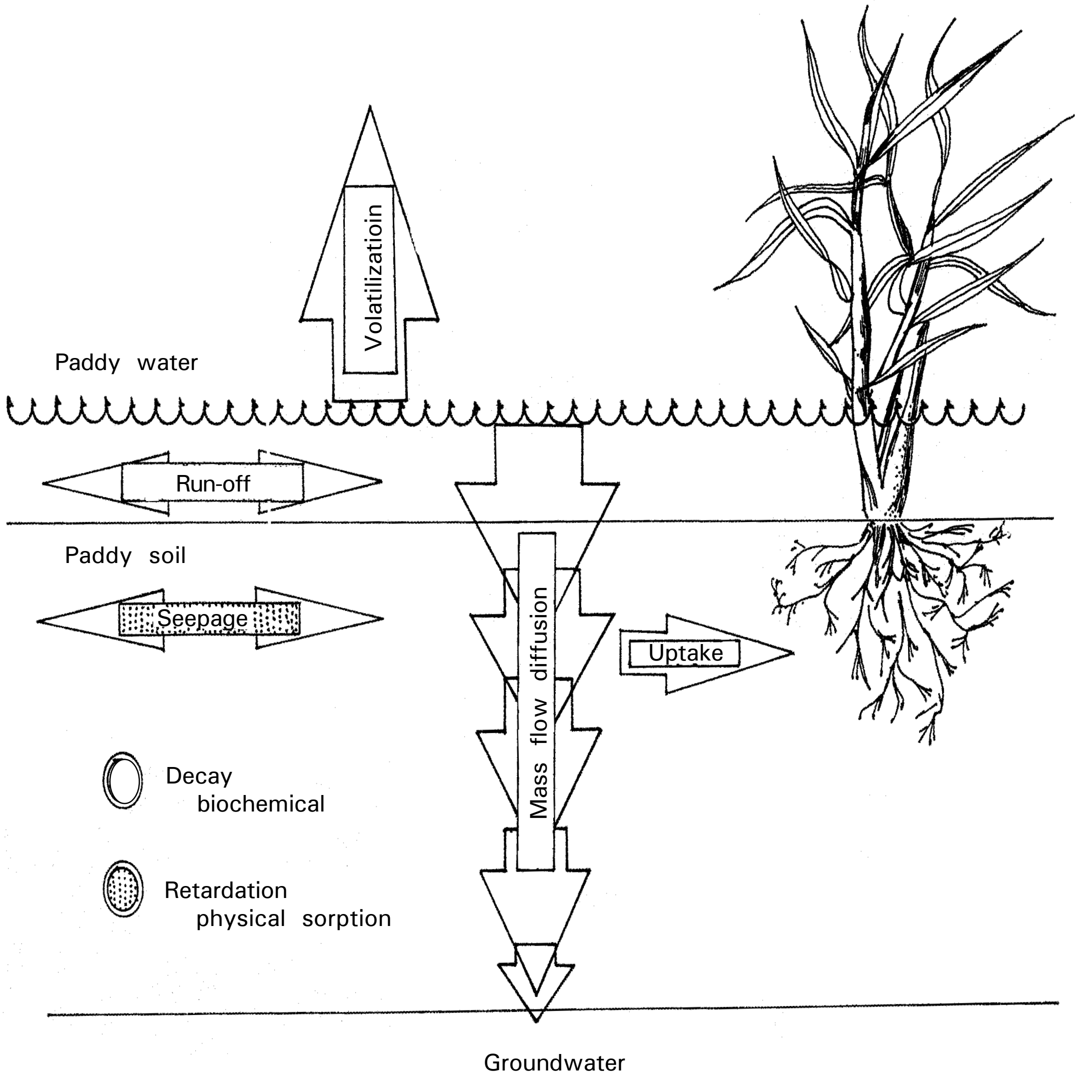

Fig. 1. Diagram of the movement of pesticide residues in a Lowland Rice Production System

island of the Philippines. Both areas are extensively used for rice production. A number of commonly used pesticides were detected, including chlorpyrifos, butachlor, endosulfan, carbofuran, methyl parathion and monocrotophos (Table 2) (Castaneda and Bhuiyan 1996).

The concentration of these six common pesticides ranged from 0.002 ppb (parts per billion) for chlorpyrifos to 0.209 ppb for monocrotophos (Table 2). The maximum concentration found in a single sample was 3.19 ppb for monocrotophos. Endosulfan was present in 79% of the samples collected, and monocrotophos in 54% of the samples. Irrigation, sandy soils and wet-season rice cultivation all contributed to higher concentrations in the groundwater.

