"Selective" Pesticides: Are They Less Hazardous to the Environment?

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For half a century, scientists and the public have been well aware of the risk posed by pesticides to humans and the environment. Worldwide concern about pesticide residues on food and in drinking water has led to legislative efforts to restrict the use of traditional, broad-spectrum pesticides. In the United States, the Food Quality Protection Act (Public Law 104-170), passed by Congress in 1996, effectively mandates a severe reduction in the use of many such pesticides for a wide range of agricultural uses. The principal rationale for restricting the use of many of these chemicals is to protect consumers, especially children, who are judged to be more susceptible to the effects of pesticides (NRC 1993, Goldman 1998).

For their part, in anticipation of the loss of many widely used organophosphorus and carbamate insecticides, pesticide producers have developed a suite of new biorational pesticides designed to target only select organisms. These new products are typically termed *selective* based on the results of simple laboratory dose–response trials with target and nontarget species to determine LD_{50}, the dose of a chemical that kills 50% of the population tested (LD = "lethal dose"). There is increasing evidence that many nontarget species are affected by several of these chemicals in ways that are often surprising and unpredictable (Banken and Stark 1998, Boyd and Boethel 1998, Losey et al. 1999, Smith and Krischik 1999).

Unfortunately, little effort has been directed toward developing alternative measures of toxicity of these new chemicals and then using them in risk assessment. Thus, we set out to quantify the extent to which these new chemicals may be lethal to nontarget organisms. We compared the toxicity of six new selective insecticides to the toxicity of a widely used, broad-spectrum, representative organophosphorus insecticide (diazinon). In addition, we used two toxicological endpoints in a simplistic hazard assessment exercise. The first hazard assessment was performed using the traditional LC_{50} method (LC_{50} is a statistical estimate of the concentration, in a medium such as water, that kills 50% of the population); the second was done using a measure of population growth rate and estimating the concentration that caused population extinction.

We focused on insecticides in this study because they represent a larger threat to biological communities and the environment than fungicides and herbicides (Croft 1990). We chose to assess the impacts of insecticides on an aquatic species, the Cladoceran *Daphnia pulex* (Walthall and Stark 1998). This animal is widely studied and is commonly used as an indicator species for environmental contaminants (USEPA 1991).

We developed acute (48 hours) lethal concentration estimates (LC_{50}) and a 10-day measure of population growth rate, the instantaneous rate of increase (Walthall and Stark 1997) for the following insecticides: diazinon, spinosad, Neemix 4.5, phloxine B, Fulfill, Aphistar, and Actara (Figure 1). All of these insecticides are relatively new, except for diazinon, a widely used organophosphorous neurotoxin that is a common contaminant found in aquatic systems (Gilliom et al. 1999, USGS 1999).

Extinction concentrations were generated by regression analysis on population growth rate–concentration data (Figure 1), in which the extinction threshold was defined as a growth rate of –0.01. Substitution of the extinction threshold into regression equations resulted in a corresponding extinction concentration (x-axis intercept of regression line) for each chemical tested.

Because environmental concentration data for the new selective insecticides are limited, we modified a hazard assessment technique geared toward direct applications of chemicals into a body of water (AAFC 1993). The technique involves the use of the expected environmental concentration

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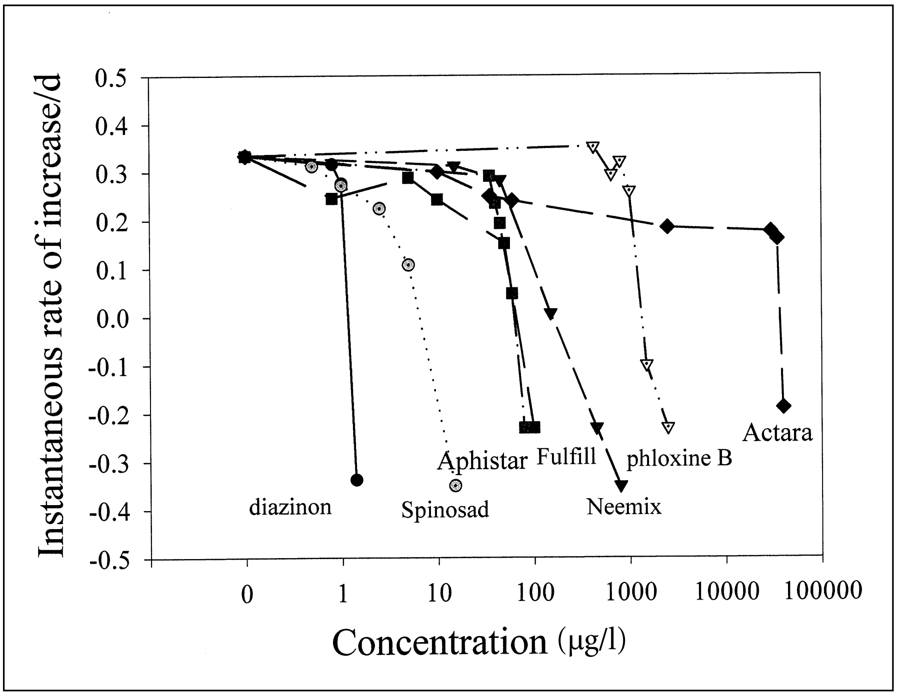

Comparison of instantaneous rate of increase for* Daphnia pulex *exposed to diazinon and a suite of selective pesticides. Instantaneous rates of increase/d is a measure of population growth rate 10 days after the start of the experiment (see Walthall and Stark 1997 for details).

