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EFFORTS BY INDUSTRY TO IMPROVE THE ENVIRONMENTAL SAFETY OF PESTICIDES

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INTRODUCTION

The use of pesticides in agriculture has helped to maintain a low-cost, high-quality food supply. In recent years, this positive contribution has been challenged by individuals and groups who suggest that the negative environmental effects of pesticides outweigh their benefit to society. This chapter examines current and future development efforts by the manufacturers of agricultural chemicals to reduce the environmental effect of their products.

Regulatory agencies around the world, and especially in the United States, have raised environmental issues to the same standard as human health issues, with which they are so interdependent. The US Environmental Protection Agency's (EPA) Science Advisory Board recommended to William Reilly, the EPA administrator, that "the value of natural ecosystems is not limited to their immediate utility to humans. They have an intrinsic, moral value that must be measured in its own terms and protected for its own sake" (16).

No less interested in and concerned about environmental issues is the industry that makes, sells, and uses agricultural chemicals. Manufacturers in this industry are willing to meet their responsibility by conducting the necessary studies to address the environmental safety of their products. However, many studies required by EPA to address safety concerns, e.g. complex wildlife and aquatic studies, are not only costly, but have provided only minimal, if any, improvement in overall environmental protection. In addition, risk-benefit considerations seem to be weighted heavily on the risk side when final registration is considered. While a direct correlation to the development costs cannot be cited, it should be noted that the number of companies developing and manufacturing agricultural chemicals has decreased markedly during the past ten years.

Prospective testing on pesticides to determine human health hazards, and, to a lesser extent, environmental hazards began with the advent of the modern agrochemical age, i.e. after World War II. Efficacy was emphasized, but not to the exclusion of safety. Rachel Carson's book *Silent Spring* focused on the chlorinated hydrocarbons and for the first time created widespread public awareness of the inadequacy of testing of pesticides for effects on the environment prior to marketing (3).

Since the publication of Carson's book, increasing government regulations and scientific capability have resulted in an expansion of environmental testing undreamed of when the EPA was established in 1970. With scientific knowledge gained from this testing has come the discovery of new environmental concerns. Advances in analytical chemistry have shown that some pesticides can move into ground and surface water following field applications and that others are persistent and can be found as residues in nonlabeled rotational crops. Some substances can move long distances in air and be found in rainwater at remote locations. Field monitoring has shown effects of some products on avian and aquatic species.

COMMERCIAL DEVELOPMENT OF TRADITIONAL CHEMISTRY

Selection Criteria: New Compounds

The agricultural chemical industry has moved from a biological discovery approach based almost solely on efficacy to one that also includes earlier and better knowledge of a chemical's effect on ecosystems and human health. The criteria for selecting compounds for screening activity are becoming more scientific as more information is obtained concerning structure-activity relationships. Historically, and to a large extent even today, new chemistry is identified through block screening. In a block screen, compounds from all major disciplines of agricultural chemistry (phytopathology, entomology, weed science, and animal health) and pharmaceutical chemistry are screened for biological activity. Once a lead structure is discovered, chemists attempt to improve activity by synthesizing analogs based on their knowledge of structure-activity relationships. While this concept of screening is empirical by design, it has led to the discovery of numerous important products. Recent examples are the fungicide metalaxyl, analogs of which were first synthesized for the herbicide screen, and the demethylation inhibitors (DMI) that were first tested as pharmaceuticals. In the future, manufacturers hope to use biorational products as models to design and develop new active ingredients that are not only highly efficacious but safe to the environment.

