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The First in a Two-Part Series on
Agricultural Inputs and Plant Breeding

HERBICIDE TOLERANCE

ISSUE: The use of genetic engineering to make plants tolerant of the damaging effects of herbicides (weed killers).
IMPACT: Industry focus on the development of herbicide tolerant crops indicates that instead of ending the chemical era in agriculture, biotechnology will be used to extend it. Herbicide tolerance could lead to an increase in the farmers' cost of production; greater risk for agricultural workers; increased environmental damage (especially groundwater contamination); more chemical residues in the food chain; danger of crop loss.
WHEN: Early 1990s.
COUNTRIES AFFECTED: All countries.
PARTICIPANTS: At least 28 enterprises have launched over 65 research programs focusing on herbicide tolerant crop varieties. These include major agrichemical companies: Monsanto, Du Pont, Ciba-Geigy, ICI, Rhone-Poulenc, Bayer, Hoechst, and more (see table).
ECONOMIC STAKES: Market value is expected to exceed $3.1 billion by the mid-nineties and touch $6 billion by the turn of the century.

Introduction

Of the 405 enterprises in 19 countries engaged in the commercialization of new biotechnologies, 103 are working in agriculture. Fifty-one of these are concentrating on agricultural inputs research.[1] Estimates of the market impact of biotechnology on agriculture vary from a low of $12.6 billion[2] to a high of $67 billion[3] on or about the year 2000. Analysts suggest that, shortly after the year 2000, about $12.1 billion of an estimated $28 billion world commercial seed market will contain contributions from biotechnology.[4]

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In recent years media attention has focused on the potential of new, agricultural biotechnologies to develop "super plants" that would require little or no chemicals. The director of research for Monsanto, a leading pesticide producer, predicted that new biological pest controls and hardier plant varieties would turn farm chemical pails into museum pieces within a few decades. In fact, the short and medium-term strategy of the genetics supply industry is to maximize the use of chemicals and use new biotechniques to broaden the applicability of pesticides. One example is the current focus on the development of herbicide tolerant crop varieties.

HERBICIDE TOLERANCE

Genetic engineering makes it possible to transfer herbicide resistant genes found in exotic species into crop varieties. At least 28 enterprises have launched more than 65 research programmes directed toward the development of herbicide tolerant (or resistant) crop varieties. Fifteen major world crops are involved including cotton, maize, potato, rices, sorghum, soybean and wheat[5] as well as some forest species and vegetables. The market value is expected to exceed $3.1 billion by the mid-nineties and touch $6 billion by the turn of the century.[6]

Incentive:

After years of steady growth, the world pesticide industry is falling upon hard times. Faced with lower crop prices, farmers are looking to cut input costs and are especially critical of high chemicals costs. Sales have been declining in the mid-1980s. At the same time, environmentalists have increased their pressure on government regulatory agencies and on the industry. Society has begun to identify important inefficiencies in the performance of the industry. Although more than a billion pounds of toxic active ingredients are poured onto American crops every year, only 1% hits its target. Since the rise of pesticides, 30 species of weeds and 447 species of insects have become tolerant of the chemicals designed to thwart them. The industry itself now estimates that errors in applying herbicides to the US maize, wheat and soybean crops alone cost farmers $4 billion per annum[7].

Given these factors, the focus of research has not been on pest resistant plant varieties but on pesticide resistance (or tolerant) varieties. The orientation is commercially--if not environmentally--logical.

First, the cost of developing a new crop variety rarely reaches $2 million whereas the cost of a new herbicide exceeds $40 million. Thus, it is cheaper to adapt the plant to the chemical than to adapt the chemical to the plant.

Second, the profitability of an existing herbicide is greatly extended if varieties are bred that survive spraying. Adapting plants to chemicals has numerous other advantages. Plant breeding is faster and less subject to government regulation, for example. On the other hand, a herbicide that has survived the regulatory maze will have a long market life. Adding new crops to the chemical's repertoire extends product life expectancy.

The additional economic returns are considerable. If soybeans could be made tolerant of Ciba-Geigy's atrazine herbicides, annual sales could rise an additional $120 million[8]. Monsanto's Roundup is the world's largest selling herbicide, but its use on crop fields is limited because it tends to kill anything green. If tolerant seeds are developed, annual sales of Roundup could increase by $150 million. According to Plant Genetic Systems (a Belgian biotech company), tolerant strains to Hoechst's Basta herbicide would up global sales by $200 million a year. When American Cyanamid developed a new family of imidizolinone herbicides, it contracted to Molecular Genetics to find a gene that would give crops tolerance to the chemical. Once found, Cyanamid gave the gene, gratis, to Pioneer Hi-Bred - the world's largest maize-breeding company. Pioneer has agreed to insert the gene into its hybrids--much to the benefit of Cyanamid[9].

