A Report of the Biotechnology Working Group

BIOTECHNOLOGY'S BITTER HARVEST

Herbicide-Tolerant Crops and the Threat to Sustainable Agriculture

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The Biotechnology Working Group

The Biotechnology Working Group is composed of representatives of public interest organizations and a state agricultural agency and citizen activists who are presently working on biotechnology-related issues in the environmental, agricultural, consumer, labor, and public health fields. The purpose of the group is to strengthen the influence of the public interest community on the development of biotechnology by sharing information, coordinating activities, and developing action strategies on specific issues.

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Persons wanting an additional copy of the report should contact a member of the BWG.

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BIOTECHNOLOGY'S BITTER HARVEST

Herbicide-Tolerant Crops and the Threat to Sustainable Agriculture

EXECUTIVE SUMMARY

INTRODUCTION

Biotechnology, as it first emerged from university and industry laboratories in the 1970's, was full of promises for agriculture and the environment. Among the most alluring was the possibility of a chemical-free agriculture, which many in the scientific community and biotechnology industry touted as soon to come. With new genetically engineered crops and biopesticides to control pests, they said, chemical pesticides would no longer be needed.

But now, a decade later, the direction of agricultural biotechnology is clear: the first major products will not be used to end dependence on toxic chemicals in agriculture. Rather, they will further entrench and extend the pesticide era.

Biotechnology's Bitter Harvest finds that at least 30 crop and forest tree species are now being purposefully modified to withstand otherwise lethal or damaging doses of herbicides. The study asks the fundamental question of whether it is wise to use biotechnology to further chemical pest management strategies.

What is needed--and what many people thought biotechnology would deliver--is an economically viable and sustainable agriculture that uses safe and ecologically sound pest management strategies. Biotechnology's Bitter Harvest shows that herbicide-tolerant crops and trees will not provide that alternative, but instead, will take agriculture farther away from sustainable practices at precisely the time they are most needed.

FINDINGS

Among the findings supporting our conclusion that herbicide-tolerant crops represent a major misstep on the road toward an environmentally sound system of agriculture are the following:

* At least 27 corporations have initiated herbicide-tolerant plant research.

* The world's eight largest pesticide companies--Bayer, Ciba-Geigy, ICI, Rhone-Poulenc, Dow/Elanco, Monsanto, Hoechst, and Dupont--all--have initiated herbicide-tolerant plant research. So have virtually all major seed companies, many of which have been acquired by chemical companies.

* Agricultural crops currently targeted for genetically engineered tolerance to one or more herbicides include: alfalfa, canola, carrot, cotton, corn, oats, petunia, potato, rice, sorghum, soybean, sugarbeet, sugar cane, sunflower, tobacco, tomato, wheat, and others.

* Sustainable agriculture systems provide a range of alternatives to chemical herbicides for weed control. The National Research Council of the National Academy of Sciences has issued a report concluding that farmers adopting alternative systems of agriculture requiring no or lowered inputs of chemicals generally derive significant sustained economic and environmental benefits.

* State and federal agricultural institutions have devoted approximately $10.5 million of taxpayer money to fund genetics research on herbicide-tolerant crops and trees over the past few years. Additional substantial research also supports herbicide use in agriculture.

* Between 1985 and 1990, the U.S. Forest Service allocated $2.8 million to adapt modern genetics techniques to develop herbicide-tolerant forest trees.

* In the three years 1988-90, the Federal government spent only $12.8 million for research in its low-input sustainable agriculture (LISA) program, its sole program directly supporting sustainable agriculture research.

* The development of atrazine-resistant soybeans could allow for three times as much atrazine to be applied to corn without damage to the subsequent soybean crop, according to industry reports.

* According to industry projections, use of crops tolerant to Hoecht's herbicide, Basta, would increase that herbicide's global sales by $200 million a year.

* "Environmentally benign" or "environmentally friendly"--terms often used by industry to describe new herbicides--is a misnomer for herbicides, especially given how little we know about their long term effects on environment and human health. Bromoxynil, for example, has recently been shown to be such a human health threat that the Environmental Protection Agency now requires risk-reduction measures for pesticide users.

* Once in widespread use, the exchange of herbicide-tolerance genes between the domesticated crops and weedy relatives could ultimately result in the need for more herbicides to control herbicide-resistant weeds.

* Widespread use of plants tolerant to certain herbicides would likely increase the severity and incidence of ground and surface water contamination.

RECOMMENDATIONS

Based on the findings of this report, the Biotechnology Working Group makes the following recommendations:

1) End federal and state support for developing herbicide-tolerant plants;

2) Increase federal and state funding for non-chemical methods of pest control;

3) Target the federal research and experimentation tax credit for corporate research toward socially and environmentally beneficial research and deny the credit for expenditures to develop herbicide-tolerant crops and trees;

4) Change federal farm policy to discourage the use of environmentally damaging agricultural practices;

5) Regulate genetically engineered herbicide-tolerant plants as pesticides;

6) Prohibit the introduction of trees genetically modified to be herbicide tolerant into our national forests and other government lands; and

7) Fully inform Third World countries of the potential negative impacts of herbicide-tolerant crops and trees and urge the Food and Agriculture Organization of the United Nations to develop restrictions on the export of herbicide-tolerant plants.

THE BITTER HARVEST

Herbicides are chemicals used by the millions of pounds each year to control weeds in fields, forests, and gardens. They pose a variety of risks to human health and the environment, especially at current high use levels. Alachlor, one of the country's most popular herbicides, for example, is a suspected human carcinogen, while another, 2,4-D, has been linked to non-Hodgkin's lymphoma in farmers in the Midwest. Many herbicides persist in the environment and are increasingly found in groundwater all over the country. Herbicides are also toxic to animals and other forms of life not usually considered in environmental toxicity testing. For example, the accidental and purposeful clearing of plant life can deprive many organisms of habitat.

At a time when pesticide residues are being found increasingly in the food supply, in drinking water, and implicated as a source of farmer and farmworker poisonings, it is both inexcusable and unacceptable that biotechnology be used to further pesticide use in agriculture, and it is most inappropriate that federal and state research dollars be used for such purposes. If the money now being spent on herbicide tolerance in the public sector alone were instead directed to be spent on new approaches to weed management, the benefits to society, farm profitability, and environmental protection would surely far outdistance the strategy of continuing the chemical treadmill with herbicide tolerance.

Perhaps the greatest problem with herbicide tolerance, however, is that it diverts us from the paths that really could lead to reduced chemical dependency in agriculture. As farmers have known for years, and in some cases are learning anew, responsible tillage practices, crop rotations, and intercropping are viable methods of managing weeds. Unlike the ephemeral benefits of herbicide tolerance, the use of these "common sense" practices will minimize chemical inputs, and maximize long-term farm income and environmental protection. These and similar efforts to make agriculture sustainable over the long term--for farmers, rural economies and the environment--should command our full attention.

As farmers around the country are concluding, herbicide tolerance is not compatible with sustainable agriculture. It ought to be rejected and exposed for what it is: a way for the agrichemical establishment to control the direction of agricultural biotechnology.

To those with high hopes for the environmental benefits from biotechnology, herbicide-tolerant crops are at best a distressing misstep, at worst a cynical marketing strategy. Both industry and the publicly supported agricultural research establishment must direct their considerable talent and resources toward sustainable alternatives for weed management and other pest controls. The risks of prolonging the chemical era of agriculture are far too clear--for farmers, consumers, and the environment. Sustainable practices provide an alternative that will never be realized if public research funds are wasted on such misguided products as herbicide-tolerant crops.

1

INTRODUCTION

> Biotechnology promises to have an enormous impact on crop production. Genetic engineers can...make crops hardier and less dependent on the input of chemicals....
>
> Howard Schneiderman, Monsanto Company
> (Schneiderman, 1986)

> If you have herbicide tolerance, you're going to expand market share [for that herbicide]. If you don't, you're going to lose.
>
> Dan Wagster, Calgene, Inc.
> (Gladwell, 1988)

For the past few years, proponents of biotechnology have touted biotechnology as the solution to a number of environmental problems. Just around the corner, they said, a new era will be born as the products of agricultural biotechnology reduce, if not outright eliminate, the use of toxic agricultural chemicals (e.g., Federoff, 1987; Melloan, 1987; New York Times, 1988). But as the first major products of agricultural biotechnology emerge, what has happened to these promises?

Biotechnology's Bitter Harvest examines the impact of agricultural biotechnology's first major product--crops genetically modified to tolerate chemical weed killers, or herbicides. Crops are being given genes that will enable them to tolerate or resist the toxic effects of herbicides. A major research focus of public and private research institutions, herbicide-tolerant crops involve most agricultural crops, including a number of food crops, in the United States.

The market strategy is clear. Many chemical herbicides kill crops as well as weeds, thus their use is limited. But, if farmers plant crops that tolerate particular herbicides, the market for these herbicides will increase.

The intent of this report is to examine the impacts of herbicide-tolerant crops and trees and to recommend changes that will discourage the development and adoption of such crops and trees in U.S. agriculture and forestry.

First, the report examines the extent of current herbicide use and the research sponsored by corporations and federal and state governments on crops and trees that tolerate herbicides. Then, it briefly discusses the human health, environmental, social, and economic impacts of herbicides and herbicide-tolerant plants. Next, the report examines the promises against the realities of widespread use of herbicide-tolerant crops, exposing a variety of detrimental effects herbicide-tolerant crops and trees will have on farmers, consumers, and the environment. Finally, it outlines the promise of sustainable agriculture to provide alternative methods of weed control. Based on its analyses, the report makes recommendations to discourage the development and adoption of herbicide-tolerant crops and trees.

2

CHEMICAL HERBICIDES AND HERBICIDE-TOLERANT CROPS

Modern agriculture depends heavily on herbicides--chemical plant killers--to control weeds. Nearly 80% of the 600,000,000 pounds of herbicides used annually in this country are applied in agricultural settings. Consumers, farmers, farmworkers, domesticated plants and animals, wildlife, and their habitats are exposed to weed killers.

Against the background of agriculture's current dependence on herbicides, biotechnology, agrichemical, and seed companies, as well as the U.S. Department of Agriculture and state agricultural institutions, are using genetic engineering to develop crops and trees resistant to herbicides. Widespread adoption of these crops and trees will lead to increased use of particular herbicides.

CHEMICAL HERBICIDES

Weeds are a major agricultural pest, accounting for significant reductions in crop yields and profits. Herbicide use to control weeds has grown enormously since mid-century. Today, chemical weed killers dominate weed control in agriculture.

History of weed control

Until the 20th century, farmers controlled weeds with a combination of physical and mechanical means and through rotations with crops that could compete with the weeds. Some chemicals, such as sulfur compounds, were available to control weeds before the turn of the century. They were not widely used, however, because the low cost of labor made mechanical control methods--primarily tillage--generally more attractive (Flint and van den Bosch, 1981). Pest control in this period "stressed the importance of correct identification of pests and the need for a solid understanding of pest biology, especially the timing of application of control measures" (Flint and van den Bosch, 1981, p. 64).

World War II changed attitudes toward weed control. Research on chemical warfare and on control of insects carrying malaria spurred a substantial synthetic chemical industry after the war (Carson, 1962; Flint and van den Bosch, 1981). This industry revolutionized pest control. The new organic chemicals available for pest control were "cheap, effective in small quantities, easy to apply, and widely toxic. They seemed to be truly 'miracle' compounds" (Flint and van den Bosch, 1981, p. 69).

The new chemicals had a revolutionary effect on farming, industry organization, and pest-control research. Farmers began to expect pests to be eradicated when before they would have tolerated certain levels as inevitable. At the same time, pesticides became big business. The synthetic organic chemical pesticide industry came to be dominated by large corporations--in contrast to the pre-war inorganic pesticide industry composed of small, specialized companies.

"The use of ... pesticides over the period became as normal to the grower as cultivating ... fields or ... sowing seeds. It was an uncomplicated, easy-to-follow procedure, and growers regarded it as inexpensive and foolproof insurance against pest damage. And they were often urged on by pesticide company representatives, who had become the farmer's chief source of information about a wide range of pest problems."

Farmers, advisors to farmers (such as Department of Agriculture extension agents), and researchers moved away from the older ecological and preventive approaches toward chemical methods of pest control. According to Flint and van den Bosch (1981, p. 70),

> The use of ... pesticides over the period became as normal to the grower as cultivating ... fields or ... sowing seeds. It was an uncomplicated, easy-to-follow procedure, and growers regarded it as inexpensive and foolproof insurance against pest damage. And they were often urged on by pesticide company representatives, who had become the farmer's chief source of information about a wide range of pest problems.

Current U.S. herbicide use

The post-World War II trend toward increasing dependence on chemicals in agriculture culminates in current high use rates of herbicides. Over 600,000,000 pounds of herbicides are applied annually. Sixty percent, by weight, of the pesticides[1] currently used in this country are herbicides (Table 1).

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[1] The major types of pesticides are insecticides, fungicides, nematicides, rodenticides, and herbicides.

TABLE 1

HERBICIDE USE COMPARED WITH TOTAL PESTICIDE USE IN THE U.S.
1987 ESTIMATES *

Application	Million pounds active ingredient Herbicides**	All Pesticides	Herbicide Percent
Agriculture	505	814	62
Industrial, Commercial and Governmental	115	200	58
Home and Garden	25	73	34
TOTAL	645	1087	59

* Data from U.S. Environmental Protection Agency, Office of Pesticide Programs, 1988.
** Includes plant growth regulators.