Historically, the selection of new compounds for development was largely based on biological efficacy, cost of production, and market opportunity. Many companies are now incorporating environmental fate evaluations into their block screen as an additional selection criterion, recognizing that the potential environmental effect of a chemical must be defined prior to investing almost $20 million into commercial development. Sufficient predictive data concerning a chemical's environmental behavior must be generated in the early stages of product development to permit a risk-benefit assessment. For example, important information from early-stage environmental fate studies can include soil hydrolytic and photolytic half-lives, water solubility, pKa, Log P, and vapor pressure. Such information contributes to better decision-making when candidate compounds are considered for early promotion. Predictive ecological toxicity studies can provide indications of effects on fish, aquatic invertebrates, birds, and mammals. These studies can include acute and chronic effects on Daphnia, fish, and quail. Candidate herbicides could also require toxicity studies on green algae.

When evaluating early-stage environmental-fate studies, careful consideration must be given to the overall results and not just to results of an individual study. For example, compounds with Log P values > 3 usually have a high potential to bioaccumulate. However, a rapid hydrolysis rate and a high adsorption rate would reduce exposure in aquatic systems, while rapid animal metabolism would reduce the potential to accumulate in fat and in the food chain.

Environmental Behavior Testing

When a compound enters the commercial development stage, the company or registrant initiates a series of studies based on EPA environmental guidelines. These studies are longer-term and provide a more in-depth knowledge of product fate and effects than those conducted during the product's early stage of development. The primary objective is to determine potential environmental effects of pesticide residues to humans and other nontarget organisms such as fish and wildlife. A second and perhaps equally important objective is to assist the registrant and EPA to estimate expected environmental concentrations (EEC) in specific habitats. This determination is especially important where endangered species or other populations-at-risk are present.

These later-stage studies are conducted with ^{14}C-radio labeled compound, which is essential to achieving the previously stated objectives. Both field and laboratory studies are necessary to provide the best information regarding physical and biological transformation products and their eventual fate and effect in the environment.

Environmental Fate Studies

Environmental fate studies serve two purposes. First, they identify routes by which a pesticide dissipates in the environment; and second, they identify mechanisms of degradation and degradation products. By examining the results of laboratory studies, the important biotic and abiotic processes can be demonstrated.

Hydrolysis and photolysis studies conducted in water provide insight into degradation rate, degradation compounds formed, and half-life under different pH and temperature regimes. Degradation compounds formed under these conditions may be representative of biological transformation products and expedite their identification in more complex soil and plant substrates. Photolysis studies are also conducted on soil surfaces and in the vapor phase, since major degradation can occur in this manner and in these matrices.

Microbial and chemical degradation in the soil are perhaps the principal means of pesticide breakdown in the environment. Both aerobic and anaerobic metabolism studies are conducted in soil. For certain proposed aquatic uses such as rice, data are generated for both aerobic and anaerobic metabolism in water. These studies provide information on the nature, persistence, and availability of pesticide residues to rotational crops and other nontarget organisms. Assessment can then begin on environmental hazards associated with availability of the compound.

Pesticide mobility in the environment is measured by a series of studies, including volatility, soil leaching, and adsorption/desorption. Data from these experiments provide information on the principal means of transport and likely destination of the compound and its degradation products. For example, a pesticide with a high-vapor pressure relative to a low-sorptive tendency (low-water solubility or soil adsorptivity) is more likely to volatilize from the site of application and become a likely candidate for vapor-phase photolysis. In contrast, a pesticide with low-vapor pressure and relatively high-water solubility is more likely to leach through the soil and reach aquatic environments. However, if products are highly adsorptive and nonvolatile, they are less subject to environmental transport and may accumulate in the soil. Again, overall results must be integrated for analysis because individual study results may lead to conflicting perceptions about environmental behavior.

Following the completion of ^{14}C-laboratory studies, field work is initiated to better understand the compound's behavior in a more natural environment.

One-year field studies of dissipation in soil are designed to determine the half-life of the parent and degradation compounds and also to monitor movement through the soil profile. Groundwater studies can be conducted if the data suggest the chemical could reach groundwater. These consist of drilling deep and shallow wells in fields where the test compound will be applied, then monitoring groundwater for residues of the parent and its degradation compounds.