Benefits:

Herbicide manufacturers argue that the use of herbicide-tolerant seeds will be a major saving to farmers since they will have access to more effective chemicals than before and these chemicals will reduce crop losses. As already noted, chemical firms now state that losses from mistakes in crop spraying in the past (including chemical residues in the soil affecting the yield of the following season's crop) cost at least $4 billion per annum. Previously, companies insisted that such damage was minimal.

Concerns:

Although the first genetically-engineered, herbicide-tolerant seeds are not expected on the market until the end of this decade or the beginning of the next, widespread commercial sale could lead to: (1) Increased use of more toxic chemicals; (2) greater risks for farm workers; (3) increased environmental damage (especially groundwater contamination); (4) more chemical residues in the food system; (5) increased production costs; (6) danger of crop loss.

Rather than encouraging the use of more environmentally sympathetic chemicals, herbicide tolerance strategies make it possible for manufacturers to employ more toxic products since the crop itself may not be harmed. These highly-toxic chemicals may be used under conditions and in environments where they have not been used in the past. According to one industry source, "The theory is that farmers would be willing to use even more of the weed-killers, safe in the knowledge that their crop won't be damaged."[10] Since governments in industrialized countries are, however, more vigilant, the package deal of herbicide tolerant seeds and toxic chemicals may find widest acceptance on estate crops in the Third World where regulation is more difficult and where the bottom line concern is crop production.

Despite statements by the biotech industry that herbicide tolerance should be able to reduce production costs by increasing yield, the "packaged" technologies of seeds and chemicals together could mean an unnecessary increase in farm costs. In addition, to be assured that the seed is "guaranteed" to survive the chemical, farmers may feel obliged to return to the market each season to buy seed rather than to save their own. Normally, farmers growing small grains and many other crops would save their own seed for planting the next season. Even non-hybrid seeds offering herbicide tolerance may demonstrate the same market characteristics as a hybrid.

The risk of crop loss is difficult to ascertain. The scientific strategies pursued in developing genetically-engineered tolerance may invite some of the same problems discovered with single-gene resistance breeding against crop diseases. The gene mutates or is overcome by other pressures leaving the crop suddenly vulnerable. Unlike single-gene resistant breeding where the crop may or may not be attacked by disease, genetically-engineered, herbicide tolerant seed is always used in conjunction with the herbicide. If the genetic protection is lost, the crop is lost. Further, the residue left by some chemicals will make it dangerous for farmers to observe the same crop rotation pattern they followed when they avoided the herbicide. An altered rotation could prove economically disadvantageous. Worse, farmers with little access to information may misunderstand and assume that all crops will tolerate the herbicide. The new crop could be damaged by the residue from the old application or with new spraying.

Other observers are concerned that it is only a matter of time before the crop's herbicide resistant gene is transferred to the crop's weedy competitors. When this happens, the chemical/pest conflict will escalate once again and farmers will be driven to yet more toxic weapons.

RAFI is convinced that the move from pest resistance breeding to pesticide resistant breeding is intellectually absurd. The beneficiaries will be the genetics supply industry. "As the plant protection companies concentrate their interests," a French industry journal noted, "As they supply both the seed and the chemical product adapted to it, they extend their commercial influence over the farmer."[11]

Feasibility:

Some observers are skeptical that herbicide tolerance is a workable strategy. They point out that many of the pesticides for which new varieties are being adapted will be at the end of their patent protection about the time the new seeds are ready for market. Plant breeders are also concerned that the time involved in fixing genetic resistance to a herbicide will leave the plant variety lagging behind its competitors in yield improvement. Farmers, they reason, will not pay a premium for herbicide tolerant seed that is not the equal of other varieties.

These are sound arguments. Herbicide tolerance strategies can only be profitable if (1) all the dominant companies adopt the same strategy so that they all compete on the same playing field; (2) farmers are persuaded that herbicide tolerant seeds are worth the price.

This appears to be the case for the world's most important seed market, maize, where Pioneer, Dekalb-Pfizer, Ciba-Geigy, and Sandoz (the dominant four firms) as well as ICI, American Cyanamid, Rhone-Poulenc, and Shell all have herbicide tolerant breeding programs. Can farmers be persuaded to buy herbicide tolerant varieties? History suggests they can. Fifty years ago, some of the same companies convinced US farmers to throw away their seed and buy hybrid maize from the store every year. The hybrids took longer to develop - yield development was delayed - and seed costs were high. Yet, despite a shocking lack of evidence, the image of the "hybrid" is now sacrosanct in farming folklore.

