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COMPARING RISKS FROM CORN ROOTWORM INSECTICIDES IN GROUND WATER, SURFACE WATER AND AIR

Environmental groups, policy-makers, and even farmers increasingly have recognized that agricultural practices can lead to serious environmental degradation. The offsite cost of soil erosion alone was over $2 billion annually in 1985 (Clark et al., 1985). Policy-makers, aware that their constituents are concerned about agricultural pollution, have responded with legislation to attack the problem (Reichelderfer, 1988; Zinn and Tiemann, 1989; Womach, 1988; Batie et al. , 1989). Probably the most significant legislation was the 1990 Food, Agriculture, Conservation, and Trade Act (FACT). The FACT strengthened existing programs to curb pollution related to soil erosion and instituted new programs to encourage the use of agronomic pest controls such as crop rotation.

One primary concern is water pollution. Evidence increasingly suggests that social welfare might be diminished from agricultural contamination of ground water (Nielsen and Lee, 1987; CARD, 1988) and surface water (Clark et al., 1985). Water pollution is an externality; its costs can be excluded from private individuals' decisions. Where markets fail to protect the environment appropriately, the government may step in to balance the economic benefits of farm production methods with their environmental costs. Social welfare is increased with programs that internalize externalities to the farm. This can be accomplished with taxes, subsidies or regulations--where the benefits of pollution abatement exceed prevention costs.

Most state and federal programs to reduce agricultural pollution target single environmental mediums such as ground water or surface water. Since the targeted mediums are not usually affected independently by agricultural pollution, these programs may not improve social welfare. The benefits of reduced pollution in the targeted medium may be exceeded by new costs imposed on other environmental mediums from the newly adopted practices. For example, soil conservation compliance can reduce the use of "sustainable agricultural" systems, thereby increasing pesticide and nutrient runoff and leaching (Hoag and Jack, 1990).

In this study, a framework is developed to help decision-makers screen policy alternatives to reduce environmental degradation. The decision-maker is given information about the impacts agricultural practices have on environmental risks for each environmental medium affected. He or she may compare risk tradeoffs by assigning weights to each medium that reflect his or her perceptions about relative importance. An empirical example is developed for corn rootworm insecticides used in Iowa. The example shows potential health risks from exposure to seven insecticides in ground water, surface water or air.

The Iowa example demonstrates that complex fate and transport modeling systems can be used to develop simple presentation tools for policy-makers. These tools can be used to direct research resources and to identify and analyze policy alternatives. For example, in our study, two insecticides, Mocap and Counter, composed over 90 percent of all risk under any weighting system for ground water, surface water and air. Only these two chemicals exceeded safety standards in air and in ground water, thus suggesting that further study about the costs and benefits of restricting these chemicals would be useful.

DEVELOPING A DECISION FRAMEWORK

Ideally, environmental damage is determined on the basis of a comprehensive evaluation of the fate of chemicals as they move through an environment, where human, animal and plant populations are exposed and face the risk of health and ecological effects. Data limitations, however, often preclude the use of complex fate and transport models coupled with risk models. For corn rootworm insecticides, benefits valued by the market include increased farm profits and lower food prices. Non-market costs include damages to all environments--in this case, ground water, surface water and air. The benefit of restricted use of these pesticides is the reduced threat to the environment. Similarly, the cost is farmer's and consumer's lost benefits of insecticide use.

The cost of obtaining cost/benefit information for a comprehensive problem can be prohibitive. We utilized an index system to compare risks among the three environmental media. The index is a proxy for risk and may or may not reflect social values. Therefore, weights were assigned to the three media as proxies for economic or social values and varied to provide results over several possible value systems. A cost/benefit study was beyond the scope of this project.

Our data were obtained from a joint effort of the U.S. Environmental Protection Agency (EPA) and the University of Iowa Center for Agricultural and Rural Development (CARD). These agencies produced a modeling system to trace pesticide movement into ground water, surface water and air (Gassman et al., 1990). This project, called CEEPES (Comprehensive Economic Environmental Policy Evaluation System), continues to develop and improve process models to provide increasingly accurate information about the environmental implications of pesticide use (Johnson et al., 1990). CEEPES provided estimates of potential exposure to rootworm insecticides in ground water, surface water or air that could be compared with health standards. These risk measures were used to rank the independent risk of each pesticide within a single environment. Value-weighted rankings relating the risk of each pesticide across all environments were also developed to yield information about combined risk.