Herbicides are used in a variety of applications. Farmers apply weed killers to field, forage, fruit, vegetable, and fiber crops. Individuals use them in lawns and gardens. Businesses apply them to commercial plantings. Plant-killing chemicals are also applied to state and federal forests, rights-of-way, parklands, and playgrounds. The Bureau of Land Management and the Defense Department apply herbicides on lands under their control.

The major use of herbicides in the U.S. is in agriculture (Table 1), and in particular, in field and forage crops[2]. In recent years, corn and soybeans alone have accounted for about 80% of farm use of herbicides (U.S. Department of Agriculture, Economic Research Service, 1983, 1986). Herbicides account for an increasingly large proportion of the total pesticides applied to field and forage crops in the U.S. (Table 2).

The decline since the mid-1980's in total weight of herbicide used in U.S. field and forage crop production (Table 2) is partly due to the use of newer, more potent herbicides that require smaller amounts of active ingredients to obtain the same killing power as older, less potent chemicals, as well as changes in farm programs (U.S. Department of Agriculture, Economic Research Service, 1986, 1987).

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2 Field and forage crops are crops such as alfalfa, cotton, and corn that are grown over a large area for agricultural purposes. The category excludes fruits, vegetables, and ornamental crops.

TABLE 2

HERBICIDE USE COMPARED WITH TOTAL PESTICIDE USE ON FIELD AND FORAGE CROPS IN THE U.S.*

Year	Million pds. active ingredient Herbicides	All Pesticides	Herbicide Percent
1971	207	405	51
1976	374	583	64
1982	451	552	81
1988**	372	439	85

* Data compiled from U.S. Department of Agriculture, Economic Research Service, 1983, 1989a.
** Data for field crops only.

The dramatic increase in the number of acres subject to herbicide use since 1956 also illustrates the nation's dependence on herbicides. For example, herbicide use on three major crops--corn, soybeans, and cotton--has increased to the point that roughly 95% of the acres planted in these crops are now treated with weed-killing chemicals (Table 3).

TABLE 3

PERCENT OF U.S. ACRES OF MAJOR FIELD CROPS TREATED WITH HERBICIDES

Crop	1956*	1971**	1982**	1988**
Corn	11	79	95	96
Soybeans	5	68	93	96
Cotton	***	82	97	95
Grain sorghum		46	59	***
Peanuts		92	93	
Tobacco		7	71	
Rice		95	98	
Wheat		41	42	38

* Data from Agricultural Law and Policy Institute, 1988.
** Data compiled from U.S.Department of Agriculture, Economic Research Service, 1983, 1989a.
*** Blank spaces indicate no data.

Exposure to herbicides

The extensive herbicide use in this country means widespread exposure of humans and other living things to weed-killing chemicals. Farmers and rural people are exposed most often and to the highest levels of farm chemicals. Many rural people use water for drinking, recreation, and hygiene that is contaminated with herbicides and their residues. Rural communities are often subject to contamination from herbicide drift. Farmers and farm workers are exposed when applying herbicides and when working in fields to which herbicides have recently been applied.

One study estimates that less than 1% of the pesticides (including herbicides) applied actually reach target pests (Pimentel and Levitan, 1986).

Urban and suburban populations are exposed to herbicides used in home lawns and gardens, commercial and government plantings, and parks and playgrounds. Consumers are exposed through contaminated water and food residues. Wild animals are also exposed to herbicides. Their habitats are sometimes destroyed as weed-killers are applied to clear crop land or development sites, and to eliminate unwanted plants in forests, other public lands, government lands, fence rows, rights-of-way, surface water, and crop land.

One study estimates that less than 1% of the pesticides (including herbicides) applied actually reach target pests (Pimentel and Levitan, 1986). Consequently, more than 99% of herbicides applied may contaminate land, water, air, humans, other animals, and wildlife habitat.

HERBICIDE-TOLERANT CROPS AND TREES

Against the background of our heavy dependence on chemical weed killers, biotechnology is creating a whole new range of crops and trees genetically engineered to tolerate herbicides. Agrichemical manufacturers, biotechnology companies, and federal and state research laboratories are using modern genetic engineering techniques to perpetuate and even broaden the use of herbicides in agriculture and forestry. They are developing crops that will resist the damaging effects of herbicides. With "herbicide-tolerant crops," greater quantities of particular herbicides can be used to control weeds.

Herbicide-tolerant crops

As the name implies, herbicide-tolerant plants can grow in the presence of amounts of herbicide that harm or kill a non-tolerant plant. Some plants naturally tolerate particular herbicides. Grasses, for example, naturally tolerate certain herbicides that kill broad-leaved plants. Despite this, use of herbicides to control agricultural weeds is often limited by the sensitivity of a crop to an herbicide (or sometimes the sensitivity of other crops which will subsequently be planted in the same field). Herbicide-tolerant crops remove this limitation. They are designed to tolerate higher levels of already-used herbicides or to tolerate herbicides that were previously lethal.

The role of genetic engineering

Traditional breeding techniques can sometimes be used to develop herbicide-tolerant crops. Breeders first find wild relatives or crop varieties that are naturally tolerant to a particular herbicide. They then cross these with crop plants to develop crops that resist that herbicide. Because traditional techniques work only with closely related plants, breeders are confined to the tolerance traits they can find in plants closely related to the target crop plant. Thus, traditional breeding programs have a limited potential to produce herbicide-tolerant crops. Modern genetic techniques remove the constraints of traditional breeding and make it possible to create many additional kinds of crops resistant to large numbers of herbicides (Sun, 1986).

At least 27 corporations have launched research programs directed toward the development of herbicide-tolerant crop varieties.

With genetic engineering, unlike traditional breeding, scientists can combine traits from widely different parents. For example, scientists have found herbicide-tolerance traits in microorganisms that live in the soil. Genetic engineers can take a gene for herbicide tolerance from a soil microorganism and put it into plants. Using this approach, Calgene, a California biotechnology company, has transferred a bromoxynil-tolerance gene into cotton, tobacco, and tomato (Stalker et al., 1988; National Wildlife Federation, 1990). Other companies have used similar approaches to develop other herbicide-tolerant crops.

Appendix A contains additional information on ways modern biotechnology techniques are being used to create herbicide-tolerant plants.

Intense commercial interest

Research on herbicide-tolerant crops is a major focus of commercial biotechnology. At least 27 corporations have launched research programs directed toward the development of herbicide-tolerant crop varieties (Table 4). Virtually all major food crops are targets, including rice, corn, wheat, potato, sorghum, and soybean. Other crops targeted include trees, vegetables, and important industrial crops: alfalfa, canola, carrot, cotton, oats, petunia, poplar, sugarbeet, sugarcane, sunflower, tobacco, tomato, and oilseeds (e.g., canola, turnip rape).

Biotechnology industry analysts originally predicted that the annual value of herbicide-tolerant seed would reach $2.1 billion by the year 2000, reaching $3.5 billion just after the turn of the century (Agricultural Genetics Report, 1983). More recent projections range from $75 million annually (beginning in the mid-1990's) (Ratner, 1989) to $320 million annually (Genetic Technology News, 1989).

TABLE 4

PUBLISHED REPORTS OF COMPANY RESEARCH TO DEVELOP HERBICIDE-TOLERANT PLANTS[1]

Herbicide[2]	Crop[3]	Company[4]	Source[5]
atrazine	soybean	Ciba-Geigy	Seed World, 5/87, p. 17
atrazine	tobacco	Ciba-Geigy	UNIDO Monitor, 7/86, p. 2
atrazine	tomato	Calgene	Seed World, 5/87, p. 17
bromoxynil	cotton	Calgene	USDA APHIS permit, 10/89
bromoxynil	soybean	Calgene with Rhone Poulenc	EBN, 11/89, p. 4
bromoxynil	sunflower	Calgene	Seed World, 5/87, p. 17
bromoxynil	tomato	Calgene	ABN, 3/88, p. 25
bromoxynil	tobacco	Calgene	ABN, 3/88, p. 25
cinmethylin	corn	Shell	Altered Harvest, Doyle, p. 469
glufosinate	alfalfa	Northrup King	USDA APHIS permit, 6/89
glyphosate	canola	Calgene	ABN, 3/85, p. 13
glyphosate	canola	Monsanto	Washington Post, 5/88, p. C1
glyphosate	cereals	Rhone-Poulenc with Calgene	EBN, 11/89, p. 4
glyphosate	corn	Phyto Dynamics	Seed World, 5/87, p. 17
glyphosate	corn	Hoechst	BioScan, 4/89, p. 322
glyphosate	corn	Rhone-Poulenc with Calgene and DeKalb	EBN, 11/89, p.4
glyphosate	cotton	Calgene with Phytogen	ABN, 1/85, p. 2
glyphosate	cotton	Monsanto	ABN, 1/89, p. 14
glyphosate	forest trees	Calgene with US Forest Service	ABN, 9/85, p. 4
glyphosate	petunia	Monsanto	AGR, 9/86, p.7
glyphosate	soybean	Monsanto	GTN, 7/88, p. 8
glyphosate	soybean	Rhone-Poulenc with Calgene	EBN, 11/89, p. 4
glyphosate	sugarbeet	Monsanto	New Scientist, 8/89, p. 23
glyphosate	sugarbeet	Rhone-Poulenc with Calgene	EBN, 11/89, p. 4
glyphosate	sunflower	Rhone-Poulenc with Calgene	EBN, 11/89, p. 4
glyphosate	tobacco	Calgene	ABN, 3/88, p. 25
glyphosate	tobacco	Monsanto	AGR, 1/86, p. 7
glyphosate	tomato	Calgene	ABN, 3/88, p. 25
glyphosate	tomato	Monsanto	The Economist, 4/88, p. 7

imidazolinones	canola	Allelix with American Cyanamid	Biotech.Newswatch, 5/89, p.1
imidazolinones	corn	Molecular Genetics	ABN, 11/85, p. 3
metribuzin	soybean	Mobay	Seed World, 5/87, p. 17
pendimethalin	corn	Phyto Dynamics	Chemical Week, 12/84, p. 29
phenmedipham	canola	Calgene	Seed World, 5/87, p. 17
phenmedipham	turnip rape	Calgene with Kemira Oy	Seed World, 5/87, p. 17
phosphinothricin	potato	Plant Genetic Systems	AGR, 4/87, p. 2
phosphinothricin	sugarbeet	Plant Genetic Systems	AGR, 5/88, p. 4
phosphinothricin	tobacco	Plant Genetic Systems	AGR, 4/87, p. 2
phosphinothricin	tomato	Plant Genetic Systems	AGR, 4/87, p. 2
sulfonylureas	soybean	DuPont	ABN, 1/87, p. 3
sulfonylureas	tobacco	Sandoz	USDA APHIS permit, 4/88
sulfonylureas	tobacco	DuPont	ABN, 1/87, p. 3
sulfonylureas	tobacco	Dupont with Advanced Genetic Sciences	AGR, 4/87, p. 1
sulfonylureas	tomato	DuPont	USDA APHIS permit, 6/88
thiocarbamate	not given	Stauffer	Seed World, 5/87, p. 17
triazines	canola	Allelix	Unido Monitor, 1987/1 p. 26
trifluralin	corn	Phyto Dynamics	Seed World, 5/87, p. 17
2,4-D	soybean	Diamond Shamrock	Benbrook/Moses, p. 37
2,4-D	tobacco	Schering	Bio/Technology, 8/89, p. 811
not given	canola	Biotechnica	Seed World, 5/87, p. 17
not given	corn	Stauffer	Benbrook/Moses, p. 37
not given	corn	DuPont	ABN, 1/89, p. 18
not given	forest trees	Forgene	GTN, 1/89, p. 33
not given	not given	Shell	Benbrook/Moses, p. 37
not given	not given	DNA Plant Technolog	As You Sow, 2/86, p.2
not given	sorghum	Stauffer	Benbrook/Moses, p. 37
not given	soybean	Rhone-Poulenc	ABN, 1/87, p. 7
not given	sunflower	Stauffer	Benbrook/Moses, p. 37
not given	vegetable	American Cyanamid	AGR, 8/87, p. 7
not given	wheat	Biotechnica	Seed World, 5/87, p. 17
not given	not given	Upjohn	BioScan, 4/89, p. 655
not given	alfalfa	DuPont	AGR, 9/86, p.7
not given	carrot	DuPont	AGR, 9/86, p. 7
not given	oats	DuPont	AGR, 9/86, p.7
not given	potato	DuPont	AGR, 9/86, p.7
not given	rice	DuPont	AGR, 9/86, p.7
not given	soybean	Agracetus	GTN, 7/88, p. 5
not given	sugarcane	DuPont	AGR, 9/86, p. 7

1 Originally developed by the Rural Advancement Fund International, Pittsboro, NC, and modified for this report, this list was compiled from published reports, primarily trade journals and newsletters. Research involving modern genetic techniques dominates the list, though a few entries represent conventional breeding research programs. Trade journals and newsletters are more likely to publish information on "high tech" plant breeding than on more conventional approaches. The list is not exhaustive. Knowledge of research sponsored by private companies is limited to information that a company is willing to release. We expect that other herbicide-tolerant plant research is underway but has not been publicized. On the other hand, some of the listed projects may have been terminated.

2 The chart is arranged alphabetically according to the common name of the herbicide to which tolerance is sought. Common and trade names of herbicides are listed in Appendix B.

3 Plants subject to genetic manipulation for herbicide tolerance are listed under their common names.

4 The company sponsoring the research is listed. In instances where the research is reported to be a joint or cooperative venture with another institution, the cooperating institution is listed.

