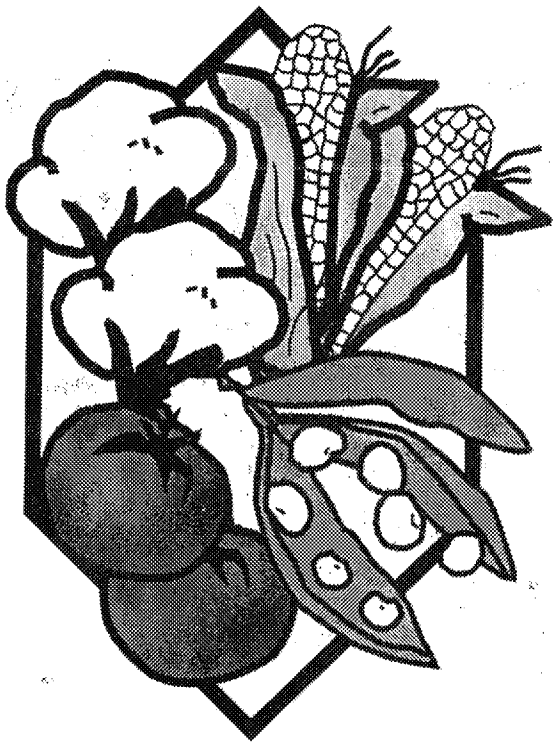
SRI CONSULTING

Subsidiary of SRI International

BIOTECHNOLOGY AND NEW CHEMISTRY:

THEIR IMPACTS ON AGRICULTURAL PEST CONTROL



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INTRODUCTION

As the 1990s draw to a close, a major technology shift is occurring in crop pest control. Ongoing research by agricultural chemical producers, biotechnology companies, seed companies, universities, and the U.S. Department of Agriculture (USDA) over the last 20 years is culminating in the concurrent development and commercialization of transgenic plants with built-in insect resistance, new biological and biologically based insect control products, and new chemical insecticides based on novel chemistry.

Transgenic insect-resistant plants constitute a new type of delivery system for crop insecticides. They have the potential both to increase yields and decrease crop production costs. At the same time, new applied insect control technologies offer the potential for more selective, safer, and more environmentally compatible crop pest control. Since 1995, a multitude of new insect control products has been announced or entered the market in North America

This report assesses four major North American crop markets for insecticides—corn, cotton, potatoes, and vegetables—that collectively account for almost two-thirds of North American growers' annual expenditures for insecticides. It provides estimates of insecticide use and grower expenditures for insecticides in each crop market by product class in 1995; reviews the new insect control technologies and products that have recently been or are expected to be launched in each market during the next few years; and projects the impact of the new technologies on demand for conventional chemical insecticides in each market by 2000 and 2005.

The market data we have developed in this study are intended to provide a base line for monitoring and reporting year-to-year sales and market penetration of transgenic insect-resistant plants, new biological and biologically based insect control products, and novel chemical insecticides on the selected crop markets for conventional chemical insecticides. This report is one of six reports issued in 1997 to first-year subscribers to SRI Consulting's new multiclient program, *Biotechnology and New Chemistry: Their Impacts on Agricultural Pest Control.*

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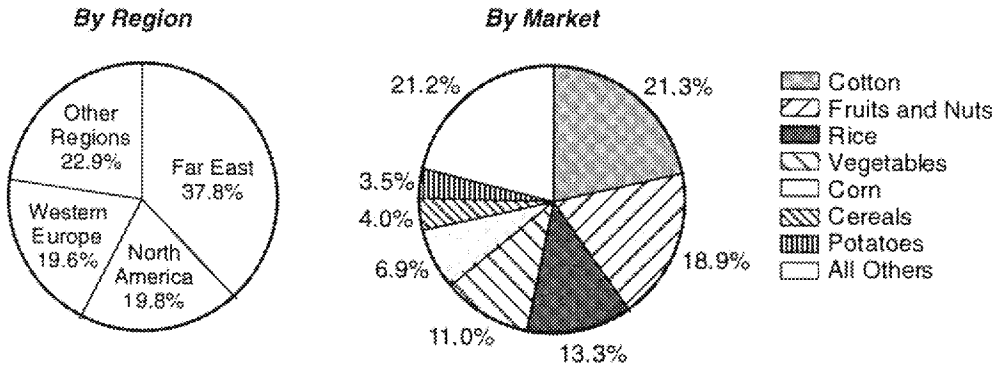
OVERVIEW

WORLD INSECTICIDES MARKET

World insecticide sales in agricultural crop markets totaled approximately $8.8 billion at the end-user level in 1995. Figure O-1 and Table O-1 show the estimated breakdown of the total world market by major region and crop sector. The Far East is by far the leading regional market for agricultural insecticides, accounting for 37.8% of total sales in 1995. North America (Canada and the United States) accounted for 19.8%, Western Europe for 19.6%, and all other regions together for 22.9%. Cotton is the largest insect control market worldwide, at 21.3% of the global market in 1995. Fruits and nuts accounted for 18.9%, rice for 13.3%, and vegetables for 11%. Corn at 6.9%, cereals at 4%, and potatoes at 3.5% were the next largest markets.

Figure O-1
WORLD CROP MARKETS FOR INSECTICIDES, 1995



Total = $8,780 Million

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Table O-1
WORLD CROP MARKETS FOR INSECTICIDES BY REGION, 1995
(Millions of Dollars, End-User Sales)

	North America						
Crop Market	Canada	United States	Total	Western Europe	Far East[a]	Other Regions	Total
Cotton	--	592	592	20	620	628	1,860
Fruits and Nuts	6	295	301	480	602	277	1,660
Rice	--	10	10	27	1,060	73	1,170
Vegetables	4	200	204	165	525	71	965
Corn	15	285	300	140	35	130	605
Cereals	30	15	45	110	60	140	355
Potatoes	7	50	57	60	125	63	305
Peanuts	--	30	30	--	100	65	195
Sugar Beets	--	17	17	100	15	48	180
Soybeans	--	6	6	1	45	88	140
Canola/Oilseed Rape	10	12	22	15	30	13	80
Others	14	140	154	602	98	411	1,265
Total	86	1,652	1,738	1,720	3,315	2,007	8,780

[a]East Asia and Australia.

Source: SRIC estimates

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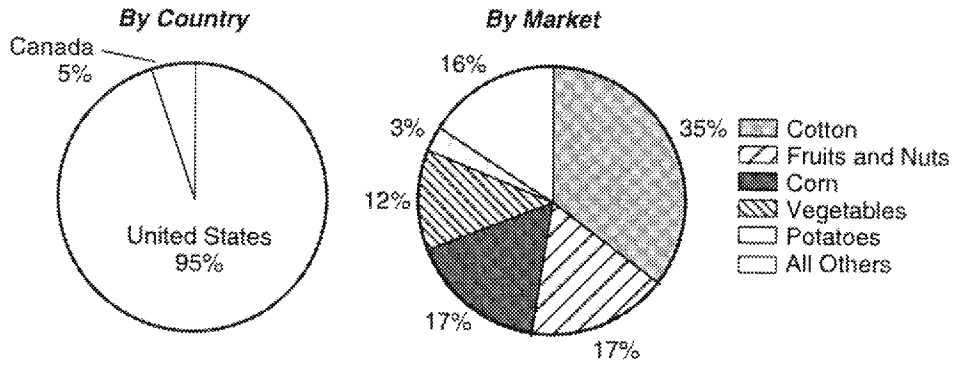
NORTH AMERICAN INSECTICIDES MARKET

North American crop markets for insecticides amounted to $1.7 billion at the grower level in 1995, of which the United States accounted for 95% and Canada for 5% (see Figure O-2). As is the case globally, cotton and fruits and nuts are the two largest insecticides markets in North America. The four markets covered in this study—corn, cotton, potatoes, and vegetables—collectively accounted for $1.2 billion, or 66% of total insecticide sales in U.S. and Canadian crop markets.

The U.S. cotton insecticides market represented about 32% of the global cotton insecticides market in 1995, and the combined Canadian and U.S. corn insecticides markets accounted for nearly 50% of the world corn insecticides market. The two North American countries also accounted for about 19% of the global potato insecticides market and for 17% of the world vegetable crops insecticide market.

Figure O-2
NORTH AMERICAN CROP MARKETS FOR INSECTIICIDES, 1995



Total = $1,738 Million

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MARKET IMPACT OF NEW TECHNOLOGIES

Transgenic Insect-Resistant Plants

Insect-resistant plants constitute a new delivery system for pesticide compounds. The first commercial plantings of transgenic insect-resistant potatoes occurred on about 1,800 acres in the United States and Canada in 1995. In 1996, plantings of insect-resistant potatoes increased to 10,000 acres, and the first transgenic insect-resistant corn hybrids and cotton varieties were planted on about 500,000 and 1.8 million acres, respectively. In 1997, insect-resistant corn and potato plantings are expected to increase ten-fold, with Bt cotton plantings increasing by about 33%. Table O-2 summarizes estimates and projections for U.S. and Canadian plantings of transgenic insect resistant plants from 1995 to 2005.

Table O-2
NORTH AMERICAN PLANTINGS OF INSECT-RESISTANT PLANTS
(Thousands of Acres)

	Corn	Cotton	Potatoes	Vegetables[a]	Total
1995	--	--	1.8	--	1.8
1996	500	1,821	10	--	2,331
1997	5,500	2,400	75	--	7,975
2000	20,000-25,000	4,000-5,000	800-900	45--50	24,845-30,905
2005	35,000-40,000	5,000-6,000	1,350-1,440	300-350	41,650-47,790

[a]Tomatoes and sweet corn.

Source: SRI Consulting

The projected market penetration of transgenic insect-resistant corn, cotton, potatoes, and vegetables—in terms of shares of total crop acreage—is summarized below and illustrated in Figure O-3.