Ecological Toxicology Studies

Studies of ecological toxicity with a pesticide are conducted on terrestrial and aquatic plants, insects, freshwater and marine fish, aquatic invertebrates, and birds. Toxicity to wild mammals is currently extrapolated from tests conducted on rodent species.

These studies can be divided into three categories: (*a*) lower-tier studies that evaluate acute exposure to a chemical; (*b*) higher-tier studies that evaluate effects of a compound on reproduction; and (*c*) exposure of mini-ecosystems (microcosms) to a pesticide under field conditions to measure community effects.

For aquatic species (animals and plants), acute exposure to varying concentrations usually occurs for either 48 or 96 hr. The test substance is solubilized in water, and the organisms are exposed under static or flow-through conditions. Results are expressed as either LC_{50} or EC_{50} values representing the test chemical concentration that is fatal to 50% of the test organisms.

To determine acute effects on avian species, the test substance is incorporated into the animal's daily diet at varying concentrations and orally ingested over a 96-hr exposure period. Results are expressed as an LD_{50} value or the concentration fatal to 50% of the test birds.

Studies of effects on reproduction in aquatic and avian species are similarly conducted. The acute studies are conducted in a similar manner except that the degree of chemical exposure is lower and the duration of exposure is longer. Exposure to the test substance spans periods when reproduction or developmental functions occur in the life cycle of the species.

Ecosystem effects are studied when lower-tier testing and EEC suggest the need. Community and ecosystem effects for aquatic systems are studied in the laboratory and in the field. Microcosms may contain water, sediment, aquatic plants, and animal species in a 10,000 liter container. The test material is added to the system and effects are observed over a defined period of time.

Additional insight into environmental effects on aquatic ecosystems can sometimes be gained through use of mesocosms. These are essentially artificial ponds measuring from 0.1 to 0.25 surface acres. They are stocked with natural sediment and pond organisms, then treated with the compound under investigation at its EEC. Such studies can take up to four years to conduct and cost as much as $5.0M. The value of these studies is questionable.

Population effects are evaluated in higher-tier systems involving terrestrial organisms (birds and mammals). These projects include the use of numerous field sites under actual product application conditions and costs can be several hundred thousands of dollars to conduct.

Exposure Assessment

Exposure assessments determine the risk of a chemical to nontarget organisms. For terrestrial animals, dietary exposure to the chemical in the treated area is often the primary factor used for calculating exposure. For aquatic organisms, the EEC is typically derived from computer models that predict the amount of applied chemical moving "off target," generally by aerial drift or surface water runoff. Data on environmental fate including solubility, half-life determination, and soil adsorption/desorption coefficients (potential to bind to soil) are used in the model. Frequently, field-exposure residue studies are also conducted to provide actual measured concentrations of pesticides to validate model estimates.

Risk Assessment

The assessment of risk to the environment is made up of two components: exposure assessment and the toxicity of the test compound to appropriate species. Once these data are available, the quotient method is most commonly used to calculate risk, i.e. the ratio of toxicity to the environmental concentration for a given organism. Acute risks are generally considered negligible if the EEC is less than 0.1 of the lowest LC_{50}. If the LC_{50} is between 0.1 to 0.5 of the EEC label restriction, buffer zones may be required to limit exposure. Chronic risks are generally considered negligible if the lowest EC_{50} is less than the no observed effect level (NOEL). Despite inherent difficulties, this method permits an estimate of environmental risk from laboratory data.

Ecological toxicology is evolving rapidly from a simple mechanistic view of toxicity to individual species toward interactive effects in communities and ecosystems. This transition will require significant advances in computer modeling of the diverse and complex components that make up an ecosystem. It is only with these developments that the question of pesticide bioavailability in interactive systems can be addressed. As this science develops, it will permit more precise assessments of environmental risk and provide a tool for development of safer agricultural products.