5 Abbreviations for many of the published sources of information are: ABN, AgBiotechnology News; AGR, Agricultural Genetics Report; EBN, European Biotechnology Newsletter; GTN, Genetic Technology News; UNIDO Monitor, United Nations Industrial Development Organization; USDA APHIS, U.S. Department of Agriculture Animal and Plant Health Inspection Service. Complete citations for Benbrook/Moses, Doyle, and As You Sow are in "References."

The development of herbicide-tolerant seeds reinforces a recent agricultural trend in which two major agricultural inputs, seeds and chemicals, are increasingly controlled by one industry. The trade publication Agricultural Genetics Report (1983) observes that:

> Many major firms involved in agricultural chemicals have staked a claim in herbicide resistance. Some are developing crops resistant to their new experimental herbicides in the hope of selling the seed and chemical as a pair. Others see herbicide resistance as a way of regaining market share lost after a well-known herbicide has declined in price and popularity. Again, the old herbicide is sold in combination with a new seed resistant to it.

As Howard Schneiderman of Monsanto says, "I don't know if we could offer a [seed-herbicide] package, but if we could, we would" (Sun, 1986). Chemical companies now own most of the major seed companies in this country. Hence, it would be relatively easy for chemical/seed companies to influence two important agricultural inputs to their market advantage.

"I don't know if we could offer a [seed-herbicide] package, but if we could, we would." Howard Schneiderman, Monsanto Company

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Eight pesticide companies now account for approximately 70 percent of proprietary pesticide sales worldwide[3]. All these companies support research on herbicide tolerance (Table 5). Many of the world's top ranking seed corporations also support research on herbicide tolerance (Table 6).

TABLE 5

HERBICIDE-TOLERANCE RESEARCH BY TOP 8 PESTICIDE COMPANIES*

Company	Location	HT Research
Bayer	FR Germany	yes
Ciba-Geigy	Switzerland	yes
ICI	United Kingdom	yes
Rhone-Poulenc	France	yes
Dow/Elanco	USA	yes
Monsanto	USA	yes
Hoechst	FR Germany	yes
DuPont	USA	yes

[3] George Kidd, L. William Teweles and Co., Milwaukee, WI, personal communication with H. Shand, 12/89.

TABLE 6

HERBICIDE-TOLERANCE RESEARCH BY WORLD'S LARGEST SEED CORPORATIONS*

Company	Location	HT Research
Pioneer Hi-Bred	USA	yes
Sandoz-Hilleshog	Switzerland	yes
Upjohn	USA	yes
La Farge/Rhone-Poulenc	France	yes
Groupe Limagrain	France	no
ICI	United Kingdom	yes
Cargill	USA	unknown
Dekalb-Pfizer	USA	yes
Takii & Co., Ltd.	Japan	unknown
Ciba-Geigy	Switzerland	yes

*Mergers and acquisitions make a definitive list impossible. Company list based on information compiled by L. William Teweles & Co., Milwaukee, WI, and ICI estimates.

Combined interests in seeds and herbicides offer considerable financial rewards. The following are a few examples:

* If soybeans could be made tolerant to atrazine herbicides, annual atrazine sales could rise by $120 million (Doyle, 1985b).

* An industry analyst has said that genetically engineering one crop--canola--to tolerate glyphosate could mean "hundreds of millions of dollars in additional sales" for Monsanto (Gladwell, 1988) --and canola is only one of at least 15 different field crops, vegetables, trees, flowers, and grasses being engineered for glyphosate tolerance.

According to Plant Genetic Systems (a Belgian biotechnology company), development of crops tolerant to Hoechst's Basta would increase the herbicide's global sales by $200 million a year.

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* When American Cyanamid developed a new family of imidazolinone herbicides, it contracted with Molecular Genetics to find a gene that would give crops tolerance to the chemical. Once the gene was identified, Cyanamid gave it, gratis, to Pioneer Hi-Bred--the world's largest corn-breeding company. Pioneer

has agreed to insert the gene into its hybrids--much to the benefit of Cyanamid (AgBiotechnology News, 1985).

* According to Plant Genetic Systems (a Belgian biotechnology company), development of crops tolerant to Hoechst's Basta would increase the herbicide's global sales by $200 million a year (Agricultural Genetics Report, 1987).

Taxpayer-funded genetics research to develop herbicide-tolerant plants

Development of herbicide-tolerant crops is not limited to the private sector. Significant amounts of taxpayer money are also being spent by the U.S. Department of Agriculture and state agricultural institutions to fund genetics research on herbicide-tolerant crops and trees. In fact, a U.S. Department of Agriculture council has declared development of herbicide-tolerant plants a research priority (U.S. Department of Agriculture, Joint Council on Food and Agricultural Sciences, 1989).

To determine the nature and extent of taxpayer-funded herbicide-tolerance research, we sought two kinds of information: the number of genetics research projects funded over the past several years for herbicide-tolerance research and the amount of funding for each project.

To obtain the number of projects funded by U.S. Department of Agriculture and state agricultural institutions, we searched the Current Research Information System (CRIS). CRIS is the U.S. Department of Agriculture computer-based information storage and retrieval system that maintains and reports records of publicly supported agricultural and forestry research in the United States. The system contains summaries of current and recently completed research conducted or sponsored by the U.S. Department of Agriculture agencies and state agricultural institutions.

We estimate that state and federal agricultural institutions have budgeted approximately $10.5 million of taxpayer money to fund genetics research on herbicide-tolerant crops and trees over the past few years.

The computer search of the CRIS database[4] November 29, 1989, yielded 409 project entries that represented a broad spectrum of taxpayer-funded research concerning herbicide tolerance. Because the major focus of this report is genetic manipulation to achieve herbicide tolerance in crops and trees and some projects had

[4] The search used the keywords: "tolerant, tolerance, resistance, resistant" connected individually to "herbicide" and the names of 11 chemical herbicides.

ended, we chose to analyze only a narrow subset of the 409 projects. This subset included those projects funded in 1989 that used genetic change to achieve herbicide tolerance as a goal, approach, or result.

As shown in Table 7, in 1989, the U.S. Department of Agriculture and state agricultural institutions supported with taxpayer dollars at least 58 projects to increase herbicide tolerance through genetic modifications. The projects were funded an average of 4.4 years.

Three characteristics of the database limit the conclusions to be made concerning the research. First, the CRIS descriptions of the research projects do not indicate the proportion of the research dedicated to herbicide-tolerant plants. Some projects may be only partially committed to herbicide-tolerant plant research. Second, since we are dependent upon the investigators for the CRIS description of the research projects, there may be additional projects concerned with herbicide-tolerant plants that were not retrieved because none of our keywords were included in the description. Third, the CRIS database may not be complete and at a minimum does not contain data from all state agricultural experiment stations[5]. Consequently, there is likely to be additional state-supported research to develop herbicide-tolerant plants.

To obtain an estimate of the extent of taxpayer funds allocated to the 58 projects listed in Table 7, we used the average dollar-amount of grants awarded by each program that sponsors the research (except for the Forest Service for which we have actual funding amounts). We used averages because we were unable to obtain total funding amounts for individual projects that received funds in fiscal year 1989[6].

The projects are funded through five programs:

* Cooperative State Research Service (CSRS) (noncompetitive grants)--25 projects;
* Agricultural Research Service (ARS)--16 projects;
* State Agricultural Experiment Stations (SAES)--12 projects;
* Competitive Research Grants Office (CRGO) of CSRS--3 projects; and

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5 Communication (11/21/89) with John Myers, Director of CRIS, U.S. Department of Agriculture.

6 The U.S. Department of Agriculture's response to a Freedom of Information Act requesting total dollar amounts for projects receiving funds in 1989 yielded data only through fiscal year 1988. Figures for 1989 are not yet available.

* Forest Service (FS)--2 projects.[7]

The latest funding figures (fiscal year 1988) for the average grant amount per project[8] (total grant--not amount per year) are as follows:

* $95,000 for projects funded through CSRS, SAES, and CRGO; and

* $251,000 for projects funded through ARS.

These figures do not reflect the full amount of taxpayer support for herbicide-tolerance research projects. Other support may include salaries of scientists and technicians conducting the research, purchase of equipment, and maintenance of laboratories and equipment.

Between 1985 and 1990, the Forest Service allocated $2.8 million to adapt modern genetics techniques to develop herbicide-resistant forest trees.

To determine the approximate amount of taxpayer funds allocated to this research, we multiplied the average grant amount from each program by the number of projects funded through that program. Multiplying 40 projects (25 CSRS, 12 SAES, 3 CRGO) by $95,000 yields approximately $3.8 million. Sixteen ARS projects funded at an average of $251,000 yields approximately $4 million.

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[7] ARS is the U.S. Department of Agriculture's internal research agency. The Forest Service has the principal federal responsibility for forestry research. SAES, the state arm of taxpayer-funded agricultural research, is composed of 50 land-grant institutions, each of which has an experiment station. CSRS is the principal federal research agency that supports the land-grants colleges of agriculture and state agricultural experiment stations. (National Research Council, 1989b)

[8] Figures obtained from John Myers, Head of the Current Research Information System, telephone conversation with J. Rissler, 2/14/90, and Holly Schauer, U.S. Department of Agriculture Competitive Research Grants Office, telephone conversation with J. Rissler, 2/20/90.

Between 1985 and 1990, the Forest Service allocated $2.8 million to adapt modern genetics techniques to develop herbicide-resistant forest trees (Table 7, projects 22 and 23)[9].

Totaling the approximations and the Forest Service figures, we estimate that state and federal agricultural institutions have budgeted approximately $10.5 million of taxpayer money to fund genetics research to develop herbicide-tolerant crops and trees over the past few years.

For purposes of rough comparison, these amounts can be considered against the $12.8 million that the U.S. Department of Agriculture has expended the past three years in its low-input sustainable agriculture (LISA) research program[10]. Initially funded in 1988, LISA supports research on innovative agricultural practices and products that enable farmers to use fewer external inputs, such as chemical herbicides. It is the only U.S. Department of Agriculture program that directly supports research in sustainable agriculture. (See Chapter 5 for more information on sustainable agriculture.)

Considering that the broader set of 409 projects also supports herbicide-dependent agricultural systems, it would appear that the U.S. Department of Agriculture's efforts to facilitate the use of herbicides in chemical agriculture far outpaces its efforts to reduce that use.

These funding estimates support the frequent criticism that the Department of Agriculture's research priorities and the land-grant university system favor the development of practices and products that favor agribusiness, while ignoring the environmental and social costs of these developments (Hightower, 1973; van den Bosch, 1978; Freidland and Kappel, 1979; Kenney, 1986).

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[9] Peter Roussopoulous, Assistant Director, North Central Forest Experiment Station, St. Paul, MN, 2/28/90 telephone conversations with R. Goldburg and J. Rissler.

[10] Funding for the 1988-90 fiscal years (FY) were: 1988, $3.9 million; 1989, $4.45 million; and 1990, $4.45 million (Neil Schaller, Director, LISA Research and Education, personal communication, 2/15/90). The proposed 1991 level remains $4.45 million (U.S. Department of Agriculture, Cooperative State Research Service, 1990).

TABLE 7

TAXPAYER-FUNDED AGRICULTURAL GENETICS RESEARCH TO DEVELOP HERBICIDE-TOLERANT PLANTS

Project[1]	Herbicide[2]	Crop(s)[3]	Institution[4]	State[5]	Funds[6]	Method[7]
*1	aciflouren	tomato	U IL	IL	CSRS	A
2	atrazine	broccoli	Cornell	NY	CSRS	B
3	atrazine	broccoli, cauliflower	Cornell	NY	CRGO	B
4	atrazine	canola	U ID	ID	CSRS	A
5	atrazine	corn	PA SU	PA	CRGO	B
6	atrazine	soybean	TN SU	TN	CSRS	B
7	atrazine	cauliflower	NYA Exp St	NYC	CSRS	B
*8	atrazine	sorghum	U GA	GA	CSRS	A
9	atrazine	cauliflower	Cornell	NY	SAES	B
*10	atrazine	soybean	U MD	MD	SAES	A
11	bentazon	peas, peppers, beans	ARS	SC	ARS	A
12	bentazon	pepper, tomato	GCP Exp St	GA	CSRS	A,B
*13	bentazon	pepper	ARS	SC	ARS	A
*14	bentazon	pepper, sweet potato	NC SU	NC	CSRS	A
*15	chloroacetanilide	corn	U MN	MN	SAES	B
16	chlorsulfuron	sugarbeet	ARS	MI	ARS	B
*10	chlorsulfuron	soybean	U MD	MD	SAES	A
17	clomazone	soybean	U WI	WI	CRGO	unclear
18	diclofop	wheat	ARS	ND	ARS	B
*19	diclofop	birdsfoot trefoil, forage grasses	U MN	MN	SAES	A,B
20	dinitroaniline	carrot	ARS	MS	ARS	A
*1	glyphosate	tomato	U IL	IL	CSRS	A
*8	glyphosate	sorghum	U GA	GA	CSRS	A
*10	glyphosate	soybean	U MD	MD	SAES	A
*13	glyphosate	pepper	ARS	SC	ARS	A
*19	glyphosate	birdsfoot trefoil forage grasses	U MN	MN	SAES	A,B
21	glyphosate	birdsfoot trefoil	U MN	MN	CSRS	A
22	glyphosate	poplar	NCF Exp St	WI	FS	B
23	glyphosate	poplar	NCF Exp St	WI	FS	B
24	glyphosate	poplar	U ID	ID	CSRS	B
25	glyphosate	potato	CO SU	CO	CSRS	B
26	glyphosate	soybean, others not given	LA SU	LA	CSRS	B
27	glyphosate	tobacco	Purdue	IN	CSRS	A,B
28	glyphosate	Bermuda grass	U AR	AR	SAES	B
*29	glyphosate	alfalfa, wheat	U WY	WY	CSRS	A
*30	haloxyfop	corn	U MN	MN	SAES	B
*31	hexazinone	alfalfa	OK SU	OK	CSRS	A
32	imazethapyr	barley	U MN	MN	SAES	B
*8	metolachlor	sorghum	U GA	GA	CSRS	A
*14	metribuzin	sweet potato	NC SU	NC	CSRS	A
33	metribuzin	soybean	U AR	AR	SAES	A
34	metribuzin	potato	WA SU	WA	SAES	A,B
35	metribuzin	potato	ARS	WA	ARS	A
*29	picloram	alfalfa, wheat	U WY	WY	CSRS	A
36	sethoxydim	corn	ARS	MN	ARS	B
*15	sethoxydim	corn, sorghum	U MN	MN	SAES	B
*30	sethoxydim	corn	U MN	MN	SAES	B
*31	terbacil	alfalfa	OK SU	OK	CSRS	A
37	triazines	wheat	OK SU	OK	CSRS	A
38	2,4-D	not given	ARS	CA	ARS	B
*10	2,4-D	soybean	U MD	MD	SAES	A
39	not given	birdsfoot trefoil	U MN	MN	CSRS	A
40	not given	cotton	DB Exp St	MS	CSRS	A
41	not given	cotton	ARS	TX	ARS	B