DATA COLLECTION AND DEVELOPMENT

Corn Rootworms in Iowa

Corn rootworms are a major economic pest in continuous corn production in Iowa, accounting for reduced yields of 10 percent or more (Table 1). Usually, corn rootworm can be controlled adequately with crop rotation, since most other crops will not host the rootworms. In 1985 farmers applied rootworm insecticide to about 36 percent of planted acres. The most commonly used insecticides were Counter, Lorsban and Dyfonate (Table 1).

There are several indications that using these insecticides has adverse environmental and health consequences. Limited ground water monitoring has identified contamination by Counter and Dyfonate at concentration levels of up to 12 and 0.9 ppb, respectively. Furadan, though not proven to contaminate ground water in Iowa, has been found in ground water in other areas of the country, as have Lorsban and Mocap. All three of these insecticides have been found to be moderately or highly toxic to humans and animals. Dust from these insecticides has been found in farmworker clothing. Granules, especially of Furadan, have been reported to kill birds that consume them.

The data for estimating environmental pollution are from simulations conducted for 12 years of Des Moines, Iowa weather. Fate and transport were based on a Hayden soil type in Story County (Manale and Gassman, 1990). Continuous corn production with reduced tillage was assumed, with the rootworm insecticides banded at planting, May 9, at a rate of 1.12 lbs/ac.

<u>Fate and Transport</u>

The concentration of chemicals resulting from their transport and fate in each environmental medium indicates the potential of exposure to human or animal populations. Total applied insecticide is partitioned into mass available for surface water transport, transport to ground water, and air transport by using PRZM (Plant Root Zone Model (Carsel et al., 1984)). PRZM requires the following chemical parameters for simulating insecticide fate and transport: half-life (decay rate), soil adsorptivity (partition coefficient), plant uptake efficiency factor, and dispersion. Half-life is measured in both soil decay and volatilization for a worst-case scenario and indicates the longevity or persistence of a chemical in a particular environment. Longevity and mobility combine to determine fate and transport. Mobility is a function of the adsorption, weather and plant uptake.

For ground water, PRZM simulates movement of the insecticide from the ground surface, through the unsaturated soil zone, to the bottom of the plant root zone. Exposure estimates here represent concentrations in the leachate at 120 centimeters. Surface loading available for runoff, as estimated by PRZM, becomes the input into a surface water transport model. "Look up" tables in the STREAM research project (Donigian et al., 1986) were used to estimate concentrations of each insecticide into surface water bodies. STREAM was developed through multiple HSPF (Hydrological Simulation Program-Fortran, Johanson et al., 1984) computer runs using default values to define representative watersheds in various agricultural regions of the country. The user must evaluate the crop(s), the region(s) of interest, the insecticide application rate, and three pesticide parameters related to movement through soil to obtain pesticide loadings and concentrations.

Exposure to pesticides through inhalation results primarily from volatilization after application to crops. Loadings from PRZM were combined with the Point, Area, and Line source (PAL) model and a Gaussian-plume steady-state algorithm developed to estimate pollutant transport for distances of up to 50 kilometers (Gassman et al., 1990). In this paper, exposure is reported as concentration on a typical day 1 kilometer from the source over a 10-year study period.

RESULTS

Estimation of Risk

Human health risks or other adverse impacts on the environment are determined by relating the concentration of pesticide to which the receptor population is exposed to the toxic or adverse environmental endpoint. Because of differences in exposures and susceptibility for receptor populations, risk may vary significantly from one individual to the next. For this study, we estimate a relationship between the concentration of pesticides in the environment (potential exposure) and a benchmark of adverse effects (toxicity). The benchmark is the minimum level of exposure that could result in adverse environmental or health consequences. A ratio between the exposure and the benchmark equal to 1.0 or greater indicates the possibility of an adverse effect. For ratios below 1.0, a lower value is more desirable.