REDUCING THE ENVIRONMENTAL EFFECT OF PESTICIDES

Screening Concepts

New technology and environmental concerns have refocused current thinking among manufacturers of pest control products. In addition to the traditional synthetic chemistry approach, biological control agents, induced resistance, and natural product chemistries are now being considered as viable options for pest control. The application of biotechnology to pest control offers tremendous potential for success in the future.

Traditional Chemistry

In the area of plant-disease control, synthesized compounds have traditionally been evaluated in a block screen on pathogens of worldwide economic importance, such as *Phytophthora infestans, Puccinia graminis, Erysiphe graminis, Rhizoctonia solani, Botrytis cineria,* and *Meloidogyne incognita.* Emphasis is now shifting to a screening approach that is more selective and specific. Highly active molecules that can be applied at lower rates of active ingredient per acre or hectare are also being sought. Hailed as milestones in fungicide development are the low-rate chemicals typified by the DMI fungicides such as propiconazole and triadimefon (22). Similar success has been achieved in weed control with the sulfonylurea and imidazolinone herbicides. These compounds are typically applied at rates of 125g ai/ha or less, in contrast to older chemistry that was recommended at rates of 0.5–5 kg ai/ha. While many environmental concerns are diminished by such low application rates, there is a certain awe when thinking about the biological potency of these small amounts. However, the only negative environmental effect that have been reported are the appearance of resistance and carry-over of residues to nontarget crops. In some instances, there is the potential for groundwater contamination, based on persistence and mobility characteristics. Several studies have been conducted by the manufacturers, and other studies are under way to evaluate this potential. The environmental community, pertinent government bodies, and the knowledgeable public have seen the development of low-rate chemicals as a major contribution to environmental and human safety. The search for low-rate synthetic chemicals will continue, with additional real and perceived benefits accruing over the long term.

Biological Control

Biological control is a "new-old" approach for crop protection (See articles by Cook and Sutton, this volume). For plant-disease control, there are new examples of successful commercial introductions such as *Agrobacterium* *radiobacter* against *Agrobacterium tumefaciens* on fruit trees (2) and *Bacillus subtilis* as a seed dressing (2). *Bacillus subtilis* and *Pseudomonas cepacia* (5) are effective control agents of storage rot diseases of fruit (9, 14) and *Gliocladium virens* (8) and *Pseudomonas fluorescens* (11) provide control of *Pythium ultimum* damping-off of cotton and cucumber, respectively.

Biological control products that are commercial herbicides include DEVINE (*Phytophthora palmivora*) for use against stranglevine on citrus and COLLEGO (*Colletotrichum gleosporoides*) for northern joint vetch control in rice. Recently, a bacterial control of *Poa annua* has been identified.

For insect control, the baculoviruses and *B. thuringiensis* (Bt) are the best known of the biological insecticides. Some companies are already developing and marketing these products to meet potential demand. A Bt strain was recently registered for control of the Colorado potato beetle, a market worldwide potentially exceeding $100 million.

Biological control agents such as Bt provide attractive alternatives for development because of their "safe" perception and the lack of significant regulatory barriers. However, problems associated with commercialization of biologicals include maintaining viability and activity of selected strains and producing consistent results on major agronomic crops under varying environmental conditions. In the future, genetic engineering offers the potential of increasing the competitiveness or useful antagonistic effects of beneficial organisms.

A new approach to biological control takes advantage of chemical technology to investigate the parasite-predator relationship. Efforts to understand how the predator controls the parasite have led to the emergence of biologically based pesticides, as opposed to synthetic chemicals. Many toxins from insects, fungi, and bacteria have now been identified and synthesized for screening. Natural products in use or under development in phytopathology include the agricultural antibiotics streptomycin and terramycin and the rice blast fungicide polyoxin. Bialophos is a nonselective herbicide that is active against annual and perennial weeds and is a metabolite of *Streptomyces hygoscopius* (15).

Improved fermentation technology will permit the production of naturally occurring compounds in commercial quantities. However, these "natural" chemicals will likely be scrutinized as carefully during the registration process as are the synthetic compounds.