42	not given	fruit and nut trees	UC Davis	CA	CSRS	B
43	not given	oats	ARS	MN	ARS	B
44	not given	peas, wheat	WA SU	WA	CSRS	B
45	not given	cucurbits	U NH	NH	CSRS	A
46	not given	raspberry, blackberry	U MD	MD	CSRS	A,B
47	not given	rice	not given	AR	CSRS	A
48	not given	rice	ARS	CA	ARS	B
49	not given	rice	ARS	AR	ARS	A,B
50	not given	rice	ARS	AR	ARS	A
51	not given	soybean	ARS	MN	ARS	A
52	not given	sugarcane	ARS	LA	ARS	A
53	not given	sweet potato	ARS	SC	ARS	A
54	not given	turfgrass	MS SU	MS	CSRS	B
55	not given	wheat	U ND	ND	CSRS	A,B
56	not given	not given	Purdue	IN	SAES	B
57	not given	soybean	U MN	MN	SAES	A
58	not given	corn	IA SU	IA	SAES	A

1 Some projects are listed more than once because the research involves more than one herbicide. A project listed more than once is starred and retains the number associated with its initial listing.

2 The chart is arranged alphabetically according to the common name of the herbicide to which tolerance is sought. Common and trade names of herbicides are listed in Appendix B.

3 Plants subject to genetic manipulation for herbicide tolerance are listed under their common names.

4 The institutions where research is conducted are listed as i) universities (U) with state names abbreviated; ii) state experiment stations (Exp St) with state names abbreviated; or iii) Agricultural Research Service laboratories (ARS).

5 Names of states where research is conducted are abbreviated.

6 Sources of funds are abbreviated as: ARS--U.S. Department of Agriculture Agricultural Research Service; CRGO--U.S. Department of Agriculture Competitive Grants Research Office; FS--U.S. Department of Agriculture Forest Service; CSRS--Cooperative State Research Service; and SAES--state agricultural experiment stations.

7 Method refers to the kind of genetic manipulation involved in producing herbicide-tolerant plants. A = conventional breeding techniques. B = modern genetic techniques or so-called "high tech" procedures that operate at the molecular, cellular, or tissue levels. "B" methods include recombinant DNA, protoplast fusion, and tissue and cell culture (see Appendix A for explanation of methods).

Herbicide-tolerant trees

Research is also being conducted on herbicide-tolerant trees. Herbicides are currently used in forestry before and after tree seedlings are planted. Herbicide use is effective because herbicide susceptibility is in many cases quite specific, dependent on the growth stage of the trees and on the species involved. Thus, before tree seedlings are planted, newly logged areas are treated with herbicides to kill potentially competing vegetation. After planting, herbicides are used to free commercially valuable trees from competition from other tree species. 2,4-D, for example, kills broad-leaved trees while only slightly injuring conifers. It can be used to relieve conifers, which are valued for timber, from competition by broad-leaved trees.

The availability of resistant trees could greatly expand the market for herbicides in forestry. At present, only a fraction of forested area in this country is sprayed aerially with herbicides. The fraction varies with forest ownership (the U.S. Forest Service has sprayed more frequently than small landowners), terrain, and tree species harvested. Other methods for removing unwanted vegetation include machinery to dislodge weeds (mechanical control), injecting unwanted trees with herbicides, and burning (Nelson et al., 1984; Boutard, personal communication).

Arguing that these other methods are expensive, some in the Forest Service would like to increase herbicide spraying (Nelson and Haissig, 1986). Forest Service researchers believe that "herbicide use would be more widespread and efficient if cultured tree species were immune or highly resistant to commonly used herbicides" (Haissig, 1984, p. 3). Facilitating herbicide use is seen as a way to encourage plantation forestry--growing trees in monocultures like agricultural crops (Nelson and Haissig, 1986; New York Times, 1990).

Forest Service researchers believe that "herbicide use would be more widespread and efficient if cultured tree species were immune or highly resistant to commonly used herbicides."

The biotechnology company Calgene and the Forest Service have, in a joint project, genetically engineered poplar trees to tolerate the herbicide glyphosate. An inserted gene from Salmonella bacteria confers tolerance (New York Times, 1990; Krugman, 1986). With support from the U.S. Department of Energy, Forest Service researchers have also used tissue culture techniques to develop poplar with increased tolerance to glyphosate and sulfometuron (Michler and Haissig, 1988; U.S. Forest Service, 1989). As noted above, the Forest Service has allocated nearly $3 million in the last five years to develop herbicide-tolerant trees using genetic engineering and tissue culture techniques.

3

THE HUMAN HEALTH, ENVIRONMENTAL, SOCIAL, AND ECONOMIC IMPACTS OF HERBICIDES AND HERBICIDE-TOLERANT CROPS

Why worry that the first major application of modern biotechnology will likely increase our dependence on chemical herbicides?

Herbicide-tolerant plants with their concomitant increase in use of particular herbicides come at a time when many people, farmers and consumers alike, are deeply concerned about the human health, environmental, and social implications of the nation's dependence on chemical pesticides. The side effects of increased herbicide use are alarming. Herbicides are now present in groundwater around the country; some are possible carcinogens. Farmer and farmworker health, wildlife, and wildlife habitats are threatened. Consumers worry about pesticide residues in food. Farmers worry about herbicide-resistant weeds that evolve in the presence of large amounts of herbicides. New herbicide-resistant weeds may also be created by the transfer of herbicide-tolerance genes to weedy relatives of crop plants. Herbicide-tolerant crops will likely contribute to the long-term industrialization of agriculture and to the decline of family farms. Widespread adoption of herbicide-tolerant plants pose significant social and economic impacts in this country and in the Third World.

HUMAN HEALTH AND ENVIRONMENTAL IMPACTS OF HERBICIDES AND HERBICIDE-TOLERANT CROPS

Herbicides as toxic chemicals

Herbicides are toxic chemicals intended to be poisonous to plants. They are best known to the U.S. public as agents used to defoliate forests in the Viet Nam War, and more recently, to eradicate marijuana and coca plants.

Because plants differ significantly from animals in many morphological and physiological characteristics, one might expect herbicides to have little effect on humans and other animals. And, in fact, many herbicides are not acutely toxic[11] to humans (Murphy, 1986) and wild animals (Hudson et al., 1984). There are, however, exceptions. Humans have died from accidental or suicidal ingestion (Murphy, 1986) or dermal exposure to certain herbicides (Moses, 1988). Acute toxicity testing in animals shows that lethal doses vary from herbicide to herbicide (Hudson et al., 1984). Many of these

[11] Acute toxicity is injury that develops soon after a single large dose is administered.

doses are higher than the levels to which one would normally expect humans or animals to be exposed.

One cannot, however, assume safety of a compound purely on the basis of low acute toxicity of the active ingredient. Commercial formulations of an herbicide, e.g., glyphosate, may contain surfactants which have a higher toxicity than the active ingredients (Sawada et al., 1988; Monroe, 1988). Furthermore, a compound that is not acutely toxic may show chronic toxicity, i.e., causes disease after low-level exposure over a long period. Chronically toxic chemicals can cause significant physiological changes that directly or indirectly lead to birth defects or illnesses such as cancer (Murphy, 1986). Often the symptoms of chronic toxicity do not appear until well after exposure.

Commercial formulations of an herbicide many contain surfactants which have a higher toxicity than the active ingredients.

Very little work has been done on the chronic health effects of the widespread use of herbicides. The limited testing and studies that are available, however, link various weed-killers with cancer, birth defects, central nervous system disorders, behavioral changes, and skin diseases in humans (Nielsen and Lee, 1987; Murphy, 1986; National Research Council, 1987b; U.S. Environmental Protection Agency, Office of Drinking Water, 1985). Strong evidence links alachlor, the herbicide tied with atrazine as the most popular herbicide in current use (Table 8) (U.S. Environmental Protection Agency, Office of Pesticide Programs, 1989), to malignant tumors (U.S. Environmental Protection Agency, Office of Drinking Water, 1985). Alachlor, which is widely used on corn and soybeans, contaminates groundwater in 12 states (Williams et al., 1988).

The limited testing and studies that are available, however, have linked various weed-killers with cancer, birth defects, central nervous system disorders, behavioral changes, and skin diseases in humans.

Phenoxyacetic acid herbicides (e.g., 2,4-D, 2,4,5-T) have been linked with oncogenicity[12] (National Research Council, 1987b) and cancer, i.e., non-Hodgkin's lymphoma (Hoar et al., 1986; Zahm et al., 1988). 2,4-D is the herbicide used in the

[12] An oncogen is a substance which can produce a benign or malignant tumor. A carcinogen produces malignant tumors.

third highest amount in U.S. agriculture (Table 8) (U.S. Environmental Protection Agency, Office of Pesticide Programs, 1989b).

Other studies connect triazine herbicides (e.g., atrazine, cyanazine, simazine) and phenoxyacetic acid herbicides to chronic health effects such as central nervous system disorders (Nielsen and Lee, 1987). Atrazine and cyanazine are herbicides used in the highest and seventh highest amounts, respectively, in U.S. agriculture (Table 8) (U.S. Environmental Protection Agency, Office of Pesticide Programs, 1989b). The Environmental Protection Agency classifies atrazine as a possible human carcinogen[13].

Lack of extensive chronic testing and epidemiological studies probably leads to substantial underestimation of the effects of herbicides on humans and other animals.

Metolachlor, the herbicide used in the fifth largest amounts (Table 8) and also a frequent groundwater contaminant (Williams et al., 1988), is considered a possible human carcinogen (National Research Council, 1987b).

Lack of extensive chronic testing and epidemiological studies (Grue et al., 1986; Hudson et al., 1984; Nielsen and Lee, 1987; National Research Council, 1984) probably leads to substantial underestimation of the effects of herbicides on humans and other animals.

TABLE 8

HERBICIDES USED IN LARGEST AMOUNTS IN U.S. AGRICULTURE*

Alachlor
Atrazine
2,4-D
Butylate
Metolachlor
Trifluralin
Cyanazine
Metribuzin
Glyphosate

* in order of use, from greatest to lowest, except the first two are used in comparable amounts.

U.S. Environmental Protection Agency, Office of Pesticide Programs, 1989b.

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13 C. Giles, U.S. Environmental Protection Agency, Office of Pesticide Programs, telephone conversation with J. Rissler, 2/14/90.

Herbicide residues in food

Residues of herbicides applied in the field remain in food found on our tables. Widespread use of herbicide-tolerant plants will increase the likelihood that additional residues of particular herbicides will contaminate food. Although the government has programs to protect the consumer against dangerous food residues, many critics doubt that the programs are adequate.

Before herbicides and other pesticides are marketed, the Environmental Protection Agency determines a maximum safe level, called a tolerance, for pesticide residues in food (National Research Council, 1987b; Mott and Snyder, 1987). Because the incidence and extent of pesticide contamination of food is not known (U.S. Congress, Office of Technology Assessment, 1988), there remains considerable uncertainty as to whether the tolerance levels set by the Environmental Protection Agency protect public health (National Research Council, 1987b; Mott and Snyder, 1987; U.S. Congress, Office of Technology Assessment, 1988).

Mott and Snyder (1987) maintain that tolerances established by the Environmental Protection Agency may permit unsafe levels of pesticides for several reasons: insufficient health and safety data, incorrect assumptions about current average diets, failure to consider other ingredients that accompany pesticides in formulations and residues, failure to revise tolerances on the basis of new data, and allowing residues of carcinogenic pesticides, even though no "safe" level of exposure to a carcinogen may exist.

Because the incidence and extent of pesticide contamination of food is not known, there remains considerable uncertainty as to whether the tolerance levels set by the Environmental Protection Agency protect public health.

Residues of herbicides and other pesticides in and on food pose a number of human health risks (National Research Council, 1987b). One of these, the oncogenic potential of residues in food has been the subject of only limited testing and evaluation. A National Research Council (1987b) study of oncogenic risk of pesticide residues in food found that herbicides account for approximately 31% of the estimated oncogenic risk of pesticide residues in fresh foods and approximately 12% of the pesticide residue risk in processed food. That study noted that the Environmental Protection Agency classified several herbicides (e.g., alachlor) as probable human carcinogens (i.e., evidence of carcinogenicity from animal studies) and others (e.g., linuron and metolachlor) as possible human carcinogens (i.e., limited evidence of carcinogenicity in the absence of human data).