- Hybrid corn seed with genetically engineered resistance to European corn borer, corn rootworms, and/or cutworms will account for up to 33% of U.S. and Canadian corn plantings by 2000 and for 45–55% by 2005.
- Cotton varieties with genetically engineered resistance to one or more major insect pests will account for up to 36% of U.S. cotton plantings in 2000 and for 36–43% by 2005.

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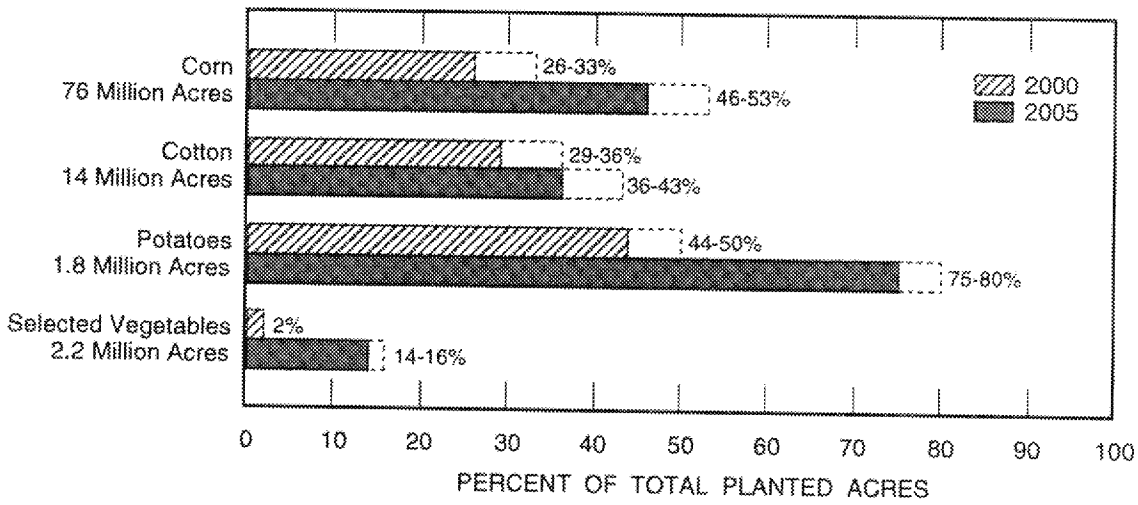
- Monsanto's NewLeaf® potatoes with either single trait resistance to the Colorado potato beetle (CPB) or multiple resistance traits (to CPB, other insects, viruses, and/or fungal diseases) are expected to account for 44–50% of the total U.S. and Canadian potato plantings by 2000 and for 75–80% by 2005.
- Transgenic insect-resistant sweet corn and tomatoes are expected to be commercialized in the 1998-2000 period. By 2000, transgenic insect-resistant varieties of the 2 vegetable crops will be planted on 45,000 to 50,000 acres, and by 2005, on 300,000 to 350,000 acres.

Figure O-3

PROJECTED NORTH AMERICAN PLANTED ACRES OF TRANSGENIC INSECT RESISTANT PLANTS



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Applied Insect Control Products

Table O-3 summarizes selected U.S. crop markets in 1995 for applied insect control products by crop and type of technology, in terms of treatment acres, and presents projections for 2000 and 2005.

Table O-3
SELECTED U.S. CROP MARKETS FOR APPLIED INSECT CONTROL PRODUCTS BY TYPE OF TECHNOLOGY, 1995-2005
(Thousands of Treatment Acres)

	1995				
Technology	Corn	Cotton	Potatoes	Vegetables[a]	Total
Biological/Biologically Based[b]	712.5	4,023.7	14.0	1,236.4	5,986.6
Insecticidal Soaps	--	--	--	130.0	130.0
New Chemistry	--	2,400.0	251.7	73.0	2,724.7
Conventional Chemistry	26,289.4	93,486.3	3,000.5	8,495.1	131,271.4
Total	27,001.9	99,910.0	3,266.2	9,934.5	140,112.7

	2000				
Technology	Corn	Cotton	Potatoes	Vegetables[a]	Total
Biological/Biologically Based	510-1,550	5,320-7,090	115-220	1,810-2,170	7,755-11,030
Insecticidal Soaps	--	--	--	130-150	130-150
New Chemistry	0-2,000	5,000-6,000	400-500	200-250	5,600-8,750
Conventional Chemistry	28,500-30,500	68,700-74,500	1,945-2,225	6,760-7,270	105,905-114,495
Total	29,010-34,050	79,020-87,590	2,460-2,945	8,900-9,840	119,390-134,425

	2005				
Technology	Corn	Cotton	Potatoes	Vegetables[a]	Total
Biological/Biologically Based	2,275-4,100	6,170-8,850	170-250	2,210-2,620	10,825-15,820
Insecticidal Soaps	--	--	--	130-150	130-150
New Chemistry	1,000-3,000	7,000-9,000	500-550	400-500	8,900-13,050
Conventional Chemistry	6,475-7,450	57,200-64,100	1,395-1,580	5,000-5,570	70,070-78,700
Total	9,750-14,550	70,370-81,950	2,065-2,380	7,740-8,840	89,925-107,720

[a]Selected major vegetable crops, including sweet corn, cucurbits, lettuce, and tomatoes.

[b]In 1995, use of pheromone-based products for corn and cotton (4,000—5,000 treatment acres and 20,000 treatment acres, respectively) are included with data for conventional chemistry.

Source: SRI Consulting

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The availability and market acceptance of transgenic insect-resistant plants will have a dramatic effect on the use of applied insect control products. By 2000, we expect the following:

- A 7–26% ***increase*** in corn insecticide treatments
- A 12–20% decline in cotton insecticide treatments
- A 10–25% decline in potato insecticide treatments
- A 1–10% decline in vegetable crop insecticide treatments
- An overall 4–15% decline in insecticide treatments for the selected crops
- An 85–89% share of the smaller overall market held by conventional chemical insecticides in 2000. They accounted for 94% of total applied insecticide treatments in 1995.

During 1995-2005, we expect the following:

- A 46–64% decrease in corn insecticide treatments
- An 18–30% decrease in cotton insecticide treatments
- A 27–34% decrease in potato insecticide treatments
- An 11–22% decrease in vegetable crop insecticide treatments
- An overall decrease of 23–36% in insecticide treatments for the selected crops.

By 2000, biological and biologically based insect control products will account for 8–11% of the total insecticide treatments made for corn, cotton, potatoes, and vegetable crops, and for 12–15% by 2005.

New insecticides based on novel chemistry will account for 4.7–6.5% of the total insecticide treatments in 2000 and for 10–12% by 2005.

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NEW PRODUCTS AND DEVELOPING COMPANIES

Transgenic Insect-Resistant Plants

Table O-4 lists the transgenic insect-resistant corn, cotton, potato, and vegetable plant products that have been launched in North America since 1995 or that are expected to be commercialized within the next 5 years. Other companies and institutions, including agricultural chemical producers, biotechnology companies, seed companies, and food processors, several universities and the USDA, are also developing transgenic insect-resistant plants (see the **Appendix** for information on insect-resistant plant field trials by crop and company).

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Table O-4
TRANSGENIC INSECT-RESISTANT CROP PLANTS ON THE MARKET OR EXPECTED TO BE LAUNCHED IN NORTH AMERICA BY 2005

Product	Supplier	Trade Name	Target Pest(s)[a]	Year On Market
Corn				
Bt Corn	AgrEvo/Plant Genetic Systams	NA	ECB	1998
	AgrEvo/Plant Genetic Systams	NA	CRW	2000-2001
	DeKalb Genetics	DeKalb®	ECB	1997
	Monsanto	Yield Gard™	ECB	1997
	Mycogen Seeds	NatureGard™	ECB	1996
	Mycogen Seeds	NA	BCW and/or CRW	2000-2001
	Mycogen Seeds	NA	Storage grain pests	2000-2001
	Novartis Seeds (Ciba)	Maximizer™ Hybrid Corn With Knock*Out*™	ECB	1996
	Novartis Seeds (Northrup King)	NK™	ECB Southwestern corn borer	1997
	Pioneer Hi-Bred	Pioneer®	ECB	1997
		Pioneer®	CRW + ECB	2000-2001
		Pioneer®	Storage grain pests	2000-2001
Bt + Cholesterol Oxidase Corn	Monsanto	NA	CRW + ECB	2000-2002
Bt + NA Corn	Pioneer Hi-Bred	Pioneer®	CRW + ECB	NA
Bt + Glufosinate Tolerant Corn	AgrEvo	Bt + Liberty®Link	ECB	1997-1998
	DeKalb Genetics	DeKalb®	ECB	1999-2002
Bt + Glyphosate Tolerant Corn	Monsanto	YieldGard™+ Roundup Ready®	ECB	1999-2002
Bt + Herbicide-Tolerant Corn[b]	Novartis	NA	ECB	1998
Cotton				
Bt Cotton	Monsanto/Delta and Pine Land	Bollgard®	TBW, CBW, PBW	1996
	Mycogen	NA	CBW	2000-2002
Dual-Gene Bt Cotton	Monsanto	NA	TBW, CBW, PBW	1999

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Table O-4 (Concluded)

Product	Supplier	Trade Name	Target Pest(s)[a]	Year On Market
Cotton (Continued)				
Cholesterol Oxidase Cotton	Monsanto	NA	Boll weevil	2000-2002
Bt + Bromoxynil-Tolerant Cotton	Calgene	BXN® + Bollgard®	TBW, CBW, PBW	1998
Bt + Glyphosate-Tolerant Cotton	Monsanto	Bollgard® + Roundup Ready®	TBW, CBW, PBW	1998-1999
Potatoes				
Bt Potatoes	Monsanto	NewLeaf®	CPB	1995
Bt + Virus-Resistant Potatoes	Monsanto	NewLeaf® Plus	CPB	1998-1999
Vegetables				
Bt Tomatoes	Monsanto	NA	Lepidoptera	1998-1999
Bt Sweet Corn	Novartis Rogers Seed Co., Subsidiary	NA	Corn earworm	1998-2000

[a]CBW = cotton bollworm; CPB = Colorado potato beetle; CRW = corn rootworm; ECB = European corn borer; PBW = pink bollworm; TBW = tobacco budworm.