Induced Resistance

Resistance resulting from the activation of a plant's defensive system by applying biochemicals from plant pathogens or by inoculating with certain microorganisms has been reported by Kuc (12). This work, which used the microorganism *Colletotrichum lagenareum* to induce resistance to cucumber anthracnose, has stimulated efforts to identify the elicitors and determine their potential as disease-control agents. The induction of resistance with specific chemicals has also been studied. Several genes and proteins related to pathogenesis (PR) have been identified as responsible for inducing resistance in tobacco to tobacco mosaic virus. According to Ward et al (19), immunization can be induced by the virus or immunization agents such as salicylic acid and methyl-2,6-dichloroisonicotinic acid. The cellular mechanisms that regulate a plant's ability to resist disease are not fully understood, but considerable progress is being made in this active research area.

Genetic Engineering

The most exciting and, in the long term, promising pest-control research lies in the biological and genetic manipulation of plants and microorganisms to enhance food and fiber production; this approach holds great promise—or risk, depending on one's perspective. The application of biotechnology to plants frequently enhances disease or insect resistance and reduces the need for application of chemicals. The concept is wonderful; the technical challenge is great; the monetary benefits are potentially vast; the social benefits are arguably high; the regulatory picture is unclear; and public acceptance of the research and products is unsure. This new science has introduced a new social and regulatory challenge, described in Europe as the fourth hurdle and in the United States as a social impact statement. What is the effect of the invention or development on the social structure and economy? As yet, this is not a requirement by any government agency.

PLANTS In the agricultural chemicals industry, research has focused on the development of plants resistant to insects, herbicides, and to specific pathogens. Several companies are developing transgenic cotton, corn, potatoes, and tomatoes that contain Bt genes for production of the delta endotoxins of *Bacillus thuringiensis*. Monsanto, St. Louis, MO, is developing soybean and cotton varieties with glyphosate tolerance (10). A bromoxynil-resistant potato has been developed (5), and Calgene, Davis, CA, has recently developed cotton with a similar tolerance. In general, the modifications of plants for these purposes seem to offer no new threat to the environment compared with crops developed by more traditional techniques. The argument has been made that engineering a single plant gene presents less risk to the environment than traditional plant breeding, which may result in multiple and sometimes unintended gene movement and transfer. With herbicides there is some concern over gene transfer from the crop to weeds; however, gene transfer by outcrossing between crops and weeds is a rare event and can be managed. Logic and experience suggest natural tolerance or resistance would more likely be a problem because of more intense selection pressure from normal herbicide use. Thus, environmental effects are remote or nonexistent.

MICROORGANISMS The biological activity of microorganisms could potentially be improved through biotechnology. Enzymes or traits associated with better root colonization or antibiotic production could be transferred to more competitive organisms. Field tests around the world have not shown new or unusual deleterious effects of genetically engineered microorganisms compared with the naturally occurring parents. Whether the interventions range from live root-colonizing bacteria or encapsulated dead bacterial cells, the chances for spread and/or producing toxicity to nontarget organisms are extremely remote. Further, oversight by public interest groups, in addition to federal and state regulatory agencies, assures that the environment will be protected. Recently, the EPA granted approval in the United States to the first two pesticides developed through the use of rDNA technology. Developed by Ecogen, Inc., Langhorne, PA, both are vegetable crop insecticides that use killed bacterial cells containing a Bt toxin (1).

CibaSeeds, Greensboro, NC, recently conducted a series of studies unique to pest control (20). Tobacco plants were genetically engineered to express a *Bt* gene for insect control and an additional gene was incorporated to delay or prevent development of insect resistance (19). Uniqueness lies in the fact that the *Bt* gene will not express unless induced by the application of a chemical. Based on this model, the grower can "turn on" production of a Bt delta endotoxin when it is needed for the crop. Among the many benefits to this approach is the lower probability of the development of insect populations insensitive to host-plant resistance.