The general form for measuring risk within an environment is:

$$(1)\quad \text{Risk}_{i,j} = \text{Exposure to chemical}_i \,/\, \text{Benchmark of Chemical}_{i,j}$$

where exposure is the amount of chemical i delivered into environment j over the study period, and the benchmark is the EPA health standard or other benchmark of concern (Manale and Gassman, 1990).

For ground water, the highest level of pesticide predicted for a single day of the year is the assumed exposure. This conservative measure was chosen because the health endpoint of concern relates to acute exposures and therefore any one-time excessive exposure is considered undesirable. The model was allowed to run until peak concentration had been reached in the infiltrate. Only two pesticides, Furadan and Mocap, reached the bottom of the rootzone. Furadan exposure was nearly twice that of Mocap; however, it was only about 2 percent as risky, since the tolerable risk level of Mocap is much lower than that of Furadan (Table 2).

Surface water exposures are calculated by a procedure similar to that used for ground water exposure. In a slight variation, results were adjusted by 36 percent, the percentage of acreage to which the corn rootworm insecticides are applied, to reflect actual application levels. Surface water pollution was spread more evenly across all insecticides than ground water pollution. Runoff into surface water was also less in absolute terms. Mocap again had the highest risk level but did not exceed 1.0 as it did for ground water.

The volatilization of corn rootworm insecticides into the air was also compared to the benchmark of EPA reference dose estimates (Manale and Gassman, 1990). Again, risks were spread more widely across the chemicals than they were for ground water. For Mocap, though risk was high, it was not as high as for Counter. Both Counter and Mocap exceeded 1.0, but other chemicals were considerably lower.

Relative-Risk Rankings

A ranking of relative risk for each rootworm insecticide is shown in Table 2. The rankings are based on estimated risk from each insecticide in each environment. The higher the risk score, the greater the ranking. Relative risk is the percentage of total risk across all pesticides in a single environment j that is contributed by insecticide i:

$$(2) \quad \text{Relative Risk}_{i,j} = \text{Risk}_{i,j} \; / \; \sum_i \text{Risk}_{i,j}$$

This ranking implies, for example, that Mocap is almost 100 times more risky than Furadan in surface water (96.22 compared to 1.01). It also assumes that actual health risk is linearly related to the risk index. In reality, however, a small change in the index below unity may correspond to actual health risk differently than the same change in index values above unity.

The level of risk was significantly below unity for most of the pesticides examined, which may indicate that absolute exposure levels are not of concern. However, for those who place a value on reducing risk below that considered safe by scientists, the relative rankings may still be helpful. That is, people may still ascribe value to marginal reductions in risk much below that estimated safe by scientists.

In ground water, Furadan and Mocap represented the only measured risk (Table 2). Only Mocap had a risk level exceeding its benchmark (relative risk > 1.0), and Mocap represented over 97 percent of all risk; that is, Mocap was almost 40 times more risky than Furadan. Mocap also represented most of the risk in surface water. In air, Counter and Mocap exposures exceeded benchmark health levels, but Counter comprised most of the risk, at 77 percent compared to 21 for Mocap.

Except for Mocap, the insecticides had different impacts across the environmental mediums examined. Furadan, a contaminant in ground water, was of little or no relative concern in surface water. Furadan's physical and chemical characteristics gave it little likelihood of occurring in runoff. Likewise, Counter was very important in air pollution at 77 percent of total risk but posed very little risk in the water media. Mocap ranks relatively high across all three media.

Risk tradeoffs are involved in dealing with most pesticides. Therefore, a decision-maker could in attempting to reduce risk in the target media increase the risk associated with another media. Ground water, surface water and air must all be evaluated to determine accurate environmental costs of pesticide use. This requires a method to combine the impacts of the insecticides into a single measurement.

<u>Value-Weighted Rankings</u>

Since several production alternatives exist, a policy-maker might simply ban or restrict the use of the two chemicals that exceed benchmark safety standards, Mocap and Counter. Together, these insecticides comprise about one-third of total insecticide use. However, risks to air, surface water and ground water may not be equal. Therefore, a more objective approach is to ascribe weights to the environmental problems associated with each pesticide that reflect the value of damage to that environment.