[b]Herbicide tolerance is believed to be glufosinate..

Source: Communications with industry and trade literature.

Applied Insect Control Products

Biological/Biologically Based Products

Table O-5 lists new biological or biologically based insecticides that have been introduced for corn, cotton, potatoes and/or vegetable crops in North America since 1995, or that are expected to be commercialized by 2000.

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Table O-5
NEW BIOLOGICAL/BIOLOGICALLY BASED INSECTICIDES RECENTLY LAUNCHED OR UNDER DEVELOPMENT IN NORTH AMERICA

Technology/Product	Target Pest(s)	Crop (Year on Market)[a]	Developing Company
Bts			
Nonrecombinant			
Bt variety kurstaki, Strain M-200 (Able®)	Lepidoptera	Corn (1996) Vegetables (1996)	Novartis
Bt var. kurstaki, Strain EG2348 (Condor®)	Lepidoptera	Corn (1996) Cotton (1996)	Ecogen
Bt var. kurstaki (CoStar®)	Lepidoptera	Cotton (1997) Vegetables (1997)	Novartis
Bt var. kurstaki (Troy-Bt)	Lepidoptera	Corn (1996) Cotton (1996) Vegetables (1996)	Troy Biosciences
Recombinant			
ABG-6413	Lepidoptera	Cotton Vegetables	Abbott Laboratories
Bt var. kurstaki, Strain EG 7841 (Crymax™)	Lepidoptera	Corn (1996) Cotton (1996) Potatoes (1996) Vegetables (1996)	Ecogen
Bt var. kurstaki, Strain EG 7826 (Lepinox®)	Fall armyworm	Vegetables: Sweet corn (1997)	Ecogen
Encapsulated blend of CryIA(c) and CryIC derived delta endotoxins of Bt (Mattch™	Lepidoptera	Cotton (1996) Vegetables (1996)	Mycogen
Encapsulated delta endotoxin of Bt var. kurstaki (M-Peril®)	Lepidoptera	Corn (1995)	Mycogen

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Table O-5 (Continued)

Technology/Product	Target Pest(s)	Crop (Year on Market)[a]	Developing Company
Bts (Continued)			
Recombinant (Continued)			
Encapsulated delta endotoxin of Bt var. kurstaki (MVP®II)	Lepidoptera	Cotton (1996) Vegetables (1996) Sweet corn Cucurbits	Mycogen
Encapsulated delta endotoxin of Bt var. aizawai (M/C)	Beet armyworm	Cotton (1997) Vegetables (1997)	Mycogen
Viruses			
Nonrecombinant			
Helicoverpa zea NPV (Gemstar®)	Tobacco budworm Cotton bollworm	Cotton (1996) Vegetables (1996)	Thermo Trilogy
Spodoptera exigua NPV (Spod-X®)	Beet armyworm	Cotton (1995)	Thermo Trilogy
Recombinant			
Autographa californica (AcNPV)	Tobacco budworm Cotton bollworm	Cotton (NA) (Vegetables (NA)	American Cyanamid
Autographa californica (AcMNPV)	Tobacco budworm Cotton bollworm Beet armyworm Cabbage looper	Cotton (NA) Vegetables (NA)	DuPont
Heliothis NPV	Tobacco budworm Cotton bollworm	Cotton (NA)	DuPont
Rachiplusia ou (Ro NPV)	European corn borer	Corn (after 2000)	Iowa State University
Fungi			
Beauvaria bassiana Strain GHA (Mycotrol™)	Aphids Lygus Thrips Whiteflies	Cotton (1996) Vegetables (1996)	Mycotech Corporation

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Table O-5 (Concluded)

Technology/Product	Target Pest(s)	Crop (Year on Market)[a]	Developing Company
Fungi (Continued)			
Beauvaria bassiana Strain JW-1 (Naturalis® L)	Aphids Whiteflies Others	Cotton (1996)	Troy Biosciences
Nematodes			
Heterorhabditis bacteriophora	Western corn rootworm	Corn	Ecogen
Steinernema carpocapsae	Western corn rootworm	Corn	Thermo Trilogy
Steinernema riobravis	Western corn rootworm	Corn	Thermo Trilogy
Botanicals			
azadirachtin (Neemix®	Broad spectrum	Cotton (NA) Vegetables (1996)	Thermo Trilogy
neem oil (Trilogy®)	Beetles	Corn	Thermo Trilogy
Pheromone-Based Products			
Pink bollworm pheromone (Frustrate™ PBW)	Pink bollworm	Cotton (1996)	Thermo Trilogy
Microbially-Derived Toxins			
emamectin benzoate (Proclaim®)	Lepidoptera	Corn (1998) Cotton (1998) Vegetables (1998) Lettuce Cole Crops Celery	Merck AgVet
spinosad (Tracer®, Success®) Spintor®)	Lepidoptera Boll weevil Colorado potato beetle Leafminers Thrips	Corn (NA) Cotton (1997) Potatoes (1998) Vegetables (1997- 1998) Lettuce Tomatoes	DowElanco

[a]Crop markets covered in this study.

Source: Communications with industry and trade literature.

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Microbially Derived Toxins

DowElanco's spinosad (Tracer®) received its first EPA crop registration for cotton in March 1997 and is expected to significantly affect the cotton insecticides market in its initial year on the market. Its advantages include a unique mode of action; selective activity; safety for beneficial insects; and high efficacy against a broad spectrum of Lepidopteran pests, in particular the cotton bollworm and tobacco budworm.

Emamectin (Proclaim®) is the second new microbially derived toxin product; it is expected to reach the market before 2000. Although Proclaim® is currently a product of Merck AgVet Division, Novartis announced on May 13, 1997 that it will acquire all of Merck & Co.'s Crop Protection business later in 1997. Proclaim® is another product for Lepidoptera control; its particular strengths include high activity against the beet armyworm and safety to beneficial insects.

New Chemistry

Eight companies—AgrEvo, American Cyanamid, Bayer, DuPont, Novartis, Rhône-Poulenc, Rohm and Haas, and Valent—have recently introduced or are preparing to launch new chemical insecticides based on novel chemistries by 2000. Table O-6 lists the new chemical insecticides, and identifies their target pests, target crop markets, and developing companies.

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Table O-6
NEW CHEMICAL INSECTICIDES RECENTLY LAUNCHED OR UNDER DEVELOPMENT IN NORTH AMERICA

Product	Target Pest(s)	Crop Market(s)	Developing Company
acetamiprid (Mosiplan®)	Whiteflies	Cotton (NA) Potatoes (NA) Vegetables (NA)	Rhône-Poulenc
buprofezin (Applaud®)	Whiteflies	Cotton (1999)	AgrEvo
chlorfenpyr (Pirate®, Alert®)	Beet armyworm Spider mites Other Lepidoptera	Cotton (1998) Vegetables (1997)	American Cyanamid
DPX-KN 128	Lepidoptera	Cotton (NA) Vegetables (NA)	DuPont
fipronil (Regent®)	Corn rootworm Boll weevil Plant bugs Thrips Colorado potato beetle Wireworms	Corn (EUP 1996) Cotton (1998) Potatoes (NA) Vegetables (1998)	Rhône-Poulenc
halsflexozide (RH 0345)	Broad spectrum	Potatoes (NA) Vegetables (NA)	Rohm and Haas
imidacloprid (Admire®, Provado®)	Aphids Plant bugs Thrips Whiteflies Colorado potato beetle	Cotton (1995) Potatoes (1995) Vegetables (1995)	Bayer
methoxyfenozide (Intrepid®)	Lepidoptera	Cotton (1998) Vegetables (1999)	Rohm and Haas
pymetrozine (Fulfil®)	Aphids Whiteflies	Cotton (1999) Vegetables (1998)	Novartis
pyriproxyfen (Knack®)	Aphids Whiteflies	Cotton (1997) Vegetables (1998)	Valent
tebufenozide (Confirm®)	European Corn Borer Beet armyworm Cotton bollworm	Corn (NA) Cotton (1997)	Rohm and Haas
vanilprole (Evaluation®)	Broad spectrum; insects and mites	Cotton (NA) Vegetables (NA)	Rhône-Poulenc

Source: Communications with industry and trade literature.

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Chlorfenpyr (Pirate®, Alert®)

Chlorfenpyr, a pyrrole compound, is a stomach poison that must be ingested to be effective; it is especially effective against the beet armyworm and spider mites. American Cyanamid will market chlorfenpyr-based products under the trade names Pirate® and Alert®. Pirate® will be sold for cotton in the Southeast, Mid-South, and Southern Plains states, and as Alert® will be sold for cotton in the West and vegetables nationwide. Pirate® was used for cotton in 1996 under Section 18 emergency use registrations (EUPs) in Texas and some other regions. Alert® is now used under EUPs for worm control in California, and on Florida tomatoes, lettuce, and cabbage.

The beet armyworm is a sporadic pest that can devastate cotton in dry summers or when insecticides applied to control other pests also kill beneficial insects that normally keep the pest in check. No existing insecticide provides adequate control of the beet armyworm in cotton. Thus, Pirate® will fill a market void, although the year-to-year demand for the product will be unpredictable.

Over the next few years, however, Pirate® will have a market for in areas where boll weevil eradication is ongoing and where area-wide malathion spraying takes place. Malathion sprays applied to kill boll weevils also kill beneficial insects that normally keep the beet armyworm in check. The boll weevil eradication program is just beginning in Texas, and the program is expected to be reinstated in Mississippi and to continue throughout the Mid-South. During the next several years, significant malathion spraying is thus expected. However, once the boll weevil is eradicated, beneficials are expected to control secondary pests.