Monocrotophos is highly soluble in water, even at a concentration of $1x10^6$ ppm, (parts per million), and is considered to be very mobile in soil (Table 3). This would make it more likely to reach the groundwater. Endosulfan has a water solubility of 0.5 ppm and is only slightly mobile in soil (Logkoc = 3.4). It was the most common pesticide found in the groundwater samples. Chlorpyrifos is less soluble and is not very mobile in soil. The concentrations in the contaminated samples exceeded the maximum admissible level

Table 1. Pesticides most often used by rice farmers in the Philippines

Unit: % (by volume)

Pesticide	Irrigated rice		Rainfed rice
	Wet season	Dry season	Wet season
Endosulfan	8	9	8
Chlorpyrifos	10	6	8
Monocrotophos/ cypermethrin	5	2	7
Carbofuran	6	9	3
Methyl Parathion	3	4	0
Butachlor	15	12	2
2,4-D	6	4	3
Aquatin	3	3	5
Cypermethrin	4	3	5
Monocrotophos	3	2	8
Pretilachlor	7	14	8
Fentinacetate	4	2	5
Other[1]	26	30	38

[1] Consists of very low application levels of 25 different pesticides in the irrigated area, and six in the rainfed area

Table 2. Pesticide residues found in groundwater samples collected from shallow tubewells near rice fields

Pesticide	No. samples	% samples contaminated	Mean concentration (ppb)	
			All samples	Contaminated samples
Chlorpyrifos	150	7	0.002	0.026
Butachlor	270	24	0.039	0.163
Endosulfan	207	79	0.089	0.113
Carbofuran	270	6	0.011	0.202
Methyl parathion	270	24	0.006	0.026
Monocrotophos	150	54	0.209	0.386
Total			0.356	0.916

Source: Castaneda 1996

Table 3. Properties of pesticides commonly detected in shallow groundwater

Pesticide	Water solubility	Log K_{oc}	Mobility
Chlorpyrifos	2		
Butachlor	23		
Endosulfan	0.5	3.4	Slightly mobile
Methyl parathion	60	1-2.6	Mobile to moderately mobile
Monocrotophos	1,000,000	1.3	Mobile
Carbofuran	351	1.3	Mobile

Source: Castaneda 1996

set by the European Economic Community for drinking water (0.1 ppb for a single pesticide and 0.5 ppb for all of the pesticides combined).

Another monitoring study of several artesian wells used by rice farmers was conducted by the University of the Philippines at Los Banos to examine the possible leaching of agrochemicals into groundwater. This study showed that commonly used pesticides for rice production were not detected during the dry season (November to April) (Table 4). However, monitoring of the same artesian wells during the wet season (May - October) showed that residues of endosulfan were found in four wells, monocrotophos in three wells, and chlorpyrifos in a single well (Table 5). These wells were located 1-15 meters from rice fields, and reached an average of 10 meters in

Table 4. Residues in well water of insecticides commonly used for rice. The wells were located near rice paddies in Calauan, Laguna, Philippines (dry season)

Unit: µg/liter

Artesian well	Endosulfan	Monocrotophos	Chlorpyrifos	Diazinon	BPMC
Well 1	NDR	NDR	NDR	NDR	NDR
Well 2	NDR	NDR	NDR	NDR	NDR
Well 3	NDR	NDR	NDR	NDR	NDR
Well 4	NDR	NDR	NDR	NDR	NDR
Well 5	NDR	NDR	NDR	NDR	NDR

NDR = No detectable residues

Table 5. Residues in well water of insecticides commonly used for rice. The wells were located near rice paddies in Calauan, Laguna, Philippines (wet season)

Unit: µg/liter

	Endosulfan	Monocrotophos	Chlorpyrifos	Diazinon	BPMC
Well 1	0.003+ 0.001	1.84+0.064	0.032+	< MDL	< MDL
Well 2	< MDL	< MDL	< MDL	< MDL	< MDL
Well 3	0.011+ 0.003	< MDL	< MDL	MDL	< MDL
Well 4	0.011+ 0.001	MDL	< MDL	< MDL	< MDL
Well 5	0.002+ 0.0	< MDL	< MDL	< MDL	< MDL
Calamba					
Well 1	MDL	0.22+0.027	< MDL	< MDL	< MDL
Well 2	MDL	0.10+0.009	< MDL	< MDL	< MDL

MDL = Minimum detectable levels

Alpha endosulfan = 0.009 ug/liter
Beta endosulfan = 0.011ug/liter
Monocrotophos = 0.03 ug/liter
Chlorpyrifos = 0.02 ug/liter
Diazinon = 0.007 ug/liter
PMC = 0.093 ug/liter