A weighting scheme should, where possible, be based on objective information such as economic values. The scheme should also reflect the values of the group or groups affected. However, collecting information about social value is expensive. We did not have information about the value of risk exposure in air, ground water or surface water. Rather than assigning subjective weights to each environment, we conducted a sensitivity analysis by comparing results for several weighting scenarios. Some results are insensitive to the weights across the environmental media. Therefore, some chemicals may surface as highly risky or as posing little risk in all of the weighting paradigms.

Once the weights are obtained, they are multiplied by estimates of the relative risk of each insecticide to each environment:

(3) $$\text{Value-Weighted Risk}_i = \sum_j (\text{Relative Risk}_{i,j}) \times (\text{Environment Weight}_j)$$

where the value-weighted risk of pesticide i is the sum of the relative risk of pesticide i on environment j times the weight of each environment j. The weights for each environment are expressed as fractions of one and should be consistent (if A is superior to B and B is superior to C, then A is superior to C). Value-weighted risks are normalized.

If air and surface water were the only environments of concern and were weighted equally, the value-weighted risk levels would be 39 for Counter (1.17 x 0.5 + 77.44 x 0.5) and 59 for Mocap. Mocap is ranked highest in this value-weighted illustration because its use had a relatively high impact on the quality of both air and surface water. The chemical posing the greatest risk to air, Counter, added less to the value-weighted risk than the chemical posing the most risk to surface water, Mocap. For Counter to rank as high as Mocap in the value-weighted index, air would have to be weighted 70 percent higher than surface water.

The value-weighted risks for ground water, surface water and air are given in Table 3. In the first column, all environments are weighted equally. In the next three columns, each environment is given half the total weight, while the other half is divided equally between the other two.

The value-weighted rankings are given for alternative weighting assumptions to indicate whether values could alter the rankings. When relative rankings are evenly weighted, the assumption is implicitly made that the absolute risk levels are evenly reflected in the relative measures. That is, an index of 50 percent in two different mediums implies the same risk level. For example, 97 percent represents a 1.8 index in ground water, and 96 only represents a 0.55 index in surface water for Mocap (Table 2). This would imply that people value an incremental movement in relative risk, from 90 percent to 80 percent, the same across each medium. The weighting system can be constructed to factor out the bias. Alternatively, weighted indexes can be computed without first normalizing the environmental media, as is done in the final four columns of Table 3.

Under all weighting schemes, two pesticides, Mocap and Counter contributed over 90 percent of total risk. Mocap was always important; Broot, Dyfonate, Lorsban and Thimet were never very important. Furadan was of marginal importance only when ground water was weighted heavily.

Relative rankings considered only one environment at a time. In Table 3, the first and second highest rankings under the relative ranking system are indicated by * and ** superscripts, respectively. In the relative ranking for ground water, Furadan received 2.5 percent of the risk and Counter received 0 (Table 2). Yet, in the value-weighted system, Furadan contributes less than 2 percent of risk and Counter comprises 20 percent or more. The weighting scheme that gave half the weight to surface water was the only one that did not change the univariate relative ranking.

Computing value-weighted rankings without first normalizing within each environmental medium did alter the results. Under the normalized results, Mocap was the most risky chemical, followed by

Counter, a pattern that was reversed under the alternative calculation. The reason Counter is now more risky than Mocap is that it was initially higher in absolute terms (Table 2). For example, Counter exposure exceeded the benchmark safety level by sevenfold in air, but Mocap only reached a maximum level of 2 in air. The appropriateness of these alternative approaches hinges on how people value changes in relative risk or absolute risk.

These examples demonstrate the sensitivity of the rankings to the weighting system. Patterns that emerge from such a sensitivity analysis may be very helpful where there is little information available about how to construct weights.

CONCLUSIONS

This study has shown that the numbers and weights given to affected environments can be important in ranking pesticide risks to health or the environment. Unless cross media environmental effects are considered, social welfare may not be improved with programs that reduce a single form of pollution. For example, the benefits gained by banning a chemical from one environment may not be as great as the damages to an alternative environment to which the chemical has been relocated.