Integrated Pest Management

Another new-old approach to minimize the environmental effect of pesticides is the implementation of integrated pest management (IPM) strategies. Many in the environmental movement consider IPM a new concept and have named it low input sustainable agriculture (LISA). The National Agricultural Chemicals Association (NACA) developed a supportive position paper on IPM in 1978 (13). The process of developing effective IPM programs is now well underway. Biological screens are designed to identify fungicides with postinfection activity that can be used in disease-forecasting programs or when a low incidence of disease is detected in the field. Weed scientists are developing herbicide screens with increased emphasis on postemergence activity so the herbicide is applied only when needed. Examples of such herbicides are primisulfuron, triasulfuron, nicosulfuron, fluazifol-butyl, and sethoxydim. Herbicide application can be delayed until the extent and characterization of the problem are determined. In entomology, beneficial insects are often included in the block screen with the intent of finding compounds that kill codling moth, for example, yet are safe to beneficial mites and honey bees.

Product Labeling

It costs millions of dollars to develop the label for a new pesticide product. The label provides a thorough, precise explanation of what the product does, how it should be used, precautions to be observed, and warning statements to the user. Labels are constantly being revised to reflect the addition of new uses, remove old uses, reflect changes in application rates, and update precautionary information. The label should be one of the most effective forms of risk communication for a product. Unfortunately, it often is not completely read by the user.

Because of persistence problems in the soil resulting in carryover to rotational crops or potential movement to groundwater, some labels now reflect reduced rates and exclude usage on certain crops and soil types. Atrazine is an good example. Frequent media reports of atrazine detections in rural wells have created the perception that the product is a major groundwater contaminant. However, an evaluation of over 5000 well-(ground) water samples concluded that less than 1% exceeded the maximum contaminant level (MCL) of 3.0 ppb established by EPA (Ciba Plant Protection, unpublished). Point sources of contamination could usually be correlated with most of those that comprise the one percent. In certain sensitive areas, movement to groundwater following application could result in concentrations that exceed the MCL. Overall, the evidence indicates that atrazine is not a major groundwater contaminant based on MCL exceedance. Nevertheless, whether real or perceived, the issue of groundwater contamination had to be addressed and managed. Ciba and other atrazine producers consequently asked EPA for major label changes that included a 25% reduction in the maximum use rate, exclusion of use in certain sensitive areas, elimination of fall applications, modification of use patterns, and the addition of several precautionary environmental safety measures. Overall, this program of best management practices has lowered the volume of atrazine use, a worthwhile step to preserve a valuable product for agriculture. Other manufacturers have shown similar responsibility with their products.

Formulations and Packaging

The development of new and innovative formulations and packaging has been pursued by most manufacturers as a key to preserve sales of products going off patent. A fortunate by-product of that research is enhanced environmental protection, including less spillage, less user contamination, and reduced environmental mobility. These innovations are now research objectives as much for environmental protection as for marketing. Having the least environmental effect can also provide a competitive advantage for a useful product.

Progress in formulation chemistry has been dramatic in recent years. Formerly, wettable powders were packaged in paper bags and liquids in metal containers and drums. Research efforts are directed at safe handling, precise measurement, and reduction in the number of containers requiring disposal. Innovations in bulk handling resulted in mini-bulk containers. These portable units are larger than the standard 55-gallon (102-L) drums and offer the grower a refillable, returnable and often recyclable container with accurate measuring devices and a closed handling system for enhanced safety.

Many new wettable powder or water-dispersible granule formulations are premeasured in water-soluble packets that dissolve in the spray tank. Primisulfuron, for example, is sold in water-soluble packets that contain 43g of product precisely measured to treat two acres. Multiple packets can be placed in the spray tank to treat a large number of acres. Compressed water-dispersible tablets are now available for some products, primarily in the lawn-care market. In the advanced research category are temperature-release formulations (21). Taking advantage of advanced polymer chemistry, these formulations offer less active ingredient needed to achieve the same degree of control as older formulations. This advantage results in fewer leaching problems and lessens volatilization, rate of degradation, and phytotoxicity. Together, formulations and packaging research are helping to minimize environmental concerns.