Changes in the Industry:

The development of herbicide tolerant seeds reinforces a recent trend in which two major inputs (seeds and chemicals) are increasingly controlled by one industry. This trend is reflected in a major restructuring of the farm inputs industry over the past decade.

Where 30 manufacturers were engaged in pesticides development in the mid-1970s in the United States, there are only a dozen today. Industry sources suggest that only half of these will survive to see the next century. The United Kingdom claimed sixty manufacturers and formulators in the early 1980s but only six were important to the market. Even this number is expected to decrease[12]. Worldwide, the $17.4 billion pesticides industry is dominated by seven transnationals (each with sales of one billion dollars or more) that share 63% of global sales[13].

The Global Pesticides Industry
THE TOP SEVEN ENTERPRISES

Enterprise:	State:	US$M. Pest. Sales	%Global	Herbicide Tolerance
Bayer	FR Germany	2,344	13	Yes
Ciba-Geigy	Swiss	2,070	12	Yes
ICI	UK	1,900	11	Yes
Rhone-Poulenc	France	1,500	9	Yes
Monsanto	USA	1,152	7	Yes
Hoechst	FR Germany	1,022	6	Yes
Du Pont	USA	1,000	6	Yes
TOP SEVEN		10,988	63%	

Of the leading seven pesticides firms, five are also ranked among the world's largest 20 or 25 seed companies. Only Bayer and Du Pont have marginal seed interests.

The seed industry has been massively transformed. Estimates of the number of takeovers in recent years vary from a low of 120 companies[14] to a high of more than 500 acquisitions and an equal number of other equity arrangements giving international firms a dominant position in world seed sales[15]. Total world retail sales in seeds per annum approximates $13.6 billion - of which $6 billion is "proprietary" (subject to patents or hybrid seed with a built-in biological patent since seed cannot be saved). The top ten companies have close to 20% of the world's commercial seed market[16].

The Global Genetics Supply Industry
THE TOP TEN ENTERPRISES

Enterprise:	State:	US$M. Seed Sales	% Global	Herbicide Tolerance
Pioneer	USA	891.0	6.55	Yes
Shell	UK/Dutch	350.0	2.57	Yes
Sandoz	Swiss	289.8	2.13	Yes
Dekalb/Pfizer	USA	201.4	1.48	Yes
Upjohn	USA	200.0	1.47	Unknown
Limagrain	France	171.5	1.26	No
ICI	UK	160.0	1.18	Yes
Ciba-Geigy	Swiss	152.0	1.12	Yes

Lafarge	France	150.0	1.10	Unknown
Volvo	Sweden	140.0	1.03	Unknown
TOP TEN:		2,705.7	19.89%	6 of 10

Of the top ten seed companies, only Pioneer and Limagrain are traditional to the industry and only these two have no significant interest in crop chemicals.

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In part two of our series on "Agricultural Inputs and Plant Breeding", RAFI will examine other farm inputs which are undergoing major corporate and technological change. The next RAFI Communique will cover new developments in somatic embryogenesis (artificial seeds), biopesticides and biofertilizers.

FOOTNOTES

1 Fifth Genetic Engineering News Guide to Biotechnology Companies, 1987.

2 Estimate by Theodore Sheets of T.A. Sheets Co. reported in Agricultural Genetics Report, March-April, 1982, p.6.

3 Reported by Maro R. Sondahkl et. al. in ATAS Bulletin No. 1, November 1984, p.14 citing "Biotechnology in the Americas: Prospects for Developing Countries" INTERCIENCIA, 1983 (in press).

4 George Kidd, senion consultant, L. Wm. Teweles Co. in BIO/TECHNOLOGY, February, 1987, p. 133.

5 RAFI data based upon survey of biotechnology journals, business newspapers, etc.

6 Agricultural Genetics Report, November, December, 1983, pages 2-7.

7 Cultivar magazine, May, 1986.

8 Jack Doyle quoting George Kidd of L. Wm. Teweles & Co. in GENEWATCH, Vol.2 Nos.4-6, page 3. Doyle is a researcher with the Environmental Pol-icy Institute in Washington D.C..

9 Agricultural Biotechnology, September-October, 1985, p.3.

10 "The Hot Market in Herbicides", Chemical Week, July 7 , 1982. pp.36-40

11 Cultivar, May, 1986

12 Pesticide Resistance and World Food Production, edited by Gordon Con-way, Imperial College Centre for Environmental Technologies, 1982, p.67

13 RAFI estimate based upon annual reports and industry investment reports

14 George Kidd, senior market analyst, L. Wm. Teweles & Co., 1986.

15 RAFI estimates over 500 acquisitions since the late Sixties with anoth-er 500 changes in the industry due to stock purchases, important cont-ractual linkages and some newly developed subsiduaries of TNE's.