Pirate® will compete with DowElanco's Tracer® in the cotton market. Although Tracer® is less effective than Pirate® against the beet armyworm, it provides better control of the cotton bollworm and tobacco budworm than Pirate®.

Because of its activity against spider mites, chlorfenpyr is expected to fill a niche in the Western cotton market.

Fipronil (Regent®)

Rhône-Poulenc's Regent® is a phenyl pyrazole compound, effective against a broad spectrum of soil and foliar insects. Its mode of action is unique, and it is effective on pests that are resistant to or tolerant of insecticides in the carbamate, organophosphate, synthetic pyrethroid, and other conventional chemical classes. In 1996, Regent® was evaluated for corn rootworm and wireworm control in corn under an EUP. Full EPA registration for corn is pending and a full registration for cotton is expected in 1998. The product is also under development for controlling the Colorado potato beetle.

Cotton pest management specialists we interviewed in the Mid-South and Texas who have worked with Regent® consider it to be an excellent boll weevil material. Once it is registered, they expect it to displace most of the conventional chemical insecticides currently used for boll weevil control.

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Imidocloprid (Admire®, Provado®)

Bayer's imidocloprid-based products, Admire® and Provado®, which have been on the market in the United States since 1995, are registered for cotton, potatoes, tomatoes, and a number of other vegetable crops. Imidocloprid's systemic activity provides long-lasting residual control of aphids, whiteflies, thrips, the Colorado potato beetle, and other pests. Admire® is used for soil treatments, and Provado® is used for foliar applications. Imidocloprid's toxicity for humans is low, and it is relatively safe for beneficials. A seed treatment formulation of imidocloprid, Gaucho®, is reported to be extremely effective for early season control of thrips and aphids in cotton.

Pymetrozine (Fulfill®)

Fulfill®, from Novartis has a unique mode of action that affects only certain species of sucking insects. It is under development for whitefly control in cotton in the U.S. West and for aphid and whitefly control in vegetables nationwide.

Insect Growth Regulators

Buprofezin (Applaud®, marketed by AgrEvo), methoxyfenozide (Rohm and Haas' Intrepid®), pyriproxyfen (Valent's Knack®), and tebufenozide (Rohm and Haas'Confirm®), are four new insect growth regulators (IGRs) that are under development for the U.S. cotton market. Applaud®, and Knack® are under development for aphids and/or whitefly control in cotton. Knack® is also targeted for control of these pests in vegetable crops. Both were used for whitefly control in cotton in 1996 under Section 18 emergency exemptions. Confirm® from Rohm and Haas has been used for cotton since 1995 under Section 18 emergency exemptions for beet armyworm and cotton bollworm control and is expected to gain full registration in 1997. Intrepid®, another Rohm and Haas product, is being developed for Lepidopteran control for both cotton and vegetables. In cotton, it provides good control of the cotton bollworm and is easy on beneficials. Its main competitor is expected to be Tracer®.

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CORN

INSECT CONTROL MARKET, 1995

Crop Area and Major Growing Regions

Figure 1 and Table 1 show the regional distribution of North American corn acreage. Canada had nearly 2.5 million acres of grain corn in 1995. The province of Ontario accounted for 71% of Canada's total grain corn acreage, and Québec accounted for about 28%. In addition to the grain corn acreage, about 0.5 million acres of corn for forage were grown throughout Canada. U.S. growers planted 71.2 million acres of corn for grain, forage, and silage in 1995. Three North Central regions—the Corn Belt, Lake States, and Northern Plains—together accounted for more than 80% of the total crop acreage.

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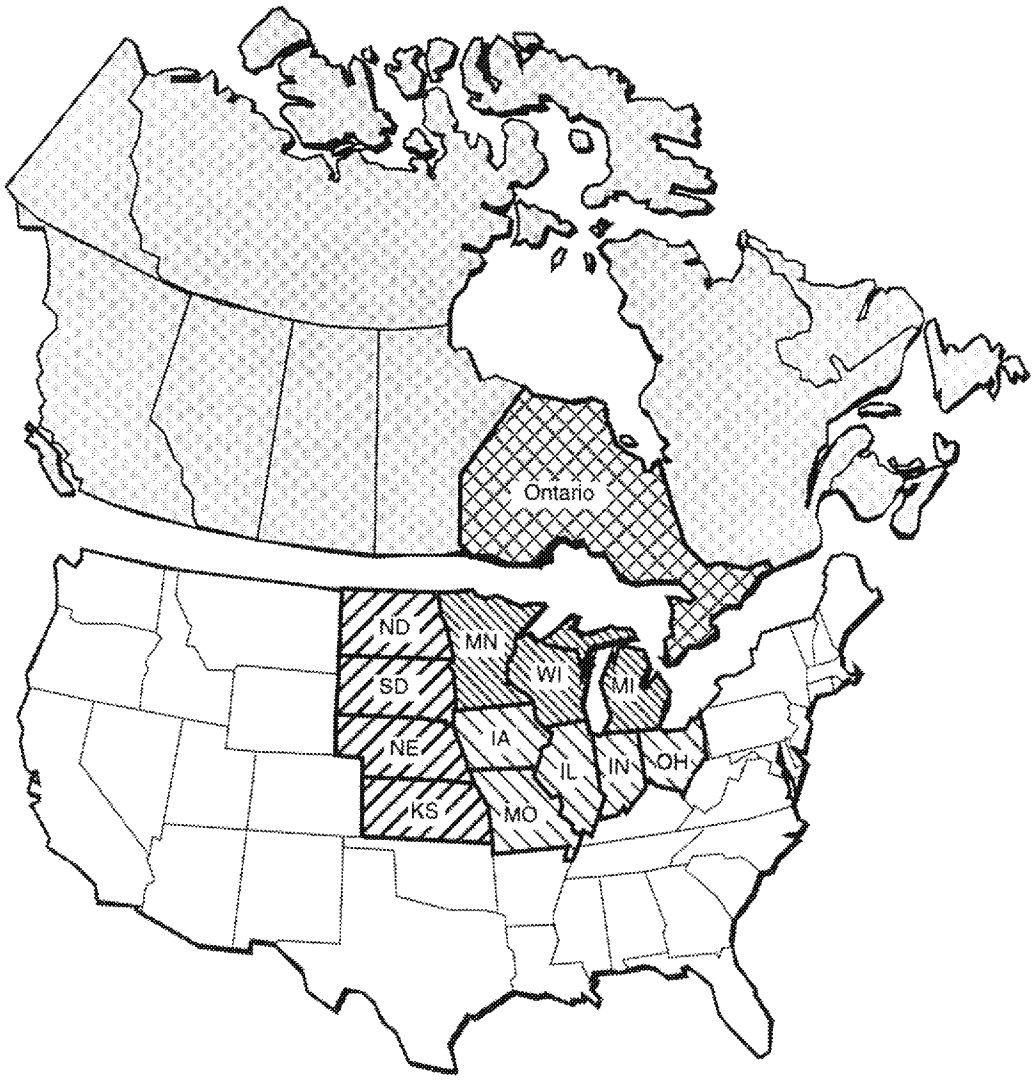
Figure 1

NORTH AMERICAN CORN ACREAGE BY COUNTRY AND REGION, 1995



	Planted Acres (1,000)	Percent of Country's Planted Acres	Percent of North America's Planted Acres
Ontario	2,073	69.6	2.8
Lake States	12,800	18.0	17.2
Corn Belt	32,250	45.3	43.4
Northern Plains	13,650	19.2	18.4
Rest of U.S.	12,545	17.6	16.9
Rest of Canada	906	30.4	2.8

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Table 1
NORTH AMERICAN CORN ACREAGE BY COUNTRY AND REGION, 1995

Country/Region	Planted Acres (1,000)	Percent of Country's Planted Acres	Percent of North America's Planted Acres
Canada			
Ontario	2,073	69.6	2.8
Other Provinces	906	30.4	1.2
Total	2,979	100.0	4.0
United States			
Lake States			
Minnesota	6,700	9.4	9.0
Wisconsin	3,650	5.1	4.9
Michigan	2,450	3.4	3.3
Subtotal	12,800	18.0	17.2
Corn Belt			
Iowa	11,700	16.4	15.8
Illinois	10,200	14.3	13.7
Indiana	5,400	7.6	7.3
Other States	4,950	6.9	6.7
Subtotal	32,250	45.3	43.4
Northern Plains			
Nebraska	8,000	11.2	10.8
Other States	5,650	7.9	7.6
Subtotal	13,650	19.2	18.4
Other Regions[b]	12,545	17.6	16.9
Total	71,245	100.0	96.0
North America, Total	74,224	NA	100.0

[a]Canadian corn acreage data include grain corn and corn for forage. U.S. acreage data include corn planted for all purposes.

[b]Northeast, Appalachia, Southeast, Delta States, Southern Plains, Mountain States, and Pacific.

Sources: Statistics Canada and USDA.