Since environments may not be directly comparable, a decision-maker often is forced to use uninformed value judgments to formulate policy that may have uneven impacts across environments. The examples used here demonstrate how objective information together with subjective weights on affected environments can be utilized to help decision-makers evaluate the impacts of their value judgments on the environment. This could help bridge the gap that often exists between scientists who conduct research and government decision-makers who must balance competing social interests.

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Table 1: Insecticide use and cost and return estimates for corn production in Iowa

Pesticide	Iowa Use[a] (% of all Iowa corn ac)	Assumed Rate (lbs/acre)	Cost[b] ($/acre)	Yield[c] (bu/acre)	Profit[d] Advantage ($/acre)
Broot (trimeth-acarb)	1.00	1.12	14.79	127	20.89
Counter (terbufos)	32.80	1.12	14.01	128	23.90
Dyfonate (fonofos)	18.00	1.12	12.40	126	21.05
Furadan (carbo-furan)	7.30	1.12	12.70	126	20.75
Lorsban (chlor-pyrifos)	25.60	1.12	13.14	124	15.85
Mocap (ethoprop)	0.40	1.12	12.35	126	21.10
Thimet (phorate)	13.10	1.12	9.72	123	17.04
Other Pesticides	1.80[e]	----			
No Pesticides	64.00		0.0[f]	111[f]	

[a] Source: USDA, 1984 Pesticide Use Survey.
[b] The cost per acre is equal to the price per unit times the application rate.
[c] Equal to the average yield on test plots treated with each pesticide (Center for Agriculture and Rural Development (CARD)).
[d] The profit advantage is the per-acre difference in net returns with an insecticide and without an insecticide.

Table 2: Insecticide concentration and risk for surface water and ground water in Iowa

Insecticide	Ground Water Risk[a] (Exp./bench)	Ground Water Relative[b] Risk (%)	Surface Water Risk[c] (Exp./bench)	Surface Water Relative[b] Risk (%)	Air Risk[d] (Exp./bench)	Air Relative[b] Risk (%)
Broot	0.000	0.00	0.0015	0.26	0.05	0.49
Counter	0.000	0.00	0.0067	1.17	7.20	77.44
Dyfonate	0.000	0.00	0.0014	0.25	0.04	0.46
Furadan	0.0478	2.53	0.0058	1.01	0.00	0.00
Lorsban	0.000	0.00	0.0038	0.66	0.01	0.10
Mocap	1.833	97.47	0.5500	96.22	2.00	21.51
Thimet	0.000	0.00	0.0025	0.44	0.00	0.00
Total		100.00		100.00		100.00

[a]Estimated exposure, concentration in the root zone, divided by benchmark risk level (Manale and Gassman, 1990).

[b]Equal to the ratio of the exposure/benchmark for the given pesticide divided by the sum of all exposure/benchmark levels in the respective environmental medium.

[c]Estimated exposure, concentrations in surface water, divided by benchwork risk level.

[d]Estimated concentration 1 kilometer from source divided by benchmark risk level.

Table 3: Value-weighted relative risk index for corn rootworm Insecticide use in Iowa[a]

	Normalized by Environment				Normalized across Environments			
	Equal Weight	One-half weight to[b]			Equal Weight	One-half weight[b]		
Insecticide	All Envir.	Ground Water	Surface Water	Air	All Envir.	Ground Water	Surface Water	Air
Broot	0.2	0.2	0.3	0.3	0.4	0.3	0.4	0.5
Counter	26.2	19.7	19.9**	39.0*	61.53	52.9	58.6	68.4
Dyfonate	0.2	0.2	0.2	0.3	0.4	0.3	0.4	0.4
Furadan	1.2	1.5**	1.1	0.9	0.5	0.7	0.5	0.3
Lorsban	0.3	0.2	0.4	0.2	0.1	0.1	0.1	0.1
Mocap	71.8	78.1*	77.9*	56.2**	37.3	45.7	40.1	30.3
Thimet	0.1	0.1	0.2	0.1	0.0	0.0	0.0	0.0
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[a]Each column shows risk constituted by each chemical as a percentage of overall risk after being weighted by each environment as indicated.

[b]Other environments weighted one-fourth each.

**Second rank with the relative single-variate ranking system.