16 RAFI estimate based upon several data sources including The Economist, 15 August, 1987, p.56 although RAFI believes magazine's figures to be outdated.

RESEARCH IN HERBICIDE-TOLERANT CROP VARIETIES [1]

TARGET CROP:	BRAND NAME:	CONTRACTING COMPANY:	CONTRACTOR:
All Veg.	imidizolinones	George J. Ball	American Cyanamid
Canola	Atrazine	Allelix	Univ. Guelph
Canola	Betanal	Calgene	Kemira Oy
Canola	imidizolinones	Allelix	American Cyanamid
Canola	Kanamycin	Calgene	Calgene
Canola	Roundup	Calgene	Calgene
Canola	Unknown	Advanced Genetic Sciences	Advanced Genetic Science
Canola	Unknown	Biotechnica Int'l.	Biotechnica Int'l.
Canola	Unknown	Phyto-Dynamics	Lubrizol
Cotton	Kanamycin	Agracetus	Agracetus
Cotton	Roundup	Calgene	Phytogen
Legumes	Roundup	Biotechnica Int'l.	Biotechnica Int'l.
Maize	Aquinol	Shell	Shell
Maize	Cinch	Shell	Shell
Maize	imidizolinones	Molecular Genetics	American Cyanamid
Maize	Prowl	Phyto-Dynamics	American Cyanamid
Maize	Roundup	Calgene	Dekalb-Pfizer
Maize	Roundup	Phyto-Dynamics	Phyto-Dynamics
Maize	Treflan	Phyto-Dynamics	Phyto-Dynamics
Maize	Unknown	Callahan	Phone-Poulenc
Maize	Unknown	ICI	ICI
Maize	Unknown	Misscher/Innes	Ciba-Geigy/Lubrizol
Maize	Unknown	Molecular Genetics	Molecular Genetics
Poplar	Roundup	Calgene	US Forest Service
Potato	Atrazine	Univ. of Guelph	Univ. of Guelph
Potato	Basta	Biogen	Plant Genetic Systems
Potato	Roundup	Calgene	Calgene
Potato	Unknown	Advanced Genetic Sciences	Advanced Genetic Science
Rice	Unknown	Rohm & Haas	Rohm & Haas
Sorghum	Bronco	Monsanto	Monsanto
Sorghum	Dual	Ciba-Geigy	Ciba-Geigy
Soybean	Atrazine	Calgene	Nestle
Soybean	Atrazine	Ciba-Geigy	Ciba-Geigy
Soybean	Glean	Du Pont	Du Pont
Soybean	Lexone/Sencor	Mobay (Bayer)	Bayer
Soybean	Roundup	Calgene	Nestle
Soybean	Unknown	Callahan	Rhone-Poulenc
Sugarbeet	Unknown	Calgene	Rhone Poulenc
Sunflower	Buctril	Calgene	Rhone Poulenc
Tobacco	Atrazine	Ciba-Geigy	Ciba-Geigy
Tobacco	Atrazine	USDA	Ciba-Geigy
Tobacco	Basta	Biogen	Plant Genetic Systems
Tobacco	Glean	Du Pont	Du Pont
Tobacco	Picloran	Univ. Cornell	Univ. Cornell
Tobacco	Roundup	Calgene	Coker's (KWS)
Tomato	Apron	Plant Genetic Systems	Japanese enterprise
Tomato	Atrazine	Calgene	Montedison-PCRI
Tomato	Basta	Biogen	Plant Genetic Systems
Tomato	Benlate	Plant Genetic Systems	Japanese enterprise
Tomato	Captan	Plant Genetic Systems	Japanese enterprise
Tomato	Roundup	Calgene	Calgene
Turnip Rape	Betanal	Calgene	Kemira Oy
Turnip Rape	Betanal	Phytogem	Kemira Oy
Unspecified	Atrazine	Ciba-Geigy	Ciba-Geigy
Unspecified	Atrazine	Univ. Harvaed	Univ. Harvard
Unspecified	Atrazine	Univ. Michigan State	Univ. Michigan State
Unspecified	Diuran	Weitzman Institute	Weitzman Institute
Unspecified	Diuron	USDA	USDA
Unspecified	Roundup	Monsanto	Monsanto
Unspecified	Roundup	Shell	Shell
Unspecified	Thiocarbanate	Stauffer	ICI
Unspecified	Unknown	DNA Plant Technology	DNA Plant Technology
Wheat	Hybrex CHA	Rohm & Haas	Rohm & Haas
Wheat	Unknown	Biotechnica Int'l.	Biotechnica Int'l.

[1] RAFI Table on "Research In Herbicide-Tolerant Crop Varieties" compiled from published sources, 1983-1987.

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