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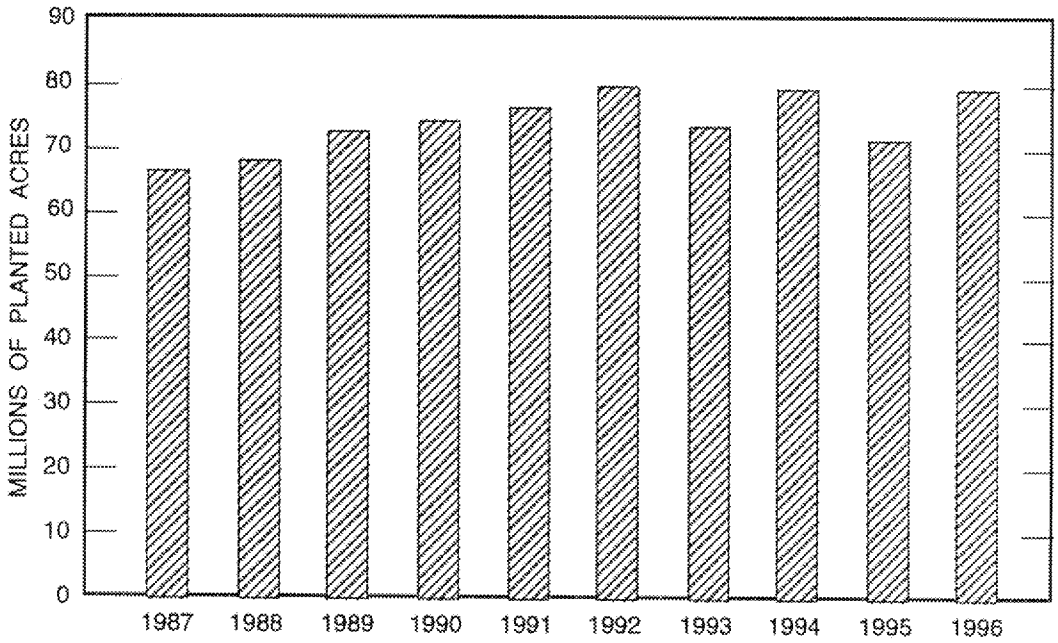
Figure 2 shows the trend in U.S. corn plantings (for grain, forage, and silage) from 1987 to 1996. Between 1987 and 1992, planted corn acreage increased steadily at an average annual rate of 3.7%, but since 1992 has fluctuated from year to year. The 71.2 million acres planted in 1995 represented a cutback of nearly 8 million acres from 1994. In 1996, however, U.S. corn plantings rebounded to an all-time high of about 79.5 million acres. Overall, U.S. corn plantings increased at an average annual rate of about 2% in the 1987–1996 period.

Figure 2
U.S. PLANTED CORN ACREAGE, 1987-1996



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Major Pests and Control Practices

Table 2 shows the relative importance of major corn insect pests (based on treated acres) in Illinois, the second-ranking U.S. corn producing state.

Table 2
ILLINOIS CORN ACREAGE TREATED TO CONTROL MAJOR INSECT PESTS, 1990

Principal Target Pest	Treated Acres (Percent of Planted Acres)
Soil Treatments	
Corn Rootworm Larvae	25
Cutworms	7
Wireworms	2
Total	34
Postemergence/Foliar Treatments	
Cutworms	0.8
First-Generation European Corn Borer	3.4
Second-Generation European Corn Borer	0.2
Corn Rootworm Beetles	<0.1
Other Pests	<0.1
Total	4.6

Source: *Pesticide Use in Illinois; Results of a 1990 Survey of Major Crops*, Extension Publ. DP-91-1, Cooperative Extension Service, University of Illinois, Urbana-Champaign.

Corn Rootworms

Corn rootworms—CRWs—(*Diabrotica* spp.) are the primary insect pests of nonrotated corn grown in Canada and the United States. Typically, they cause damage only when corn is grown in the same field for two successive seasons. Northern corn rootworm (*D. barberi*) and Western CRWs (*D. virgifera*) are the most serious problems in the principal Canadian and U.S. growing regions. The southern CRW (*D. undecimpunctata howardi*) occurs in most areas east of the Rocky Mountains, in southern Canada, and in Mexico, but it is most abundant and destructive in southern U.S. states.

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During the 1970s and 1980s, Canadian corn growers' use of soil-applied insecticides increased rapidly as CRWs migrated across Ontario. However, use of soil insecticides has declined in the 1990s because of widespread use of crop rotations. New integrated pest management (IPM) methods that permit more accurate prediction of when insecticides should be applied to prevent economic damage in corn grown after corn are expected to reduce soil insecticide use further. Canadian growers rarely apply postemergence or foliar insecticide treatments for corn.

Rotation to an alternative crop has traditionally been recommended to U.S. corn growers for preventing damage from CRWs. Adult female northern and western rootworm species deposit most of their eggs in the soil of corn fields during August and early summer, and the eggs lie dormant until the following spring. Because rootworm larvae cannot survive on roots of crops such as soybeans, alfalfa, or wheat, crop rotation is recommended. In nonrotated corn fields, soil insecticides are typically applied at planting to protect plant roots from rootworm feeding.

In the late 1970s, nearly two-thirds of the corn acreage in the North Central region was treated with soil insecticides. Today, however, only about 33% is treated. This change has occurred largely because university extension services advise growers to practice crop rotation and not to treat "first year corn" (i.e., rotated corn). Rotation is currently practiced on more than 70% of the corn acreage in the North Central region.

Cutworms

Several cutworm species occur in corn, but the black cutworm (*Agrotis ipsilon*) is the most common. Cutworms are more prevalent in fields that have plant residue and weed growth during the fall, winter, and early spring, as well as in no-till corn culture. Cutworms burrow in soil or plant debris during the day and emerge at night. Small cutworm larvae feed on seedling leaves, whereas half-grown and larger larvae cut off or partially sever corn seedlings. The damage they do is usually greatest when seedling growth is slow. Tactics recommended for minimizing the potential for serious cutworm infestations in corn fields include keeping fields relatively weed-free in the fall and late winter–early spring, and cultural practices that promote rapid seed germination and seedling growth (e.g., use of starter fertilizers).

Currently, corn growers have two options for cutworm control—preventative applications of soil insecticides at planting and rescue treatments after an infestation appears. Because of the low incidence of cutworm problems over the past 30 years and the uncertainty in predicting in which fields infestations will occur or the severity of the infestations, extension advisors encourage growers to scout their fields during plant emergence and to apply an insecticide only if cutworm larvae are present at the economic threshold level.

European Corn Borer

The European corn borer—ECB—(*Ostrinia nubilalis*), a major economic pest of corn, is a caterpillar that feeds on leaves and tunnels through stalks, causing dropped ears and reduced grain yields. University and seed company entomologists and corn

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specialists estimate that ECB infestations occur on 60 million acres of U.S. corn cropland annually, and cause average yield losses in the range of 5% to 15%. Losses of 30% to 40% have resulted from severe infestations. ECBs also significantly affect production of other important crops, including sorghum, cotton, and many vegetables. Overall, yield losses and control expenditures associated with the ECB cost U.S. farmers more than $1 billion annually.

Control methods for ECB in corn have included weed and grass management, early planting, moderately resistant hybrids, and insecticide sprays. Although insecticide sprays are recommended as a valuable IPM tool, they are seldom used. To be even moderately effective, insecticide sprays need to be timed very carefully, and two generations of ECBs per season are typical in the major North Central U.S. growing regions. The cost of the insecticide and application, uncertainty about achieving an economic return on investment, lack of confidence in scouting, and uncertainty concerning application timing are other reasons why insecticides are not commonly used. Some farmers choose simply to ignore the ECB.

Table 3 lists the leading insecticides applied in 1995 to control one or more of the major corn insect pests and indicates the target pest(s) of each product.

Other Pests

Wireworms, mites, armyworms, corn earworm, flea beetles, and corn leaf aphid are considered secondary pests of field corn and may require treatment.

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Table 3
PRINCIPAL INSECTICIDES USED TO CONTROL MAJOR INSECT PESTS OF U.S. CORN, 1995

Insecticide		Target Pest			
Product Class/ Common Name	**Trade Name**	**CRW Larvae**	**CRW Adults**	**Cutworms**	**ECB**
Biological					
Bacillus thuringiensis (Bt)	Various				X
Conventional Chemistry					
Carbamate					
carbofuran	Furadan®	X			X
Organophosphate					
chlorpyrifos	Lorsban®	X	X	X	X
fonofos	Dyfonate®	X			X
methyl parathion	Penncap-M®, Methyl Parathion		X		X
phorate	Thimet®	X			
terbufos	Counter®	X			
Pyrethroid					
bifenthrin	Capture®		X		X
permethrin	Ambush®, Pounce®		X	X	X
tefluthrin	Force®	X		X	

Source: SRI Consulting

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Insecticide Use and Market Value, 1995

In 1995, insecticides were applied to an estimated 29% of the North American corn acreage, and an average of 1.3 applications was made per treated acre (see Table 4). The percentage of planted acreage treated varied from just 14% in the U.S. Lake States to 40% in the U.S. Northern Plains region. The majority of the insecticide treatments were soil applications made at the time of planting.

Table 4
INSECTICIDE USE FOR NORTH AMERICAN CORN BY COUNTRY AND REGION, 1995

Country/Region	Planted Acres[a] (1,000)	Treated Acres: Percent of Planted Acres	Treated Acres: 1,000 Acre	Average Number of Applications[b]	Insecticide Treatment Acres (1,000)
Canada	2,979	30	893.7	1.2	1,072.4
United States					
Lake States	12,800	14	1,792.0	1.2	2,150.4
Corn Belt	32,250	26	8,385.0	1.3	10,900.5
Northern Plains	13,650	40	5,460.0	1.3	7,098.0
Other Regions [b]	12,545	38	4,815.7	1.4	6,853.0
Subtotal	71,245		20,452.7		27,001.9
Average		29		1.3	
North America, Total	74,224		21,346.4		28,074.3
Average		29		1.3	

[a]Acreage figure for Canada includes 2,485,000 acres of grain corn and 494,000 acres of corn grown for forage. U.S. acreage data include corn planted for all purposes.

[b]Components of tank mixes and premixes are counted as separate applications.

[c]Northeast, Appalachia, Southeast, Delta States, Southern Plains, Mountain States, and Pacific.

Sources: SRIC estimates.