Where herbicide residues exist with the current levels of herbicide use, it is likely that the use of herbicide-tolerant crops in the nation's food supply will lead to increased residues of particular herbicides. The U.S. Department of Agriculture acknowledges "that these new [herbicide-tolerant] crop varieties might carry more herbicide residues..." (Reilly, 1989, p. 3).

Uncertainties about genetically engineered food

Where herbicide-tolerance has been genetically engineered rather than naturally bred into plants, additional risks must be considered. To genetically engineer plants, scientists isolate genes for herbicide-tolerance from foreign sources and transfer the genes to host plants. In the host plants, the genes are integrated into the genetic machinery, where they enable plants to make new substances. Genetic engineers employ a variety of strategies and genes from different sources to confer herbicide-tolerance on plants.

The U.S. Department of Agriculture acknowledges "that these new [herbicide-tolerant] crop varieties might carry more herbicide residues...."

Scientists could inadvertently render genetically engineered plants harmful or less nutritious. Two concerns are particularly relevant to herbicide-tolerant plants. First, genes conferring herbicide tolerance will often be transferred from organisms not used for human food. It cannot be assumed that the transferred genetic material will produce substances safe for human consumption (International Food Biotechnology Council, 1989). Second, when scientists transfer foreign genetic material to a plant, they generally cannot control where in the plant's genetic material the foreign genetic material is inserted. Herbicide-tolerance genes could be inserted so that they interfere with the functioning of plant genes, disrupting plant metabolism. As a result, some genetically engineered plants might be less nutritious or even produce higher levels of natural plant toxins than non-engineered plants (Wickelgren, 1989).

Because genetic engineering is relatively new, no one knows how often these concerns will materialize. Particularly when herbicide-tolerant crops are intended as human food, however, these possibilities should be examined <u>before</u> herbicide-tolerant crops are permitted on the dinner table.

The Food and Drug Administration is entrusted with assuring the safety of our food supply. Although agency officials have been discussing issues related to genetically engineered foods for years, to date they have failed to announce any specific procedures that they will employ to screen genetically engineered foods for their safety and nutritional value.

Herbicide contamination of drinking water

In 1985, groundwater provided drinking water for 53% of the U.S. population; surface water[14] provided the remaining 47% (U.S. Department of Interior, Geological Survey, 1988). Public water suppliers obtain 60% of their water from surface bodies and 40% from groundwater (Solley et al., 1988).

In 1988, the Environmental Protection Agency reported that 74 pesticides had been detected in the groundwater of 38 states. Of this total, normal agricultural use (i.e., non-point sources) accounted for leaching of 46 different pesticides into the groundwater of 26 states.

Groundwater provides 97% of drinking water for rural populations (U.S. Geological Survey, 1988). Surface water and groundwater are contaminated with pesticides, including herbicides, though the incidence, extent, and health implications are unknown (U.S. Congress, Office of Technology Assessment, 1984; U.S. Environmental Protection Agency, Office of Water, 1987; Nielsen and Lee, 1987; Schmidt, 1988; U.S. Department of Interior, Geological Survey, 1988).

In 1988, the Environmental Protection Agency reported (Williams et al., 1988; U.S. Environmental Protection Agency, Office of Public Affairs, 1988) that 74 pesticides had been detected in the groundwater of 38 states. Of this total, normal agricultural use (i.e., non-point sources) accounted for leaching of 46 different pesticides into the groundwater of 26 states. Of the twenty-one herbicides among the pesticides detected, atrazine, alachlor, simazine, cyanazine, metolachlor, metribuzin, trifluralin, and dinoseb were among the most frequently detected. The Agency notes that many agricultural areas were not sampled in the survey.

A survey of groundwater contamination by triazine herbicides (atrazine and others) in the High Plains Aquifer in Nebraska showed that 32% of the samples from 6 Nebraska counties contained detectable concentrations of the triazines (Chen and Druliner, 1988). The report concluded that the quality of shallow groundwater was affected by the application of triazine herbicides at the surface. Hallberg et al. (1987) estimate that 25% of Iowans drink water containing pesticide residues. The 1988

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[14] Surface water included rivers, streams, lakes, estuaries, waterways, coastal waters, and reservoirs.

Environmental Protection Agency figures on groundwater contamination (Williams, et al., 1988) show an increase--both in numbers of pesticides detected and the number of states where detections occurred--over earlier reports (U.S. Congress, Office of Technology Assessment, 1984; Nielsen and Lee, 1987). Additional increases can be expected as monitoring continues and is expanded.

Several of the herbicides mentioned most frequently as groundwater contaminants--atrazine, other triazines, metribuzin, metolachlor, trifluralin--are the subject of herbicide-tolerance research.

Agricultural runoff is an important non-point source of common pollutants of surface water; yet, neither the Environmental Protection Agency nor most states know the kinds or amounts of pesticides in surface waters (U.S. Environmental Protection Agency, Office of Water, 1987). One state, Ohio, recently sampled surface water supplies for alachlor and metolachlor, two of the most commonly used herbicides in Ohio. Twenty surface water supplies, of 163 sampled, were positive for the two herbicides (Ohio Environmental Protection Agency, 1987). Additional monitoring will no doubt reveal additional contamination of surface water.

Several of the herbicides mentioned most frequently as groundwater contaminants--atrazine, other triazines, metribuzin, metolachlor, trifluralin--are the subject of herbicide-tolerance research (Tables 4 and 7). Widespread use of plants tolerant to herbicides would likely increase the severity and incidence of ground and surface water contamination.

Farmer and farmworker illnesses

Farmers and farmworkers are exposed to more and higher levels of pesticides that any other segment of the population. They mix, load, and apply pesticides; they cultivate and harvest crops covered with pesticides; they drink water contaminated by pesticides; they bathe in irrigation water containing pesticides; they eat fresh produce soon after harvest when pesticide residues are higher. Their homes and their children's playgrounds are subject to direct pesticide applications or drift of pesticides from adjacent fields (Moses, 1988).

Yet there is little information on the incidence or extent of exposure of farmers and farmworkers to pesticides. Nor is much known of the magnitude of chronic health problems related to occupational exposure to pesticides (Moses, 1988). The lack of information derives from insufficient chronic toxicity testing of pesticides (National Research Council, 1984), failure to maintain adequate records of pesticide exposures, the long period of latency between exposure and some effects such as cancer (Moses, 1988), and the difficulties of conducting meaningful epidemiological studies on populations exposed to high and low doses of many different toxicants over a period of many years.

Bromoxynil causes birth defects in laboratory animals and may pose birth-defect risks for pesticide mixers, loaders, and applicators, i.e., farmers and farmworkers who apply bromoxynil.

A few studies have, however, explored possible connections between herbicide exposure and chronic health effects. As mentioned above, Hoar et al. (1986) found that the relative risk of non-Hodgkin's lymphoma among white male Kansans increased significantly with the number of days of herbicide exposure per year, especially to phenoxyacetic acids such as 2,4-D. A study in Nebraska showed a three-fold increase in non-Hodgkin's lymphoma risk associated with exposure to 2,4-D more than 20 days a year (Zahm et al., 1988).

Recently, the Environmental Protection Agency cancelled registration of some bromoxynil-containing herbicide formulations and imposed measures to reduce the risks to users of other bromoxynil formulations (U.S. Environmental Protection Agency, Office of Pesticide Programs, 1989a; U.S. Environmental Protection Agency, Office of Public Affairs, 1989). Bromoxynil causes birth defects in laboratory animals and may pose birth-defect risks for pesticide mixers, loaders, and applicators, i.e., farmers and farmworkers who apply bromoxynil (U.S. Environmental Protection Agency, Office of Public Affairs, 1989).

The toll of herbicides on wildlife and their habitats

Ecosystems most affected by herbicides are those subject to direct applications, those adjacent to treated areas, and aquatic ecosystems that receive runoff from treated areas (Pimentel and Levitan, 1986). In general, the direct and indirect effects of pesticides, including herbicides, on wild animals and their habitats are not well understood (Smith, 1987; Hudson et al., 1984).

Pimentel and Levitan (1986) note that pesticides alter structure, function, and productivity of ecosystems. Herbicides, for example, are likely to eliminate certain plant species. Animal populations that depend on those plant species for food and cover may be eliminated or significantly reduced in that ecosystem--leading perhaps to further disruptions of the ecosystem (McEwen and DeWeese, 1987; Grue et al., 1986). Herbicides that accumulate in aquatic systems due to runoff, such as atrazine (Hamilton et al., 1988), can kill phytoplankton--reducing the productivity of lakes and streams.

Although one could reasonably expect that some herbicides and other pesticides cause cancer, birth defects, and reproductive and behavioral changes in wild animals, few researchers have investigated these connections.

Sometimes, the so-called "inert" ingredients included in herbicide formulations are more toxic to wildlife or their habitats. For example, some popular formulations of glyphosate contain a surfactant toxic to some developing fish and other aquatic organisms (Monroe, 1988; Folmar et al., 1979).

Eliciting herbicide-resistant weeds

In the late 1960's, the first case of evolution of weeds resistant to a herbicide--in this case atrazine--was noted. Since then, LeBaron (1989) reports that more than 50 different weeds are known to have developed resistance to atrazine and resistance to 14 other types of herbicides has also evolved.

Widespread use of herbicide-tolerant crops--with their associated potent herbicides--will exert significant pressure on additional populations of weeds to develop resistance to the herbicides.

In recent years, weeds have rapidly, and unexpectedly, evolved resistance to the new generation of low-dose herbicides--the sulfonylureas and imidazolinones. Weed resistance problems with these new herbicides threaten their once-touted capacity to replace older, more toxic herbicides. Weed specialists are already urging farmers not to replace but rather to mix the newer herbicides with older, more toxic ones like 2,4-D (Gianessi and Puffer, 1989; Brosten, 1988). The mixing is intended to reduce the rate at which weeds evolve resistance to the new herbicides.

Repeated and prolonged exposure of weeds to potent herbicides is a major factor in the evolution of weeds resistant to that herbicide (Gressel, 1986; Brosten, 1988). Already, resistant weeds have evolved to three of the major groups of herbicides to which herbicide-tolerant crops are being sought: triazines, sulfonylureas, and imidazolinones. Widespread use of herbicide-tolerant crops--with their associated potent herbicides--will exert significant pressure on additional populations of weeds to develop resistance to the herbicides.

Interbreeding with related weeds

"The sexual transfer of genes to weedy species to create a more persistent weed is probably the greatest environmental risk of planting a new variety of crop species"

(Goodman and Newell, 1985, p. 51). The risk is particularly serious when the genes that may be transferred are herbicide-tolerance genes. Transfer of herbicide tolerance to weedy species could make weeds even more difficult to control (Goodman and Newell, 1985), since certain chemicals could not applied even in integrated pest management programs.

"If cultivated crops even have a limited opportunity to cross with related wild, weedy relatives, the escape of engineered genes that might prove beneficial to the weed is virtually inevitable."

Pollination is the most likely way that herbicide-tolerance genes would be transferred from a crop plant to other plants in the environment. Cross pollination can occur from a herbicide-tolerant crop to closely related weeds (either of the same species or sexually compatible weeds of another species) growing nearby (within the range of pollen dispersal) (Goodman and Newell, 1985). Wheat, rice, barley, corn, sorghum, oats, and potatoes are among the crops that have close weedy relatives (Harlan, 1982).

According to Norman Ellstrand of the University of California, "If cultivated crops even have a limited opportunity to cross with related wild, weedy relatives, the escape of engineered genes that might prove beneficial to the weed is virtually inevitable" (Ellstrand, 1988, p. S30). David Ehrenfeld of Rutgers University confirms that "it will only be a few growing seasons before we can expect to see this engineered herbicide resistance transferred naturally, in the field, to the weeds themselves" (Ehrenfeld, 1987). This is a particular problem in places like South America where domesticated crop species, such as potatoes (Astley and Hawkes, 1979), may be cultivated in close proximity to wild and weedy relatives (Levin, 1988).

Herbicide-tolerant trees

Substantial negative environmental effects can be expected with widespread use of herbicide-tolerant trees in forestry. In addition to the effects of herbicides on wild animals and their habitats, noted above, the use of herbicide-tolerant trees could also affect the long-term productivity of forests.

In areas planted with tree seedlings after clear-cutting, "pioneer" vegetation--brambles, shrubs, vines--rapidly grows over the newly opened area and competes with the seedlings. It is this pioneer vegetation that herbicides are often used to suppress. In a famous experiment at Hubbard Brook Forest, scientists clear-cut a section of a watershed and prevented regrowth of plants with herbicides. Without pioneer plants to stabilize the soil, nutrients were washed away and the quality of the site rapidly diminished (Bormann and Likens, 1979). Widespread use of herbicides and herbicide-tolerant trees for suppression of pioneer vegetation will likely contribute to long-term deterioration of forests.

It is ironic that the Forest Service is developing herbicide-tolerant trees at the same time as a lawsuit settlement[15] has forced the Pacific Northwest management region of the Forest Service, and the northwest office of the Bureau of Land Management, to prepare environmental impact statements that consider the effects of vegetation management practices on natural ecosystems, as well as timber production. The Forest Service's final impact statement promotes reduction of herbicide use as the preferred alternative for vegetation management.

Herbicide-tolerant trees may make short-term economic sense for foresters, but they are incompatible with land stewardship and long-term economic productivity. Using them in government forests would be a strong expression of timber primacy--the idea that our national forests are managed for timber production, not conservation and recreation.