Application Technology/Timing

Research into delivery systems is also taking advantage of advanced technology. Variable rate and direct injection technology, computer driven and, in the future, satellite connected, will further enhance environmental and human safety. The question is: who can afford this kind of technology? Will small farm operations or farmers in developing countries derive any benefit?

Danger of runoff or drift to aquatic areas is being reduced with buffers between sites of application and sensitive areas. New chemicals are being evaluated for use as seed treatments, which allows the product to be placed directly on the plant or plant part where disease control is needed, with contamination limited to seed spillage.

The timing of pesticide applications and subsequent pest control is being improved by disease scouting and forecasting programs. This approach frequently results in reduced quantities of pesticides applied in pest or disease control. Early scouting programs are used to determine the most appropriate time to apply fungicides for controlling Rhizoctonia sheath blight on rice. Disease forecasting programs are routinely used on thousands of acres of potatoes to control foliar diseases (17). Soilborne pathogens such as *Phytophthora citrophthora* on citrus can be detected and quantified using selective media (18) or, in the future, with the aid of diagnostic kits.

Immunoassay technology is providing a new means for detecting plant diseases (4). Plant-disease diagnostics services based on this technology are now available commercially. The goal is to provide farmers or other decision makers with an easy-to-use kit to increase the accuracy of disease diagnosis, and thus improve the precision of plant-disease control.

Education

The pesticide industry has taken action through education and outreach both to explain the potential environmental effects of agricultural products and to correct inaccuracies about products. Success of the pesticide industry depends on a strong educational effort to ensure proper and safe use of pesticides. Education is perhaps the only way to prevent or counter perceived problems with pesticides based on misinformation. Some companies and groups are more proactive than others, but as an industry, progress has been made in educating the public. Advertising campaigns are being refocused to include information on the safer use and environmental behavior of the products and on pertinent new state and federal government regulations. When products are indicted by environmental activists or the media, companies are providing the in-depth explanations needed by sales people, dealers, and university researchers, and farmers. Ideally, companies should try to maintain an open line of communication with reporters and even critics.

A good example of outreach in industry is the Alliance for a Clean Rural Environment. Designed to focus strictly on preservation of water quality through the proper use of pesticides, this organization has received acclaim from the entire spectrum of interest groups. The Alliance provides good scientific information in layman's language that benefits the farmer and dealer, and in so doing alerts the general public that the agricultural chemicals industry does care about the environment.

Many graduates now entering the laboratories of the agricultural chemicals industry are environmentalists. Using their knowledge and concern, they can develop and improve the types of testing needed before products can be labeled. In addition, they can learn first hand that this is a responsible industry and assure their friends of the same. Science alone will not convince the public that pesticides are necessary and can be used safely, but without good science, the regulatory and public-perception challenges associated with pesticides will not be overcome.

There is a burgeoning world population to be fed, and no substantial increase in available crop land is foreseen. Consequently, all effective and safe tools for pest and disease management, including agricultural chemicals, will be required to increase productivity on available land to meet this continuing need.

CRITICAL ISSUES

Water quality

The most notable effect on the environment by pesticides is, arguably, their movement into water, particularly groundwater. Does their mere presence denote risk or hazard? Concentrations found must be toxicologically or biologically significant to constitute a real hazard. However, there are those, including some scientists, who believe there is no acceptable pesticide concentration in water, regardless of available safety data.

Avian Toxicity

Granular insecticides, as a group, have been indicted because of their potential to kill birds and other wildlife, and negatively affect the aquatic environment. The use of diazinon on sod farms and golf courses was removed from the label of this insecticide, for example, because some 2000 birds were documented as dying from poisoning during over 30 years of product use. Most were incidents involving relatively small numbers of waterfowl. There were no claims that the product has or would have had any effect on bird populations, which would justify regulatory action. This example also points out the real versus the perceived issue. Diazinon is the first pesticide since DDT to have had uses indicted because of environmental concerns.