North American corn growers spent an estimated $300 million for insecticide products applied in 1995; of that amount, Canadian growers spent an estimated $15 million and U.S. growers spent about $285 million. Figure 3 and Table 5 show the breakdown of the 1995 U.S. corn insecticides market by product class and leading product in terms of both treatment acres and grower expenditures

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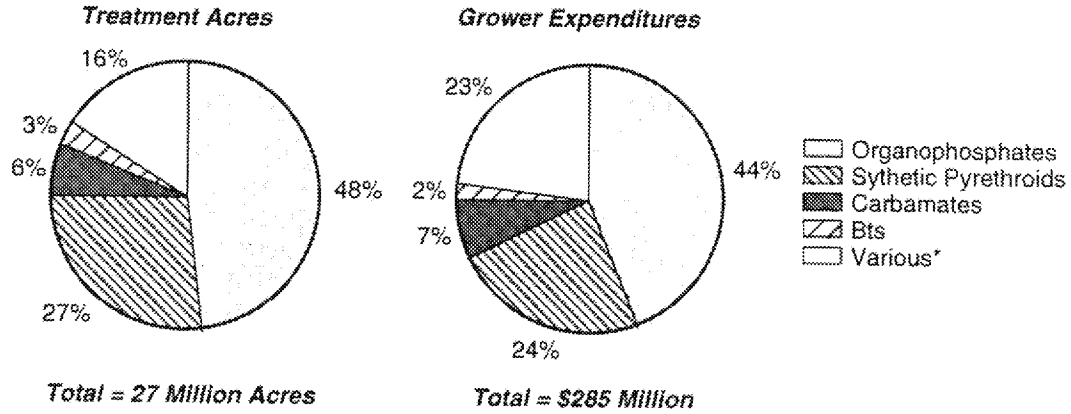
Figure 3
U.S. CORN MARKET FOR INSECTICIDES BY PRODUCT CLASS, 1995



* Includes other products of the three major chemical classes as well as products in other chemical classes

Organophosphate insecticides accounted for 49.1% of the corn insecticides market, based on treatment acres; and for 44.4% of the market, based on grower expenditures. Synthetic pyrethroid products accounted for 26.6% of treatment acres and for 23.8% of grower expenditures. Carbofuran (Furadan®), the principal carbamate product used for corn, accounted for 5.8% of treatment acres and 7.2% of grower expenditures. *Bacillus thuringiensis* (Bt)-based products were the only biological insecticides used for U.S. corn in 1995, accounting for 2.6% of treatment acres and 1.8% of grower expenditures.

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Table 5
U.S. CORN INSECTICIDE MARKET BY PRODUCT CLASS AND LEADING PRODUCT, 1995

Class/Product	Treatment Acres: 1,000 Acres	Treatment Acres: Class/ Product Share (%)	Volume Applied (1,000 Pounds, A.I.)	Grower Expenditures[a]: 1,000 Dollars	Grower Expenditures[a]: Class/ Product Share (%)
Biological					
Bts	712.5	2.6	42.7	5,129.6	1.8
Conventional Chemistry					
Carbamate					
carbofuran	1,567.4	5.8	1,395.0	20,492.2	7.2
Organophosphate					
chlorpyrifos	4,987.2	18.5	5,186.6	55,341.4	19.4
terbufos	4,274.7	15.8	4,402.9	50,413.7	17.7
phorate	712.5	2.6	783.7	7,484.3	2.6
methyl parathion	2,564.8	9.5	1,179.8	6,630.6	2.3
fonofos	712.5	2.6	627.0	6,739.8	2.4
Subtotal	13,251.6	49.1	12,180.0	126,609.7	44.4
Synthetic Pyrethroid					
tefluthrin	3,562.3	13.2	356.2	44,528.1	15.6
permethrin	2,849.8	10.6	285.0	14,106.5	4.9
bifenthrin	783.7	2.9	39.2	9,208.4	3.2
Subtotal	7,195.7	26.6	680.4	67,843.1	23.8
Various[b]	4,274.7	15.8	4,274.7	65,189.2	22.9
Total	26,289.4	97.4	18,530.2	280,134.2	98.2
Total, All Products	27,001.9	100.0	18,572.9	285,263.8	100.0

[a]Based on grower price per pound of active ingredient.

[b]Includes pheromone-based products (applied on 4-5 thousand acres for mite control), other products in the conventional chemical classes listed above, and other products, none of which were applied on more than 0.5% of the total crop acres.

Source: SRIC estimates.

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MARKET TRENDS AND ISSUES

New Technologies

The most significant trend in the North American corn insecticides market since 1995 is the development and commercialization of new insect control technologies, including transgenic insect-resistant corn hybrids, biological and biologically based insecticides, and new chemical insecticides.

Transgenic Insect-Resistant Plants

Table 6 lists transgenic insect-resistant corn plants that were commercially available in North America in 1996, will be launched in 1997, or are under development and expected to be launched within the next five years.

ECB is the target pest of the first transgenic insect-resistant corn hybrids, which carry a gene (CryIA(b)) inserted from the Bt soil bacteria. The gene produces a crystal protein in corn leaves and pollen. In 1993, Ciba Seeds, a division of Ciba-Geigy Corporation and Mycogen Corporation, entered into a cross-licensing agreement and research collaboration to develop corn hybrids with Bt-based insect resistance. Separately, the two companies received U.S. Environmental Protection Agency (EPA) approval in August 1995 to commercialize Bt corn hybrids, and they both launched their first proprietary Bt corn hybrids in 1996. Cargill Hybrid Seed launched a Bt corn hybrid (NG7059) in 1996 that was developed by Mycogen Plant Sciences (now Mycogen Seeds). Enough Bt corn seed to plant approximately 500,000 acres was sold in North America in 1996 (see Table 10 below).

In August 1996, the EPA approved the full commercial use of Northrup King's transgenic ECB-resistant corn technology. Canadian regulatory approval was also received for the Northrup King technology in summer 1996. Northrup King's Bt corn technology differs from the Ciba and Mycogen technologies in both genetic composition and the levels of the pesticide expressed in different parts of the corn plant.

In late December 1996, Monsanto received temporary EPA approval to market its genetically engineered ECB-resistant corn, YieldGard™. Monsanto has licensed this technology to Cargill Hybrid Seeds, DeKalb Genetics, Golden Harvest Seeds, and Pioneer Hi-Bred International. Under the terms of the temporary registration, which will expire on April 1, 2001, Monsanto will institute a resistance management program that it will closely monitor and will provide grower education. Furthermore, because of EPA's concerns about potential for increasing Bt resistance in the corn earworm/cotton bollworm (*Helicoverpa zea*,), Monsanto must also ensure that total annual sales of hybrid seed containing the YieldGard™ gene in the combined cotton growing states of Alabama, Arkansas, Georgia, Florida, Louisiana, North Carolina, Mississippi, South Carolina, Oklahoma, Tennessee, Texas, Virginia, and Missouri will not exceed the amount required to plant 100,000 acres.

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Table 6
TRANSGENIC INSECT-RESISTANT CORN HYBRIDS AVAILABLE OR UNDER DEVELOPMENT IN NORTH AMERICA

Technology	Target Pest(s)[a]	Trade Name	Developing Company	Year on the Market
Bt Corn	ECB	NA	AgrEvo/Plant Genetic Systems	1998
	ECB	DeKalb®	DeKalb Genetics	1997
	ECB	YieldGard™	Monsanto	1997
	ECB	NatureGard™	Mycogen Seeds	1996
	ECB	Maximizer™ Hybrid Corn with Knock*Out*™	Novartis Seeds (Ciba)	1996
	ECB	Pioneer®	Pioneer Hi-Bred	1997
	ECB Southwestern corn borer	NK™	Novartis Seeds (Northrup King)	1997
	CRW	NA	AgrEvo/Plant Genetic Systems	2000-2001
	CRW	NA	Novartis Seeds (Northrup King)	2000-2001
	CRW+ECB	Pioneer®	Pioneer Hi-Bred	2000-2001
	BCW and/or CRW	NA	Mycogen Seeds	2000-2001
		Pioneer®	Pioneer Hi-Bred	2000-2001
	Storage grain pests	NA	Mycogen Seeds	2000-2001
	Storage grain pests	Pioneer®	Pioneer Hi-Bred	2000-2001
Bt + Cholesterol Oxidase corn	CRW+ECB	NA	Monsanto	2000-2002
Bt + NA Corn	CRW+ECB	Pioneer®	Pioneer Hi-Bred	NA
Bt + Herbicide-Tolerant corn	ECB	Liberty® Link + Bt Corn	AgrEvo/Plant Genetic Systems	1997-1998
	ECB	DeKalb®	DeKalb Genetics	1999-2002
	ECB	YieldGard™ + Roundup Ready®	Monsanto	1999-2002
	ECB	NA	Novartis	1998

[a]CRW = corn rootworm; ECB = European corn borer.

Source: Communications with industry and university pest management specialists.

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On January 1, 1997 Ciba Seeds and Northrup King merged into Novartis Seeds, Inc. In 1997, the Bt corn hybrids developed by Ciba Seeds continue to be marketed under the Maximizer™ trade name and those developed by Northrup King continue to be marketed under the NK™ trade name. Cenex/Land O'Lakes, a major agricultural cooperative, will distribute the Maximizer™ line of Bt corn hybrids in 1997.

To growers, the key benefits of transgenic ECB-resistant corn hybrids include:

- Built-in resistance, which allows:
  - Reduced need for insecticide sprays
  - Reduced worker safety concerns
  - Time savings
  - Convenience
- More effective ECB control
- Elimination of the problem of accurately timing insecticide applications
- Yield protection
- Potential for increased yield over comparable hybrids without built-in insect resistance.

In 1996, growers paid $5 to $10 more per acre for Bt corn seed than for seed of conventional hybrid corn varieties, and similar premiums are expected to be charged in 1997.