SOCIAL AND ECONOMIC IMPACTS OF HERBICIDE-TOLERANT CROPS FOR U.S. FARMERS

In addition to risks to human health and the environment, the widespread use of herbicide-tolerant crops will also have social and economic impacts in U.S. agriculture.

Industry expects herbicide-tolerant plants to be a profitable venture. A recent market forecast published in Genetic Technology News (1989, p. 8) estimates that the U.S. market for herbicide-tolerant seeds for corn, cotton, rice, soybeans, and wheat, alone, will be $320 million in five years, and concludes, "We feel that companies that are successful in developing commercial strains of herbicide-resistant crops will be able to sell them at a premium."

Yet, considerable uncertainty surrounds the adoption of many herbicide-tolerant crops in U.S. agriculture. Early reports indicate that crops developed for tolerance to herbicides may produce lower yields. In the case of canola (rapeseed), the herbicide-tolerant varieties have lower yields and reduced fertility (Genetic Engineering Letter, 1987; AgBiotechnology News, 1988; Forcella, 1987).

Also, the price may discourage adoption. The patent status of herbicides in an herbicide/tolerant seed package will affect price. The development of crop varieties tolerant to a patent-protected chemical would likely create a more profitable position for

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[15] Northwest Coalition for Alternatives to Pesticides et al. v. Block et al. U.S. District Court, Oregon, 1984.

the manufacturer, at greater cost to the farmer. For example, Monsanto's glyphosate, an expensive herbicide for which many tolerant plants are sought, has recently had its patent extended and will therefore remain costly.

Herbicide-tolerant crops may well be a bonanza for the chemical companies but what will they mean for farmers' income? If herbicide-tolerant crops are adopted, economic benefits are more likely to flow to the chemical/seed companies than to farmers. Dennis Keeney, agronomist and Director of the Leopold Center for Sustainable Agriculture, Iowa State University, evaluated the potential economic impacts of herbicide-tolerant crops for U.S. farmers as follows (Iowa Groundwater Association newsletter, December 1989, p. 3):

> The economics of this technology are no more defensible than its environmental ramifications. A recent study [Tauer and Love, The potential economic impact of herbicide-resistant corn in the USA, J. Prod. Agric., 202, 1989] indicated that complete control of weed losses with this technology, when compared to current herbicide techniques, would increase yields by 2 to 4 percent, add to the current grain surpluses, and lower corn prices by as much as $.30 per bushel. If herbicide-resistant crop varieties generate additional income, little will end up in the pockets of farmers.

In addition to their economic impacts, herbicide-tolerant crops could also have important social impacts on farmers and the rural communities they support. If successful, availability of herbicide-tolerant crop varieties could facilitate the trend toward bigger and fewer farms, by reducing the need for mechanical weed control and thereby enabling a given number of people to farm more acres with a fixed amount of labor and management.

"The economics of this technology are no more defensible than its environmental ramifications. If herbicide-resistant crop varieties generate additional income, little will end up in the pockets of farmers."

Dennis Keeney, agronomist and Director of the Leopold Center for Sustainable Agriculture, Iowa State University

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Adoption of herbicide-tolerant crops could accelerate the shift in the value-added process in agriculture from farms to corporations by reducing the role of farmers in weed control and increasing the role of purchased inputs--seeds and herbicides. Concomitantly, a smaller share of gross farm income would likely be retained by farmers in the form of returns to labor and management. Fewer dollars would support fewer people in agriculture (Hassebrook and Hegyes, 1988).

Increased concentration in agriculture could lead to social and economic decline in rural communities, as described by University of California Anthropologist Dean MacCannell (1983) in his review of research on social impacts of the industrialization of agriculture:

> As farm size and absentee ownership increase, social conditions in the local community deteriorate. We have found depressed median family incomes, high levels of poverty, low education levels, social and economic inequality between ethnic groups, etc., associated with land and capital concentration in agriculture.... Communities that are surrounded by farms that are larger than can be operated by a family unit have a bi-modal income distribution with a few wealthy elites, a majority of poor laborers, and virtually no middle class. The absence of a middle class at the community levels has a serious negative effect on both the quality and quantity of social and commercial services, public education, local governments, etc.

THIRD WORLD IMPACTS OF HERBICIDE-TOLERANT CROPS

The potential market for herbicide-tolerant seeds extends far beyond the United States to other industrialized countries and to the Third World. Incorporation of herbicide-tolerant crops into agricultural systems in other countries would bring similar impacts to those we have discussed above in relation to U.S. agriculture. Widespread adoption of herbicide-tolerant crops in the Third World could erode genetic diversity of crop and wild plants and exacerbate pesticide-caused human health and environmental problems.

The introduction of herbicide-tolerant crops in the Third World is particularly troubling for several reasons.

Exacerbating genetic erosion

For decades, plant breeders have used the genetic resources found in traditional crop varieties and their botanical relatives to help agriculture evolve and adapt to ever changing needs and conditions. Third World countries are the primary source of such genetically diverse plants. These genetic resources are essential for maintaining disease and pest resistance in modern crops. The trend in recent decades, however, has been toward the loss of this crucial Third World diversity. When modern high-yielding crop varieties were first introduced into many parts of the Third World on a large scale during the Green Revolution of the 1960's and 1970's, farmers adopted these new varieties, and many old varieties became extinct.

With the advent of biotechnology, a second wave of new and attractive crop varieties will be offered to Third World markets. Without adequate programs for collection and conservation of crop genetic resources, the current "gene revolution" could usher in a new and perhaps more destructive era of genetic erosion. To the extent that herbicide-tolerant varieties are widely marketed and cultivated in the Third World, these products also threaten to displace existing varieties. In some areas, this could contribute to the extinction of traditional landraces and cultivars.

Interbreeding with wild relatives

As noted above, herbicide-tolerance genes are likely to be transferred by pollen from herbicide-tolerant crops to any nearby weedy relatives. This problem will be particularly serious in Third World countries, which are the sites of origin of all major food crops, and thus are likely to be home to their weedy relatives. If herbicide-tolerant crops, such as potatoes and wheat, were introduced in countries where they originated, transfer of herbicide-tolerance to weedy relatives would be expected.

Human health and environmental risks

The increased use of some herbicides, which would likely accompany the use of herbicide-tolerant varieties, raises concerns about the health of agricultural workers and environmental problems associated with pesticide use (as detailed above). In many areas of the Third World where regulations governing the labeling, proper use and application of agricultural chemicals are notoriously lax, increases in problems associated with herbicide use would be especially severe.

4

FALSE PROMISES

Despite the fact that herbicide-tolerant crops will not reduce our dependence on chemicals and seem most likely to increase it, proponents of herbicide-tolerant crops, nevertheless, argue that herbicide-tolerant crops will have environmental benefits. These arguments, examined below, are seriously flawed.

THE PROMISE: Herbicide-tolerant crops will promote use of "environmentally benign" pesticides.

Probably the most frequently articulated argument for genetically engineering crops to tolerate new herbicides is that such crops will permit the replacement of older, more dangerous herbicides with newer, more "environmentally benign" ones (Sun, 1986; Anthan, 1989a; Benbrook and Moses, 1986). Proponents offer this as an environmental silver lining to the prolonged use of herbicides. According to this argument, the availability of crops tolerant to these herbicides will allow a shift away from the widely used, persistent, and toxic herbicides--alachlor, atrazine, and 2,4-D--to supposed "better" classes of herbicides--imidazolinones, glyphosate, sulfonylureas, glufosinate, and bromoxynil.

THE REALITY: The promise fails on several levels.

1) Herbicide tolerance is currently being sought for older, more toxic herbicides. Market incentives exist to increase markets for both older and newer herbicides.

2) The newer herbicides cannot be properly considered "environmentally benign."

3) Rapid evolution of weeds resistant to a number of the newer herbicides make it unlikely that they will replace older, more toxic herbicides.

First, herbicide tolerance is already being sought for several older, more toxic herbicides--reflecting that there is plenty of incentive to protect and increase markets for the old as well as the new herbicides. Many companies and universities have developed or are developing crops tolerant to a number of the older, more toxic, more persistent herbicides, such as metribuzin, atrazine, other triazines, metolachlor, and 2,4-D (Tables 4 and 7). Atrazine-resistant canola is already commercially available (Forcella, 1987). Among these herbicides--as noted in Chapter 3--are groundwater contaminants and possible carcinogens.

Second, the newer herbicides cannot be properly considered "environmentally benign." At a minimum, all are toxic to plants and therefore can threaten wildlife habitat because of drift or direct applications. In addition, serious environmental or human health problems have arisen with many so-called "benign" herbicides. For example:

* The Environmental Protection Agency recently canceled registration of some bromoxynil-containing formulations and imposed restrictions on users to reduce the risks to users of other formulations containing the herbicide. Laboratory tests show that bromoxynil causes birth defects in animals and may pose developmental risks for users of the herbicide (U.S. Environmental Protection Agency, Office of Pesticide Programs, 1989a; U.S. Environmental Protection Agency, Office of Public Affairs, 1989).

* A sulfonylurea, chlorsulfuron (Glean) and an imidazole (Scepter) are among the newer, low-dose herbicides that persist so long in the environment that they harm subsequent crops (Gianessi and Puffer, 1989; Looker, 1989a and b).

* So-called "inert" ingredients in some formulations of glyphosate are toxic to some developing fish and other aquatic organisms (Monroe, 1988; Folmar et al., 1979).

* Sulfonylureas are toxic to plants in minute quantities, and they do not degrade especially quickly, so that slight pesticide drift can have disastrous consequences for crops and native vegetation. In Franklin County, Washington, for example, potatoes, carrots, fruit trees, and other crops were damaged after a sulfonylurea herbicide was applied to roadsides (Tsalaky, 1985).

Third, rapid evolution of weeds resistant to a number of the newer herbicides, e.g., the sulfonylureas and the imidazoles, makes it unlikely they will replace the older herbicides. As discussed above, weed scientists are already recommending that farmers use the newer herbicides mixed with an older, more toxic one like 2,4-D (Giannessi and Puffer, 1989; Brosten, 1988).

THE PROMISE: Herbicide-tolerant crops will reduce the amount of herbicide use.

Proponents argue that herbicide tolerance will enable farmers to switch to new products effective at lower application rates than were required with older herbicides and thereby reduce the number of products and applications necessary for effective weed control (Anthan, 1989b; Benbrook and Moses, 1986).

THE REALITY: Herbicide-tolerant plants will not reduce the "plant-killing power" of herbicides applied in the environment; they may only allow a reduction in the weight of the chemical applied. Herbicide-tolerant crops and trees will increase the use of certain herbicides and will perpetuate agriculture's dependence on herbicides.

Proponents argue that herbicide-tolerance to newer, low-dose herbicides will mean decreases in herbicide use. This is a weak argument. Increased use of low-dose herbicides will mean a decrease in the pounds of active herbicide ingredients added to the environment but only because low-dose herbicides are extremely potent. A similar amount of acreage will still be treated with herbicides.

Furthermore, problems associated with herbicide drift are exacerbated with low-dose herbicides, small amounts of which provide the same "plant-killing power" as large amounts of high-dose herbicides. Drift of low-dose herbicides means more "plant-killing power" drifting to wildlife habitats and to adjacent fields with potentially sensitive crops.

Widespread adoption of crops tolerant of particular herbicides will mean increased applications of the particular herbicides to which the crops are tolerant. Industry has made it clear that increasing market share for particular herbicides is the motivation behind the development of herbicide-tolerant crops. For example, tolerance to atrazine will clearly increase use of atrazine. One of the major factors limiting atrazine application has been the problem of atrazine carryover. The compound persists in the soil and can damage subsequent plantings of crops such as soybeans and oats. The development of herbicide-resistant soybeans will allow three times as much atrazine to be applied to corn without damage to subsequent soybean crops, according to seed industry consultant James Kent (Halas Steel, 1987).

Furthermore, in some situations, use of herbicide-tolerant crop varieties may blunt the economically motivated reduction in herbicide use taking place on many farms.

In Nebraska, for example, the majority of row crop acres receive broadcast application of herbicides (application on the entire field). However, interest is growing in reducing application to a narrow band directly over the row, referred to as banding[16], since weeds between the rows can be controlled by cultivation.

The availability of herbicide-tolerant crop varieties could reverse the trend to reduced herbicide use through banding by enabling farmers to get better weed control with chemicals, and thereby making it feasible to eliminate cultivation between the rows. This might be accomplished through the use of more effective, though expensive, herbicides such as glyphosate or through application of a greater number of herbicides to a given field. The potential for increased herbicide use would be particularly enhanced if herbicide-tolerant crop varieties were used to increase the number of herbicides applied to a given field in pursuit of total chemical weed control.

THE PROMISE: Herbicide-tolerant crops will provide more weed-control options for farmers.

As more herbicide-tolerant crops are developed, farmers growing a particular crop may have a wider variety of herbicides among which to choose. Proponents argue that herbicide-tolerant crops will provide options that allow farmers to make good environmentally sound decisions about herbicide use (Mazur and Falco, 1989; Center for Science Information, 1987).

THE REALITY: Herbicide-tolerant crops could reduce farmers' options by increasing problems with herbicide-resistant weeds.

As herbicide use has increased since World War II, a number of weed species have evolved resistance to herbicides. As mentioned above, over 50 weed species are now documented to resist herbicides, up from just 12 in 1980 (Agrichemical Age, 1989; LeBaron, 1989). If weeds are resistant, herbicides cannot be used when legitimately

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[16] Alex Martin, University of Nebraska Extension Weed Specialist, telephone conversation with C. Hassebrook, 2/2/90.

needed, such as in weed management programs (see Chapter 5). These problems are not limited to widely used herbicides that have been used for decades, such as the triazines (LeBaron, 1989); weeds resistant to sulfonylurea herbicides evolved after only a few years of use (Agrichemical Age, 1989; Gianessi and Puffer, 1989). If a shift to herbicide-tolerant crops led to greater use of certain herbicides such as the sulfonylureas, problems associated with resistant weeds would likely increase.