Source: Tejada *et al.* 1995

Table 6. Relative depths and distance from paddy fields of wells monitored in Calauan and Calamba, Laguna, Philippines

	Depth (meters)	Shortest distance from paddy field (meters)
Well 1	10	10
Well 2	10	5
Well 3	13	4
Well 4	20	3
Well 5	13	2
Calamba		
Well 1	na	6
Well 2	na	6

na = not available

depth (Table 6) (Medina *et al.* 1991). Endosulfan was the most commonly detected pesticide, followed by monocrotophos. Endosulfan had been widely used by the rice farmers of Laguna three years before monitoring was conducted. Although the degradation of these pesticides may be rapid in soil and water under tropical conditions, the presence of residues in the well water indicates that they could have persisted long enough to allow movement by mass flow to occur, so that the residues leached into the groundwater.

These findings are very significant, since in rural areas of the Philippines most rice farmers depend on groundwater from shallow aquifers underneath rice fields for their household water supply. Pesticides in shallow groundwater are of particular concern. Although some of the pesticides may be retained in the soil profile as they move downward with percolating water, it is only a matter of time before the absorption capacity of the soil profile is used up and the pesticides reach the water table and the aquifer.

This is especially true when intensive rice culture keeps the land saturated for most of the year. It is the local hydrology, and the type of soils that comprise the subsurface profile and the groundwater aquifer, which mainly determine how much pesticide leaches into the groundwater (Bhuiyan and Castanda 1995).

The leaching potential of several pesticides was studied under humid tropical conditions with saturated soils. Residues of monocrotophos at different soil depths showed that a significant proportion of the residues leached down into the soil. The leaching of residues appeared to be rapid, since monocrotophos was detected at a depth of 175 cm only 48 days after the first spraying (Table 7).

Downward movement of the residues seemed to follow the chemical behavior of the movement of solutes in the soil. The residues at a particular soil depth increased, reached a peak value and then declined over time. This pattern can be expected with chemicals which can dissolve in the soil water, which moves by mass flow and diffusion, but which are degraded, delayed or absorbed in the soil.

The movement and accumulation of endosulfan residues appeared to be similar to that of monocrotophos (Table 8). A significant amount of endosulfan moved through the soil during the first week. When endosulfan was applied to rice in an irrigated field, its half-life

Table 7. Monocrotophos residues detected at different soil depths following three applications to rice, dry season, Calamba, Laguna, Philippines

Unit: ug/liter

	Days after first spraying					
Soil depth (cm)	13	20	27	34	41	48
0	31.68+ 3.79	1.97+ 0.04	NDR	*	NDR	NDR
25	8.86+ 0.40	4.82+ 0.43	NDR	NDR	NDR	NDR
50	3.02+ 0.48	5.70+ 0.88	8.34+ 1.45	0.78+ 0.06	NDR	NDR
125	1.06+ 0.15	2.86+ 0.38	4.99+ 1.04	0.38+ 0.04	1.31+ 0.14	0.29+ 0.06
175	NDR	0.54+ 0.04	0.66+ 0.04	0.28+ 0.01	0.24+ 0.08	0.40+ 0.02

*No surface water
NDR = No detectable residue

Source: Paningbatan *et al.* 1993

Table 8. Endosulfan residues at different soil depths in a farmers field following two application in rice. Calauan, Laguna, Philippines

Unit: ug/L

Soil depth (cm)	Days after first spraying			
	6	31	59	73
0	0.037+0.00	Trace	0.038+0.006	-
25	2.467+0.057	Trace	0.483+0.089	-
50	0.039+0.003	0.060+0.005	0.262+0.049	NDR
125	0.104+0.001	0.035+0.000	0.127+0.005	0.153+0.000
175	Trace	0.053+0.004	0.044+0.006	0.009+0.000

NDR = No detectable residues

Source: Paningbatan *et al.* 1993

Table 9. Contamination of lake ecosystem, with pesticides

Unit: ppb (=parts per billion)

Lake ecosystem	DDT	DDE	DDD	OP's
Manila Bay Tributaries				
1st sampling (water)				
Batang	-	0.4	-	-
Orani	-	0.8	-	-
2nd sampling (water)				
Batang	2.5	0.6	1.2	-
Orani	2.0	0.2	1.2	-
3rd sampling (water)				
Pangilisan River	-	0.3	-	-
Mamata River	-	-	0.2	-

in water was found to be in the range of 8-10 days (Medina - Lucero 1980, Paningbatan 1993). Endosulfan persists longer in wet soil than in dry soil. Small amounts of endosulfan were detected at the lower soil depths, where they persisted for some time. This indicates that endosulfan, as well as monocrotophos, has the potential to move and contaminate the groundwater, especially if the soil is saturated.