Within the next 5-10 years, corn hybrids with genetically engineered protection from a variety of pests and diseases will become available. Fall armyworm, black cutworm, and CRW are other corn pests that are targeted for control through genetically engineered plant resistance. Mycogen, in collaboration with Pioneer Hi-Bred International, will use its proprietary Bt genes to develop CRW and black cutworm resistance in corn and the two companies are also collaborating to develop corn varieties with resistance to storage grain pests. Monsanto, in collaboration with DeKalb Genetics, is working on cholesterol oxidase for control of CRWs and Lepidopteran insects. Tables A-1 and A-2 in the Appendix provide company-by-company summaries of transgenic insect-resistant corn field trial release permits during 1991-1995 and field trial notifications during January 1995-August 1996, respectively.

Biological/Biologically Based Insect Control Products

Table 7 lists new biological or biologically based insect control products that have been launched in the North American corn market since 1995, or that are under development and may achieve registration for use on corn before 2005.

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Table 7
BIOLOGICAL/BIOLOGICALLY BASED INSECTICIDES RECENTLY LAUNCHED OR UNDER DEVELOPMENT FOR CORN

Technology/ Active Ingredient	Trade Name	Target Pest(s)[a]	Developing Company	Year on the Market
Bts, Nonrecombinant				
Bt var. kurstaki, Strain M-200	Able®	Lepidoptera	Novartis	1996
Bt var. kurstaki, Strain EG2348	Condor® G	ECB Southwestern corn borer	Ecogen	1995
Bt var. kurstaki	Troy-Bt	Lepidoptera	Troy Biosciences	1996
Bts, Recombinant				
Encapsulated delta encotoxin of Bt var. kurstaki	M-Peril®	Lepidoptera	Mycogen	1995
Encapsulated delta encotoxin of Bt var. kurstaki	MVP® II	ECB Southwestern corn borer Fall armyworm	Mycogen	1996
Viruses, Recombinant				
Rachiplusia ou (Ro NPV)	--	ECB	Iowa State University	After 2000
Nematodes				
Heterorhabditis bacteriophora	NA	WCRW	Ecogen	NA
Steinernema carpocapsae	NA	WCRW	Thermo Trilogy	NA
Steinernema riobravis	NA	WCRW	Thermo Trilogy	NA
Botanicals				
neem oil	Trilogy®	Beetles	Thermo Trilogy	
Microbially -Derived Toxins				
emamectin benzoate	Proclaim®	Lepidoptera	Merck AgVet	1998
spinosad	Tracer®	ECB Fall armyworm Southwestern corn borer	DowElanco	NA

[a]ECB = European corn borer; WCRW = western corn rootworm.

Source: Communications with industry and university pest management specialists.

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The new biological or biologically based insect control products for corn listed in Table 7 include naturally occurring and recombinant Bt-based products, a recombinant virus, nematodes, a botanical insecticide, and microbially derived toxins.

Current research by an Iowa State University scientist may eventually result in a recombinant virus product to control ECB. The virus to which ECB is most susceptible, *Rachiplusia ou* (Ro NPV), has been identified and will be genetically engineered to speed up its kill rate. Then a stable formulation must be developed so that the virus can be sprayed on corn plants.

Chemical Insecticides

Table 8 lists new chemical insecticides that have been recently registered or are under development for use on corn in the United States; the table also indicates their target pests and identifies the developing companies.

Table 8
NEW CHEMICAL INSECTICIDES RECENTLY LAUNCHED OR UNDER DEVELOPMENT FOR U.S. CORN

Chemical Class/ Product	Trade Name	Target Pest(s)[a]	Developing Company	Year on the Market
New Chemistry				
fipronil	Regent®	CRW Wireworms	Rhône-Poulenc	NA (EUP 1996)
tebufenozide	Confirm®	ECB	Rohm and Haas	NA
Conventional Chemistry				
Organophosphate				
tebuprimiphos premix	Aztec®	CRW Cutworms Wireworms Other soil pests	Bayer	1995
chlorethoxyfos	Fortress®	CRW	DuPont	1995
Synthetic Pyrethroid				
RU-58753	--	CRW	AgrEvo	NA

[a]CRW = CRW; ECB = European corn borer.

Source: Communications with industry and university pest management specialists.

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Three of the five new insecticide active ingredients listed in Table 8 are based on conventional chemistry. Bayer's Aztec®, a formulation of tebuprimiphos, an organophosphate compound, and cyfluthrin (a synthetic pyrethroid) was launched in 1996 for planting use to control CRW larvae, cutworms, wireworms, and other soil pests. DuPont's new organophosphate insecticide, Fortress®, was marketed in limited quantities in 1996 for control of CRW in Illinois, Iowa, Nebraska, Minnesota, and Colorado. AgrEvo is evaluating a new synthetic pyrethroid soil insecticide under the experimental code number RU-58753 for CRW control.

The two new insecticides based on new chemistry are fipronil (Regent®) from Rhône-Poulenc and tebufenozide (Confirm®) from Rohm and Haas. Regent® was evaluated for control of CRW and wireworms under and experimental use permit in 1996. The expected year of registration of Confirm®, an insect growth regulator, is not known.

Issues

The potential for insect resistance is a major issue associated with Bt corn. The EPA requires registrants of Bt corn technologies to implement resistance management strategies. Such strategies include requiring growers to plant "refuges" near Bt corn plantings and incorporating more than one Bt gene into corn hybrids. Marketers of Bt corn hybrids are also required to educate growers about insect resistance management (IRM).

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MARKET PROJECTIONS, 2000 AND 2005

Total Market

Table 9 summarizes projections for the U.S. corn insect control market in 2000 and 2005 by technology and product type, in terms of treatment acres (planted acres for transgenic insect-resistant plants).

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Table 9

U.S. CORN INSECT CONTROL MARKET BY TYPE OF TECHNOLOGY, 1995-2005[a]
(Thousands of Acres)

Technology/ Product Group	1995	2000	2005
Transgenic Insect-Resistant Plants[b]	--	20,000-25,000	35,000-40,000
Applied Insect Control Products			
Biological/Biologically Based			
Bts	712.5	500-1000	500-750
Viruses	--	--	500-750
Nematodes	--	0-500	250-500
Pheromone-Based Products	--	10-20	25-50
Botanicals	NEG	0-30	0-50
Microbially derived toxins	--	--	1,000-2,000
Subtotal	712.5	510-1,550	2,275-4,100
New Chemistry	--	0-2,000	1,000-3,000
Conventional Chemistry			
Carbamate	1,567.4	1,000-2,000	400-450
Organophosphates	13,251.6	15,000-16,000	3,300-3,700
Synthetic Pyrethroids	7,195.7	8,000-8,500	1,775-2,050
Other[c]	4,74.7	3,700-4,000	1,000-1,250
Subtotal	26,289.4	28,500-30,500	6,475-7,450
Total	27,001.9	29,010-34,050	9,750-14,550
Total, All Products	27,001.9	49,010-59,050	44,750-54,550

[a]Based on assumed total planted acreage of 76 million acres in both 2000 and 2005. Data represent planted acres for transgenic plants and treatment acres for applied insect control products.

[b]Projections for transgenic plants are for Canada and the United States, but those for applied insect control products are for the United States only.

[c]Data for other conventional chemistry in 1995 includes pheromone-based products (about 8,000 treatment acres).

Source: SRI Consulting

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Transgenic Insect-Resistant Plants

Bt corn hybrids resistant to the European corn borer are expected to be planted on approximately 5.5 million acres in North America in 1997 and on about 10 million acres in 1998 (see Table 10). Grower expenditures for Bt corn licensing fees and/or seed (exceeding what they would pay for traditionally bred hybrid corn seed) are expected to total about $40 million in 1997 and $50 million in 1998. By 2000, the North American market for transgenic insect-resistant corn seed is expected to grow to 20-25 million planted acres with a grower level value of $100–125 million. By 2005, 35 million–40 million acres will be planted with transgenic corn seed resistant to ECB, CRW, cutworms, and/or other corn insect pests; growers' expenditures for that seed will amount to $170–195 million. Both technology licensing fees and seed price premiums above prices charged for traditionally bred corn hybrids are expected to decline over time with the increasing availability of transgenic insect-resistant hybrid corn seed.

Table 10
NORTH AMERICAN MARKET FOR TRANSGENIC INSECT-RESISTANT CORN, 1995-2005

Year	Planted Acres (Thousands)	Grower Expenditures[a] (Millions of Dollars)
1995	--	--
1996	500	4
1997	5,500	40
1998	10,000	50
2000	20,000-25,000	100-125
2005	35,000-40,000	170-195

[a]Includes technology licensing fees and/or seed costs above costs of traditionally bred hybrid corn seed.

Source: SRIC estimates

Annual plantings of ECB-resistant corn are expected to vary according to yield performance and the extent of ECB problems in the previous year. Because of the increasing awareness of ECB and the yield losses that pest causes, corn pest management specialists believe potential exists for the use of Bt corn by growers who do not currently spray insecticides against ECB. Thus, with the exception of Bt-based products, the initial market penetration of Bt corn may not necessarily come at the expense of applied insecticides.

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Applied Insect Control Products

Use of applied insect control products is expected to increase by as much as 26% in the 1995-2000 period, but to decline rapidly after 2000 because of competition from transgenic insect-resistant corn hybrids, as well as hybrids with multiresistance traits.

Biological/Biologically Based Insecticides

The use of biological and biologically based insect control products for corn is expected to grow from 712,500 treatment acres in 1995 to 2.3 million to 4.1 million treatment acres in 2005. Biological and biologically based products will account for about 2–4.5% of the total corn insecticide treatment acres in 2000 and for 23–28% by 2005.

As Bt corn plantings increase, the use of applied Bts for corn is expected to decline and is likely to be restricted to organic corn production or to corn grown in regions where little or no Bt corn is planted.

The nematode-based products of Ecogen and Thermo Trilogy have been evaluated in corn field trials, but it is not known if registrations for these products will be pursued.