Resistant weeds could also blunt any substantial shift to use of low-dose herbicides, that, as discussed above, herbicide-tolerant crop proponents argue will result from use of herbicide-tolerant crops. To slow the evolution of sulfonylurea-resistant weeds, some pesticide experts already recommend that sulfonylureas be mixed with the older, more toxic herbicides such as 2,4-D (Brosten, 1988; Agrichemical Age, 1989; Gianessi and Puffer, 1989). If use of herbicide-tolerant crops promotes the evolution of resistant weeds, such mixing could become increasingly necessary.

THE PROMISE: Herbicide-tolerant crops are necessary to promote soil conservation.

Herbicides, instead of mechanical tillage, are currently used to kill weeds in no-till farming systems. Because expanses of loose bare soil are never exposed, conservation tillage or no-till systems have lower rates of soil erosion than many conventional farming systems. Weed control problems have been a barrier to adoption of no-till systems. Proponents of herbicide-tolerant crops argue that adoption of no-till farming systems would increase if herbicide-tolerant crops were available (Netzer, 1984; Benbrook and Moses, 1986).

THE REALITY: Herbicide-tolerant crops are not necessary to promote soil conservation.

Control of soil erosion is vital to the long-term productivity of U.S. agriculture. But there are tillage options which provide the soil conservation benefits of no-till without the excessive herbicide-reliance of no-till. For example, ridge-till systems can provide soil conservation benefits nearly equal to no-till, with less reliance on herbicides. University of Nebraska researchers estimate that ridge till provides an 86% erosion reduction relative to moldboard plowing versus a 92% reduction for no-till (Dickey et al., 1988). Ridge-till farmers such as Dick Thompson have accomplished effective weed control with minimal use of herbicides (National Research Council, 1989). A broad range of practices provides erosion control without the herbicide dependence of no-till, including use of cover crops, contour farming, terracing, strip cropping, and crop rotation, to name a few.

5

THE BETTER CHOICE: SUSTAINABLE AGRICULTURE

Since herbicide-tolerant crops are clearly the wrong choice for weed control, what alternatives do farmers have to manage weeds? The better choice is weed management options developed in the context of sustainable agriculture.

SUSTAINABLE AGRICULTURE--THE BETTER CHOICE

Sustainable agriculture, also known as alternative agriculture or low-input sustainable agriculture (LISA), encompasses ways of farming that "combine responsible stewardship of natural resources with farm profitability" (Keeney, 1989). A recent report Alternative Agriculture by the National Research Council of the National Academy of Sciences (1989a) attempted a definition of sustainable agriculture in terms of its goals. It described the goals of sustainable agriculture systems as:

* Enhanced use of natural systems, such as nitrogen fixation, in the agricultural production process;

* Reduced use of off-farm inputs, such as pesticides, that pose significant threats to the environment or human health;

* Greater use of existing biological and genetic potential of plants and animals;

* Improved accommodation between cropping patterns and the climatic and physical limitations of agricultural lands;

* Profitable and efficient production emphasizing improved management and conservation of natural resources, such as soil, water, wildlife, and wildlife habitats.

A major fear and criticism of sustainable agriculture systems is that they are not profitable. Yet, the National Research Council (1989a, p. 5) found:

> A small number of farmers in most sectors of U.S. agriculture currently use alternative farming systems, although components of alternative systems are used more widely. Farmers successfully adopting these systems generally derive significant sustained economic and environmental benefits. Wider adoption of proven alternative systems would result in even greater economic benefits to farmers and environmental gains for the nation.

SUSTAINABLE WEED MANAGEMENT METHODS

As with other aspects of agriculture, farmers who practice sustainable agriculture have a different "mindset" about weeds than most farmers who use more conventional methods. Alternative agriculture emphasizes weed management, not weed control, and acknowledges that "the presence of weeds in crop fields cannot be automatically judged damaging and in need of immediate control" (Altieri, 1988).

Weed management is similar, in concept, to integrated pest management (IPM) strategies that developed in the late 1960's to control insect pests. These alternative strategies for insects developed as entomologists realized the harm arising from almost total dependence on insecticides to control the pests. In the last decade, weed scientists have developed similar integrated approaches for keeping weeds at acceptable levels (Altieri and Liebman, 1988).

Management strategies are based on substantial amounts of biological, agronomic, and ecological data and rely heavily on natural mortality factors such as natural biological enemies (e.g., weed pathogens, weed-eating insects) and weather. In practice, IPM uses a variety of mechanical, cultural, and biological methods (discussed below), as warranted. Weed management programs may use herbicides, but only after systematic monitoring of weed populations and natural control factors indicate a need. Ideally, a management program considers all available actions, including no action; evaluates the potential interaction among various control tactics, cultural practices, weather, other pests, and the crop to be protected; and adjusts farming practices to avoid a recurrence of the problem.

The paragraphs below explain some of the methods available for use in sustainable weed management programs.

Mechanical methods

Mechanical methods are among the oldest weed control methods--dating back to the earliest forms of tilling used in agriculture. Physical means of disrupting soil to dislodge weedy plants or to reduce weed seed germination are still used in some form and to varying extent by most farmers today.

A range of implements exists to provide weed control at various stages in crop development (pre-plant or post-plant), at various stages of weed development (pre-emergence or post-emergence), and with varying amounts of herbicides (from none to large). Moldboard plowing, dragging, rotary hoeing, ridge tilling, and other practices provide farmers with alternatives for varying the nature and degree of soil disruption. Choices depend upon weather, soil type, weeds, crop, costs, and other methods available to combine with cultivating (Granatstein, 1988).

Ridge tilling is an example of a cultivation method that reduces or eliminates use of chemicals, including herbicides, while retaining many important features of conservation tillage. Designed for row crops, ridge tilling and planting confines the crop plants to ridges that are alternately built up and torn down by a ridge-till cultivator to control the weeds and enhance crop growth.

Ridge tilling reduces costs, use of chemicals, and soil erosion by mechanically eliminating weeds, focusing chemical applications on the ridges, minimizing the number of times the field must be cultivated, and preventing compaction associated with conventional tillage (Granatstein, 1988; Heller, 1988). Though ridge tilling is not appropriate for all farms and farm systems, it does provide many farmers with an alternative that enables them to reduce herbicide use without forfeiting weed control (Delmarva Farmer, 1988; Granatstein, 1988; Heller, 1988). In some cases, ridge tilling has enabled farmers to completely eliminate herbicides.

Cultural methods

Cultural methods involve manipulation of the growth environment to avoid, eliminate, or reduce competition from weeds. Examples include:

* Crop rotation to discourage weeds that accompany particular crops (Granatstein, 1988);

* Taking advantage of natural plant competition through cover crops and intercropping (Gliessman, 1987; Granatstein, 1988; Hinkle, 1983); and

* Timing of tillage and/or planting, e.g. to take advantage of differences in timing of weed and crop seed germination (Granatstein, 1988; Hinkle, 1983).

Crop rotation discourages weeds that flourish along with the continuous culture of a particular crop--weeds that have a life cycle similar to that of the crop (Granatstein, 1988). Different combinations of tillage methods and rotations can be used to suppress weeds (Granatstein, 1988; Hinkle, 1983).

Natural plant-plant competition is due, at least in part, to "allelopathic" chemicals, substances produced and released by certain plants which inhibit other plants (Tschirley, 1987). These chemicals account for some of the weed-inhibiting properties of certain cover crops (e.g., rye and barley) (Blum, 1986; Doyle, 1986; Granatstein, 1988) and intercropping systems (i.e., growing two or more crops in the same field) (Hinkle, 1983; Granatstein, 1988).

Biological methods

Biological methods include using weed pathogens and herbivores to reduce weeds, and breeding crop species to reduce the competitive effects of weeds (e.g., enhance allelopathic properties of crop plants).

Tschirley (1987) lists a number of weeds that have been successfully controlled by plant pathogens: northern jointvetch, milkweed vine, spurred anoda, prickly sida, velvetleaf, sicklepod, and winged waterprimrose. Two plant pathogenic fungi are registered as herbicides: Phytophthora palmivora, trade name DeVine, controls the milkweed vine in citrus groves; and Colletotrichum gloeosporioides, trade name Collego, controls northern jointvetch in rice and soybean (Charudattan, 1983).

In certain circumstances weeds have been controlled by herbivorous insects, e.g., the prickly pear cactus in Australia by an Argentine moth. Of the 300 attempts at introducing insects to control a weed, most are directed at controlling an introduced weed on uncultivated land (Harris, 1988). Many control attempts also involve the importation of a host-specific, exotic plant-eating insect (Andres and Goeden, 1971).

Some current U.S. Department of Agriculture-funded research projects include importation of insects from South America and the Middle East to suppress brush on Southwestern range land, importation of a fly from Greece to control the yellow starthistle on Western lands, and identification of European insects to control leafy spurge in the northern Great Plains (U.S. Department of Agriculture, Agricultural Research Service, 1988).

MORE RESEARCH NEEDED

Achieving the full potential of alternative agriculture will require substantial and sustained research support. For the most part, agricultural research is not now organized to address the needs of sustainable agriculture (National Research Council, 1989) nor does the U.S. Department of Agriculture provide adequate support for those researchers trying to develop successful alternative systems. Since 1988, the first year for funding LISA (Low Input Sustainable Agriculture) research, Congress has allocated a total of only $12.8 million[17].

To develop an agricultural system for long-term economic stability and land stewardship, the priorities of taxpayer-supported research must be shifted from conventional, chemical-based agriculture to alternative agriculture. These new approaches need sophisticated and continuing research support. With the same massive

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[17] Neil Schaller, Program Director, LISA Research and Education, telephone conversation with M. Mellon, 2/90.

support now provided chemical agriculture, these new approaches could lead to environmentally sound pest control. Even if the money now being spent on herbicide tolerance in the public sector alone were redirected to new approaches to weed management, the benefits to society in the form of farm profitability and environmental protection surely far outdistance the strategy of herbicide tolerance.

To develop an agricultural system for long-term economic stability and land stewardship, the priorities of taxpayer-supported research must be shifted from conventional, chemical-based agriculture to alternative agriculture.

Additional research is particularly needed in the following areas to reduce dependence of growers on herbicides for weed control:

* Development of practical integrated pest management programs;

* Breeding of crops resistant to competition from weeds;

* Breeding of row crops well suited to mechanical weed control, including varieties which germinate and emerge quickly;

* Encouragement of natural weed predators and antagonists through maintenance of biological diversity;

* Development of alternatives to herbicide use under conservation tillage systems, particularly ridge till and other systems employing light tillage for weed control while leaving crop residues on the surface to control erosion;

* Use of cover crops and crop rotations for weed control, including breeding improved cover and rotation crops and development of new uses/markets for such crops;

* Understanding the interactions between living organisms, environmental conditions, and farming practices in agriculture ecosystems to enable farmers to choose combinations of farming practices and cropping systems which produce desired results;

* Development of innovative cultural techniques that favor lower inputs and increase profits for farmers;

* Development of integrated systems of farming which use these interactions (Edwards, 1987).

THE THREAT TO SUSTAINABLE AGRICULTURE

Herbicide-tolerant crops are a threat to sustainable agriculture in two major ways. One, their adoption would perpetuate the high chemical dependence of conventional farming. Herbicide-tolerant crops are a part of modern agriculture's "silver bullet" approach--"a fix-it approach that does not reflect a truly integrated understanding of the biological systems that make crop and animal agriculture possible in the first place" (Doyle, 1989). Such solutions to weed control are temporary at best as opposed to an ecological systems approach to weed management.

Second, public funding of research on herbicide-tolerant crops (Chapter 2) is money not spent to develop weed-management strategies that contribute to long-term sustainability and conservation of natural resources. Scarce resources should be shifted away from support of chemically dependent agriculture to sustainable agriculture.

The Leopold Center [for Sustainable Agriculture] does not support the development of herbicide-resistant crop varieties as part of the proper path to sustainability.

Dennis Keeney, Director of the Leopold Center for Sustainable Agriculture, Iowa State University, evaluates (Kenney, 1989, p.3) the contribution of herbicide-tolerant crops to sustainable agriculture as follows:

> Weed control is and will remain a serious impediment to farmers in their efforts to make a living off the land. Expensive inputs predicated on high chemical dependence is not the long-term answer. If we are serious about keeping farming profitable, if we are sincere in our efforts to protect our natural resources, we cannot rely simply on weed control packages that promise greatest convenience and least short-term risk. The Leopold Center does not support the development of herbicide-resistant crop varieties as part of the proper path to sustainability.

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CONCLUSIONS AND RECOMMENDATIONS

This reports asks whether the production of herbicide-tolerant plants is a wise use of the powerful new techniques of modern biotechnology. Our conclusion is that it is not. Not only does it extend our dependence on dangerous chemicals but it diverts us from the path we ought to be taking--the one toward sustainable agriculture.

This report shows that a major objective of companies now employing the new biotechnologies is to produce a new generation of agricultural crops and forest trees that are tolerant to chemical herbicides. It is inescapable that the widespread use of herbicide-tolerant crops and trees will prolong the use of chemical herbicides for weed control. Such products are truly astounding in light of the promises that have been made for a pesticide-free agriculture.