Recently, carbofuran has been indicted for its adverse effects on birds and other wildlife, while the pyrethroids are under scrutiny for their potential negative effect on ecosystems. To our knowledge, the validity of these allegations has not been confirmed in the literature, but they do signify the importance of environmental effects, real or perceived, from the perspective of the regulatory agencies.

There are many other environmental issues that could be discussed within the context of perceived versus real risk, but from the industrial standpoint, they all have to be addressed as real.

Public Relations

Despite the focus within the industry on developing data to address the safety of products, information about the safety and benefits of pesticides has not been communicated to the public. This failure has contributed to the negative image of these products. Millions of dollars have been spent to develop labels that specify how to use products and what precautions the user must observe. Additional millions have been spent on advertising and promoting the use of products to growers. By contrast, industry has failed to adequately inform the general public about pesticides, particularly their benefits.

Container Management

Close attention has been given to combat the problems related to the disposal of used containers and associated rinsates. In the United States, the National Agricultural Chemicals Association (NACA) in conjunction with a few states, Mississippi being first, has successfully held several plastic container collection days. These containers are then used for research on feasible methods for recycling. It is hoped, in the near future, that a nationwide strategy for handling used plastic pesticide containers will be available.

Environmental Organizations

Environmental organizations have capitalized on the real and perceived problems associated with the use of agricultural chemicals. The chemical industry as a whole, not just the agricultural chemicals sector, has made changes in the conduct of business in response to issues raised by public interest groups. However, while the agrochemical industry is helping greatly to feed and clothe the world, the moral high ground on pesticide use has not been won. The challenge is obvious. The pesticide industry is doing many things right and the safety record for pesticides is remarkably good. Nevertheless, testing for efficacy and safety must continue to use state-of-the-art scientific methodology, and there must be increased communication with the public and public interest groups about the benefits of pesticides.

A widely accepted perspective is that reducing the detriment of pesticides on the environment equates to substantially reducing the volume of pesticides currently applied. Some European countries and US states have adopted or discussed policies to reduce pesticide use by 50% or more in this decade. Some would even ban all pesticides. Such a proscription does not appear feasible in the foreseeable future and thus we make no comments on strictly organic agriculture. Those who propose stringent restrictions are often uninformed about the efforts undertaken, especially in recent years, to minimize environmental degradation associated with pesticide use. Many of these efforts do focus on volume reduction, whereas others simply promote better management practices and policies that are equally or, arguably, more important than volume reduction.

Most in the research community who understand ecological principles subscribe to Garrett Hardin's modification of the first law of ecology, "We can never do merely one thing" (6). It is within this framework that we always, or should always, ask the follow-up question about our study results, again quoting Hardin, "and then what?" (7). As scientists, we are aware that our products and practices may have nontarget effects, and it is our responsibility to moderate them by using good science and logic to identify, evaluate, and mitigate the real risks.

SUMMARY

Considerable progress has been made by the agricultural chemical industry in reducing negative effects of pesticides on the environment. Some of this initiative resulted from increased federal and state regulations and some continues to be self-motivated. The preservation of the integrity of the environment and human safety have become major criteria for selecting new compounds for commercial development in addition to product efficacy. Studies to determine the effect of compounds on nontarget organisms are being conducted concurrent with the efficacy trials. The additional studies required to define the environmental risk for a product have added significantly to its development costs, projected now to be approximately $20 million. This increased cost for new product development and for re-registration of commercial products has resulted in voluntary cancellation of registrations for many existing products and fewer companies developing new products.

The search for new ideas to reduce the environmental effect of pesticides will continue. In the future, seed treatment will likely play a more important role in disease control, together with increased reliance on biological control and the application of techniques from biotechnology. However, a total replacement of chemicals for disease control is not anticipated in the foreseeable future.

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