Concern over pesticides in soil is not confined to the possibility that they will leach into groundwater and runoff. There is also the risk that soil-bound residues may become bioavailable with time. The presence of soil-bound residues from soil-applied pesticides has been well documented (Tejada 1995, Varca 1997), including under humid tropical conditions.

In the Philippines, watermelon or garlic are usually planted after rice. Soil was treated with ^{14}C-isoprocarb (a radioactive pesticide created for scientific purposes). After all extractable residues had been removed, the soil was then planted in a crop of rice, followed by a crop of watermelon. Autoradiography showed that the ^{14}C isoprocarb was distributed throughout the whole rice plant. The watermelon plants were also able to absorb the ^{14}C isoprocarb residues, which were assumed to be bound (Tejada 1997).

CONTAMINATION OF LAKE ECOSYSTEMS

The lakes, rivers and seas are the ultimate basin for all the washings and wastewater in the environment.

Water samples from irrigation canals in Pagsanjan, Laguna, which emptied into Pagsanjan River contained residues of organophosphate pesticides. Levels ranged from 0.04 ppb to 0.08 ppb. Traces (0.02 ppb) were detected in Laguna Lake (NCPC Annual

Report 1994). Water samples from various tributaries in the Manila Bay contained residues of DDT (2.0 ppb), and other important pesticides. The samples also contained DDE and DDD, both formed when DDT breaks down in the bodies of living plants and animals (Table 9).

CONCLUSION

The long-term use of pesticides to control pests and diseases, especially in rice production, may contribute to the contamination of soil and groundwater with their residues. Although the levels being detected in the Philippines are not alarmingly high, efforts should be made to develop models that will help to predict their long-term effects. Pesticide residues may become an urgent problem, now that the Philippine government is pushing for the utilization of high-yielding hybrid rice varieties to increase rice production. This technology however would rely on the use of pesticides. We should do all we can, including frequent monitoring, to prevent this from contributing to the further deterioration of our environment and its resources.

REFERENCES

Bhuiyan, S.I. and A.R. Castaneda. 1995. The impact of ricefield pesticides on the quality of freshwater resources. In: *Farmer Health and the Rice Environment*, P.L. Pingali and P.A. Roger (Eds.) International Rice Research Institute, College, Laguna, Philippines.

Castaneda, A.R. and S.I. Bhuiyan. 1996. Groundwater contamination by ricefield pesticides and some influencing factors. *Jour. Environ. Sci. Health*, A 31,1: 83-99.

Paningbatan, E.P. and J.R. Medina, S.M.F. Calumpang and M.J.B. Medina. 1993. Movement of monocrotophos and endosulfan in saturated soil. *The Philippine Agriculturist* 76, 3: 259-268.

FAO, 2000. *Assessing Soil Contamination: A Reference Manual.* FAO Pesticide Disposal Series. Food and Agriculture Organization of the United Nations, Rome.

Helling, C.S. and T.J. Gish. 1986. Soil characteristics affecting pesticide movement in groundwater. In: *Evaluation of Pesticides in Groundwater*, W.J. Garmer, R.C. Honeycutt and H.N. Niggs (Eds.). ACS Symposium Series, American Chemical Society, Washington, D.C., United States.

Medina -Lucero, C. 1980. The Dynamics of Transport and Distribution of Two Organochlorine Insecticides (Lindane and Endosulfan) in a Lowland Ricefield Ecosystem. Unpub. Ph.D. dissertation, University of the Philippines at Los Banos, College, Laguna.

Medina, J.R., S.M.F. Calumpang and M.J.B. Medina. 1991. Insecticide residues in selected well waters in Calamba and Calauan, Laguna. *The Philippine Agriculturist* 74, 2: 195-206.

Tejada, A.W. 1995. Pesticide residues in foods and the environment as a consequence of crop protection. *The Philippine Agriculturist* 78, 1: 63-80.

Tejada, A.W., L.M. Varca, S.M.F. Calumpang, C.M. Bajet and M.J.B. Medina. 1997. Fate of pesticides in a model rice paddy ecosystem. In: *Environmental Behaviour of Crop Protection Chemicals*. IAEA/FAO, Vienna.

Varca, L.M. and E.D. Magallona. 1994. Dissipation and degradation of DDT and DDE in Philippine soil under field conditions. *Jour. of Environmental Sciences and Health* B29, 1: 25-36.

Wyman, J.A., J.O. Jensen, D. Curwen, R.L. Jones and T.E. Marquardt. 1985. Effects of application procedures and irrigation on degradation and movement of aldicarb residues in soil. *Environ. Toxicol. Chem.* 4: 641-651.