Many popular herbicides, including some to which genetically based tolerance is now being sought, are suspected human carcinogens or potential causal agents of birth defects. Farmers and farmworkers are exposed to these chemicals in their jobs. Most citizens are exposed to them in their food and increasingly in their drinking water. In addition, wildlife is adversely impacted both by exposure to the herbicides and indirectly through disruption of ecosystems.

From a social and economic standpoint, the introduction of herbicide-tolerant crops could exacerbate trends toward economic concentration in agriculture, the decrease in farm numbers, and the deterioration of rural communities. Applied in the Third World, such plants could have unwelcome impacts on human and environmental health and genetic diversity, as well as increasing petrochemical dependence.

Rather than simply continuing to rationalize the chemical pesticide era with the new power of biotechnology, a fundamental shift in public attitude and public policy is needed. Clearly, the National Academy of Sciences, in its report Alternative Agriculture, as well as hundreds of farmers across the United States, have taken the first steps in that direction. But much more is needed. Sustainable agriculture will not succeed if we continue to support misguided investment of limited capital and scarce scientific talent in products such as herbicide-tolerant crops and trees.

Industry and government are both failing to address the serious and prolonged environmental, human health, economic, and social consequences of their research to develop herbicide-tolerant crops and trees. To encourage the research priorities and agricultural policies that will put us on the right path toward a truly sustainable agriculture, we recommend the following:

1) End federal and state support for developing herbicide-tolerant plants;

2) Increase federal and state funding for non-chemical methods of pest control;

3) Target the federal research and experimentation tax credit for corporate research toward socially and environmentally beneficial research and deny the credit for expenditures to develop herbicide-tolerant crops and trees;

4) Change federal farm policy to discourage the use of environmentally damaging agricultural practices;

5) Regulate genetically engineered herbicide-tolerant plants as pesticides;

6) Prohibit the introduction of trees genetically modified to be herbicide tolerant into our national forests and other government lands; and

7) Fully inform Third World countries of the potential negative impacts of herbicide-tolerant crops and trees and urge the Food and Agriculture Organization of the United Nations to develop restrictions on the export of herbicide-tolerant plants.

END FEDERAL AND STATE SUPPORT FOR DEVELOPING HERBICIDE-TOLERANT PLANTS.

The federal and state governments should end their support for research on the development of herbicide-tolerant crops and trees for use in agriculture or forestry. There is no need for scarce public funds and scientific resources to be devoted to the development of products that represent a wrong direction for agriculture.

Congress has an opportunity to change the U.S. Department of Agriculture's commitment to herbicide-tolerant plants as a high research priority (U.S. Department of Agriculture, Joint Council on Food and Agricultural Sciences, 1989). The Research Title of the 1990 Farm Bill will outline the Department of Agriculture's research program for the next five years. We urge Congress to amend that law and stipulate that:

> A primary focus of U.S. Department of Agriculture-sponsored weed control research should be the reduction of herbicide use in agriculture. The Department of Agriculture shall spend no funds to support mission oriented research to develop herbicide-tolerant plants.

Congress should also explore means of revising the U.S. Department of Agriculture's process for setting research priorities. The potential social and environmental consequences of applied research should be evaluated, and public funds should be targeted to socially and environmentally beneficial research.

INCREASE FEDERAL AND STATE FUNDING FOR NON-CHEMICAL METHODS OF PEST CONTROL.

The U.S. Department of Agriculture and states must shift their research priorities away from herbicide-tolerant crops to sustainable methods of pest management.

Funding for the Low Input Sustainable Agriculture Research Program (LISA) should be increased from its fiscal year 1989, 1990, and proposed 1991 level of $4.45 million to $50 million. The ten-fold increase we recommend is similar to the recommendation by the Board on Agriculture of the National Research Council that funding for research on alternative agriculture be increased to $40 million annually (National Research Council, 1989a).

LISA provides competitive grants for research focused on environmentally sound farming systems with reduced reliance on petrochemicals. At the current funding level of $4.45 million, this program accounts for less than 0.5% of the annual federal investment in agricultural research[18]. The expenditure on this program could be more than doubled simply by reprogramming federal funds currently used for genetic herbicide-tolerance research (see Chapter 2).

TARGET THE FEDERAL RESEARCH AND EXPERIMENTATION TAX CREDIT FOR CORPORATE RESEARCH TOWARD SOCIALLY AND ENVIRONMENTALLY BENEFICIAL RESEARCH AND DENY THE CREDIT FOR EXPENDITURES TO DEVELOP HERBICIDE-TOLERANT CROPS AND TREES.

Existing federal tax subsidies for research by private companies (Section 41, Internal Revenue Service Code) to develop herbicide-tolerant crops and trees should be eliminated. The current provision gives a 20% tax credit on the amount by which private firms increase certain research expenditures, relative to expenditures in the previous three years.

In effect, taxpayers pay the tab for 20% of any increase in corporate spending on the development of herbicide-tolerant crops and trees.

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[18] M. Deely, U.S. Department of Agriculture Central Budget Office, telephone conversation with R. Goldburg, 2/27/90.

Congress should explore means of targeting the tax credit toward socially and environmentally beneficial research and deny the credit for expenditures to develop herbicide-tolerant plants.

CHANGE FEDERAL FARM POLICY TO DISCOURAGE USE OF ENVIRONMENTALLY DAMAGING AGRICULTURAL PRACTICES.

The effort to develop herbicide-tolerant crops is symptomatic of larger problems in U.S. agriculture. In particular, subsidies to U.S. agriculture, such as tax incentives and the commodity and set-aside programs favor unsustainable agricultural practices (National Research Council, 1989a; Ward et al., 1989).

Commodity and set-aside programs favor production of particular crops in particular fields year after year. This results in heavy use of agricultural chemicals that are expensive for farmers and builds up insect, weed, and pathogen populations as resistance to overused pesticides develops. These programs should be reformed to remove penalties on farmers who practice low-input sustainable crop rotations. They should be designed to reward stewardship, including reduced petrochemical use. Such reforms would lower the use of farm chemicals and reduce the market for herbicide-tolerant crops.

Analysis of options for reform to subsidy programs is beyond the scope of this paper. However, several studies (e.g., National Research Council, 1989a; Ward et al., 1989; Sustainable Agriculture Working Group, 1990) outline specific steps that could be taken to reduce existing incentives for environmentally damaging practices--including herbicide use.

We urge Congress to change the agricultural subsidy system to provide economic incentives to farmers who practice low-input agriculture.

REGULATE GENETICALLY ENGINEERED HERBICIDE-TOLERANT PLANTS AS PESTICIDES.

Genetically modified crops and trees are not currently regulated for their impacts on herbicide use and their consequent threats to health and the environment described in this report. This is not surprising since prior to the development of modern genetic engineering techniques, genetic modifications of plants did not result in dramatic changes in herbicide use.

These and other environmental effects of genetically engineered organisms would best be addressed by new legislation (Jaffe, 1987; McGarity, 1987; Mellon, 1988). Until such legislation is enacted, however, the Environmental Protection Agency should regulate crops and trees genetically engineered to tolerate herbicides as pesticides under the federal pesticide statute, the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). The Environmental Protection Agency should use FIFRA to scrutinize use of herbicide-tolerant plants for a full range of environmental and health effects, including the effects on herbicide use. In general, herbicide-tolerant plants that promote environmental degradation, including increased pesticide use, should not be registered.

PROHIBIT THE INTRODUCTION OF TREES GENETICALLY MODIFIED TO BE HERBICIDE TOLERANT INTO OUR NATIONAL FORESTS AND OTHER GOVERNMENT LANDS.

In addition to ending their funding for research to develop herbicide-tolerant trees, the U.S. Forest Service and other government agencies should prohibit the introduction of trees genetically modified to tolerate herbicides to our national forests and other government lands.

Two reasons support such a ban. First, the increased use of toxic chemicals that would result from the use of such trees would pose a threat to wild animals, their habitats, and the quality of surface and groundwater. As discussed in the report, use of herbicide-tolerant trees would run counter to a recent environmental impact statement from the Forest Service's Pacific Northwest region. The impact statement promoted a reduction of herbicide use as the preferred alternative for vegetation management.

Second, as we move into the age of genetic engineering, we need to reserve some ecosystems in which human intervention by way of genetic manipulation is minimized. Genetic "improvement" of forest species solely for their economically valuable qualities is generally incompatible with the government's responsibility to conserve biological diversity in forest environments.

FULLY INFORM THIRD WORLD COUNTRIES OF THE POTENTIAL NEGATIVE IMPACTS OF HERBICIDE-TOLERANT CROPS AND TREES AND URGE THE FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS TO DEVELOP RESTRICTIONS ON THE EXPORT OF HERBICIDE-TOLERANT PLANTS.

Members of Third World governments and non-government organizations must be fully informed of the potential negative consequences of importing herbicide-tolerant crops and trees. They must be informed that the adoption in their countries of plants that are genetically modified to tolerate herbicides is particularly problematic because of the substantial risks of interbreeding with wild plant relatives, potential contribution to erosion of crop genetic diversity, and hazards of herbicides to agricultural workers and the environment. Furthermore, capital-intensive technologies, such as herbicide-tolerant crops, are often inappropriate in developing countries and other places where capital is scarce and unemployment high.

The Food and Agriculture Organization of the United Nations is currently developing a Code of Conduct on Biotechnology. We urge that the Food and Agriculture Organization invite representatives of diverse interests, including non-government organizations, to participate in the development of the Code, and that the Code include restrictions on export of herbicide-tolerant plants. We also encourage the widespread dissemination of this report, not only to inform Third World countries of problems with this specific application of agricultural biotechnology, but also to stimulate discussion of the broader social, economic, environmental, and human health impacts of biotechnology in the Third World.

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Appendix A

Brief Explanation of Techniques of Modern Plant Biotechnology

Recombinant DNA:

Enzymes are used to cut a desired piece of DNA from one organism and paste it into another piece of DNA from a bacterial plant disease agent called Agrobacterium (Weising et al., 1988). Because the piece of DNA from Agrobacterium has the natural ability to insert itself into plant DNA, it is used as a vector to carry the cut DNA into plant cells in tissue culture. The resulting recombinant cells can then be regenerated into whole plants. This method can be used to take a gene from any organism and paste it into a wide variety of plants. And, there are other techniques available to insert DNA into plants not susceptible to Agrobacterium.

Thus, with recombinant DNA techniques, once a gene that confers herbicide tolerance is discovered, it can potentially be moved into any other plant species. The ability to transfer genes from widely dissimilar organisms, such as bacteria and animals, to plants is proving especially valuable to researchers developing herbicide-tolerant plants, since some genes that confer herbicide tolerance are in bacteria.

Tissue Culture:

Aggregates of plant cells are grown in a solution of nutrients and hormones (U.S. Congress, Office of Technology Assessment, 1981). By adding herbicide to the tissue culture solution, researchers can screen vast numbers of plant cells for herbicide tolerance. By applying plant hormones, researchers can then regenerate the surviving tolerant cells into whole plants. Cells in tissue culture often exhibit greater genetic variation than whole plants, so tissue culture allows researchers to rapidly select among a wide variety of genotypes.

Protoplast Fusion:

Cells in tissue culture are enzymatically stripped of their cell walls leaving the cell contents, or "protoplasts." Protoplasts can then be combined, bringing the genetic material from two cells into one, and the resulting fusion regenerated into a whole plant (U.S. Congress, Office of Technology Assessment, 1981). Protoplast fusion can be used to combine the genetic material of a cell from a herbicide-tolerant plant with the genetic material of another closely related plant.

Appendix B

Common and Trade Names and Manufacturers of Herbicides*

Common Name	Trade Name	Manufacturer
aciflouren	Blazer/Tackle	BASF/Rhone-Poulenc
alachlor	Lasso	Monsanto
atrazine	several	several
bentazon	Basagran	BASF
bromoxynil	Brominal/Buctril	Rhone-Poulenc
butylate	Sutan/Genate	ICI/Valent
chlorsulfuron	Glean/Telar	DuPont
cinmethylin	Cinch	DuPont
clomazone	Command	FMC
diclofop	Hoelon	Hoechst
dinitroaniline**	several	Compagine Francaise de Produits
dinoseb	several	several
glufosinate	Ignite	Hoechst
glyphosate	Accord/Rodeo/Roundup	Monsanto
haloxyfop	Verdict	DuPont
hexazinone	Velpar	DuPont
imazethapyr	Pursuit	American Cyanamid
imidazoles	Scepter	American Cyanimid
imidazolinones**	several	American Cyanamid
linuron	Lorox	DuPont
metolachlor	Dual	Ciba-Geigy
metribuzin	Lexone/Sencor	DuPont/Mobay
oryzalin	Surflan	Elanco
oxadiazon	Ronstar	Rhone-Poulenc
paraquat	Gramoxone Super	ICI
pendimethalin	Prowl	American Cyanamid
phenmedipham	Betanal	Nor-Am
phosphinothricin	Basta	Hoechst
picloram	Tordon	Dow
pronamide	Kerb	Rohm and Haas
sethoxydim	Poast	BASF
simazine	Princep	Ciba-Geigy
sulfometuron	Oust	DuPont
sulfonylureas**	several	DuPont
terbacil	Sinbar	DuPont
terbutryn	Igran	Ciba-Geigy
thiocarbamate	Reward/Surpass/Vernam	ICI
triazines**	several	several
trifluralin	Treflan	Elanco
2,4-D	several	several

*Not all chemical herbicides are listed. Moreover, many commercial preparations are mixtures, containing two or more chemical herbicides. Additional information is available in books such as Crop Protection Chemicals Reference, which is regularly revised and published by Chemical and Pharmaceutical Press, John Wiley and Sons, NY.

**Class of herbicides