(EEC), which is defined as the concentration of pesticide in 150 liters of water after direct application on a forest at the maximum application rate. To develop the EEC, we used the average foliar application rate (Table 1) instead of the maximum rate. To determine the average, we calculated the mean of the lowest and highest recommended application rates given by manufacturers or listed in *Crop Protection Reference* (1998). EECs used in the hazard assessments are shown in Table 1. Hazard quotients were generated by dividing the EEC by the LC_{50} or population extinction concentration. Hazard quotients greater than 1 indicate that a chemical may cause damage to an ecosystem (Suter 1993).

Table 1. Average foliar application rates and expected environmental concentrations of insecticides evaluated in the hazard assessments.

Chemical	Average foliar application rate (mg active ingredient per m²)	EEC[1] (mg per l)
Diazinon	237.8	1.585
Actara	6	0.040
Aphistar	0.028	0.186
Fulfill	21	0.140
Neemix	5	0.033
Phloxine B	14.6	0.097
Spinosad	0.2	0.068

1. EEC is the concentration of pesticide in 150 l of water after a direct over spray of a forest at the average foliar application rate.

Acute LC_{50} assessments indicated that all the new insecticides were significantly less toxic than diazinon ($p < 0.05$) (Table 2). Hazard assessment based on the LC_{50} suggests that none of the new insecticides posed a hazard to *D. pulex* except for the acetylcholinesterase inhibitor Aphistar (Table 3). In contrast, hazard assessment based on a concentration that would cause extinction indicated that most of the new insecticides pose a hazard to *D. pulex* (Table 3). Actara was borderline with a hazard quotient of 1, and phloxine B was far below the environmental hazard threshold.

The traditional LC_{50} measure indicated that the least toxic selective insecticide was Actara, at approximately 6.6×10^4 times less toxic than diazinon (Table 2). On the other hand, the extinction concentration indicated that Actara was only 22 times less toxic than diazinon. Hazard quotients generated using two different toxicological endpoints spanned three orders of magnitude, varying from 1.5- to 1122-fold (Actara). For some insecticides, both hazard quotients gave similar results (Aphistar and phloxine b), but for others, huge differences were present (Actara, Fulfill, Neemix, and spinosad; Table 3).

Population extinction concentrations for the new selective insecticides ranged from 3 to 406 times less than diazinon. With such variable patterns of relative toxicity, it is evident that generalizations about the toxicity of the new generation of selective pesticides may be premature.

The differences we found between LC_{50} and population extinction–based risk assessments serve as a cautionary tale for those establishing toxicological protocols for these new chemicals. Furthermore, they highlight the need to more carefully screen the full range of effects that chemicals may have at both the individual and population levels. While the more simplistic (and standard) LC_{50} analysis indicates that the new insecticides pose little hazard to *D. pulex*, the population extinction analysis reveals a substantially greater overall menace. Field studies have further indicated that the ability to predict how organisms will respond to selective pesticides becomes even more challenging in the context of biological communities, including target and nontarget organisms along with their suite of natural enemies (Banks and Stark 1998).

Table 2. Acute (48h) lethal concentration estimates for Daphnia pulex *exposed to different insecticides.*

Chemical	Number tested	Slope + SE	LC_{50}, with 95% fiducial limits (mg per l)
Diazinon	210	2.34 ± 0.27	0.00062 (0.00056–0.00070)
Actara	100	9.1 ± 2.0	41 (37.6–45.7)
Aphistar	125	8.8 ± 1.8	0.053 (0.047–0.057)
Fulfill	210	0.72 ± 0.11	0.165 (0.077–0.325)
Neemix	100	8.09 ± 1.55	0.680 (0.595–0.748)
Phloxine B	320	3.6 ± 0.37	0.423 (0.376–0.477)
Spinosad	320	1.01 ± 0.17	0.129 (0.077–0.181)

Note: See Walthall and Stark 1997 for the full description of methods of toxicity testing.

Table 3. Hazard of insecticides to Daphnia pulex.

Chemical	Extinction concentration (mg per liter)	Hazard quotient based on population extinction	Hazard quotient based on LC_{50}[1]	Difference in hazard quotients (percentage)
Diazinon	0.0016	991.0	2,556	2.58
Actara	0.035	1.1	0.00098	1122.45
Aphistar	0.035	5.3	3.55	1.49
Fulfill	0.005	28.0	0.851	32.90
Neemix	0.015	2.2	0.049	44.90
Phloxine B	0.65	0.15	0.23	0.65
Spinosad	0.007	9.7	0.527	18.41

1. This assessment takes into account both toxicity and potential exposure based on average spray application rates. Hazard quotients were generated by dividing the expected environmental concentration by LC_{50} or population extinction measures for each chemical. Hazard quotients equal to or less than 1 indicate that the chemical poses a risk.

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