The new insecticides based on microbially derived toxins, spinosad (Tracer®) and emamectin benzoate Proclaim®), assuming their manufacturers decide to pursue registrations for corn, together could account for as much as 3% of corn insecticide treatments by 2000 and 3–5% by 2005.

Chemical Insecticides

Recently, the use of soil insecticides at planting and in preplant, preemergence, and postemergence tank mix applications has been growing. Increasing CRW problems in first-year corn (i.e., corn planted after a rotation to soybeans) in the North Central states and a general trend to minimum or no-till corn production systems have resulted in more preventive soil insecticide treatments to ensure maximum stand establishment. Furthermore, a reduction in the U.S. government's conservation reserve programs, combined with the recent increase in corn prices, is expected to result in the planting of corn on extensive acreages of previously fallow land. Fallow land is often a reservoir of soil pests that may affect crop stand establishment. For these reasons, increasing use of soil insecticides is expected, at least until transgenic plants with resistance to CRW and cutworms become available.

By 2005, insecticides based on new chemistry will account for 10–21% of the total corn insecticide treatment acres. Conventional chemical insecticides, which accounted for about 97% of the corn insecticides market in 1995, based on treatment acres, will lose market share to both biological/biologically based products and new chemical products. On the basis of treatment acres, by 2005 the corn market for conventional chemical insecticides will be only 25–28% the size of the 1995 market.

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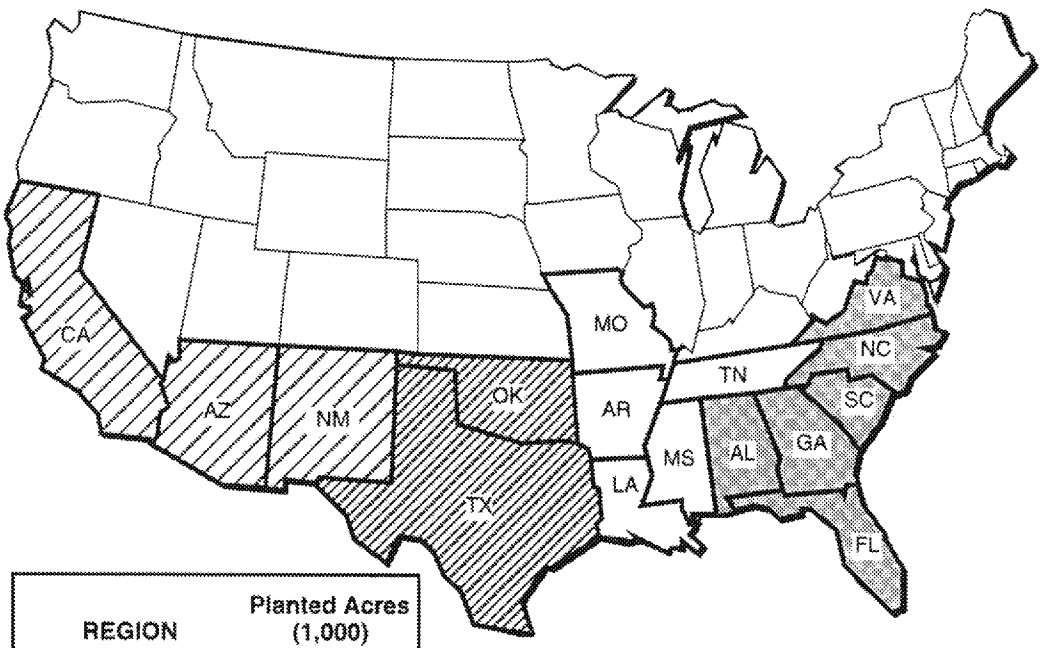
COTTON

INSECT CONTROL MARKET, 1995

Crop Acreage and Major Growing Regions

Figure 4 shows the four U.S. cotton growing regions and each region's total planted cotton acreage in 1995. The Southern Plains constitute the largest cotton growing region, followed by the Mid-South, the Southeast, and the West. Table 11 presents a breakdown of the regional crop acreage by state. Texas is by far the leading state in cotton crop acreage, with 38% of U.S. planted acreage in 1995. The next most important cotton producing states are Georgia, with 8.9% of the planted crop acreage in 1995, Mississippi with 8.6%, California with 7.6%, Arkansas with 6.9%, and Louisiana with 6.4%.

Figure 4
U.S. COTTON ACREAGE BY REGION, 1995



REGION	Planted Acres (1,000)
Southeast	3,460
Mid-South	4,877
Southern Plains	6,820
West	1,775
Total	**16,931**

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Table 11
U.S. COTTON ACREAGE BY REGION AND STATE, 1995

Region/State	Planted Acres (1,000)	Percent of Total
Southeast		
Georgia	1,500.0	8.9
North Carolina	805.0	4.8
Alabama	590.0	3.5
South Carolina	348.0	2.1
Florida	110.0	0.6
Virginia	107.0	0.6
Subtotal	3,460.0	20.4
Mid-South		
Mississippi	1,460.0	8.6
Arkansas	1,170.0	6.9
Louisiana	1,085.0	6.4
Tennessee	700.0	4.1
Missouri	462.0	2.7
Subtotal	4,877.0	28.8
Southern Plains		
Texas	6,436.0	38.0
Oklahoma	380.0	2.2
Kansas	3.8	0.0
Subtotal	6,819.8	40.3
West		
California	1,285.0	7.6
Arizona	413.6	2.4
New Mexico	76.0	0.4
Subtotal	1,774.6	10.5
United States, Total	16,931.4	100.0

Source: Crop Production, 1996 Summary, January 1997, USDA, NASS.

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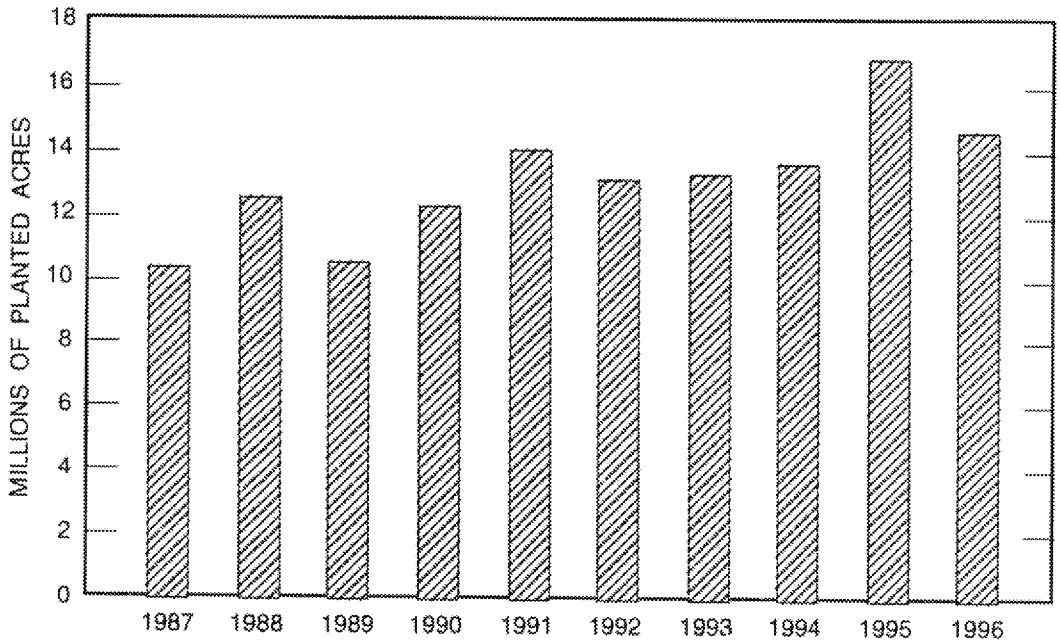
Figure 5 shows the trend in U.S. cotton plantings since 1987. The crop acreage increased from 10.4 million acres in 1987 to 16.9 million acres in 1995. In 1996, however, cotton plantings were cut back by 13% to 14.7 million acres.

Figure 5
U.S. PLANTED COTTON ACREAGE, 1987-1996



Since eradication of the boll weevil in the Southeast, cotton plantings in the region have increased dramatically. Georgia's cotton crop acreage increased form 260 thousand acres in 1989 to 1.5 million acres in 1995. Cotton acreage in Georgia (and virtually every other cotton producing state) declined in 1996 because of more favorable corn and soybean prices, but is expected to stabilize at an average of about 1.3 million acres per year, with year-to-year fluctuations, depending on competitive crop prices.

Cotton lint prices tend to be cyclical and in 1996 were down to about 70¢ per pound, on average. However, cotton production expenses continue to increase. Alabama growers' production costs amounted to $400–450 per acre in 1996. The average yield in that state (as in Georgia) is about 700 pounds of lint per acre. At 70¢ per pound, the average grower's gross return was $490 per acre, or just $40–90 more than the cost of production.

Texas has at least seven well-defined and distinctly different cotton growing environments. Yields and crop economics vary widely from environment to environment, depending primarily on the amount of annual rainfall and whether or not irrigation is employed. In the Coastal Bend area (around Corpus Christi), for example, yields average about 600 pounds of lint per acre. Only about 10% of the cotton land in that area is irrigated, and a drought in 1996 severely affected yields. As much as 60% of the acreage

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was plowed out, and yields on the acreage that was harvested were extremely low (one-eighth to one-quarter bale per acre).

Major Pests and Control Practices

The three most widespread and widely treated major insect pests of U.S. cotton are the cotton bollworm (*Helicoverpa zea*), the tobacco budworm (*Heliothis virescens*), and the boll weevil (*Anthonomus grandis*). A variety of other insects are considered major pests in particular cotton growing regions. Table 12 ranks the major cotton insect and mite pests in descending order of total treatment acres in 1995.

Table 12
MAJOR INSECT AND MITE PESTS OF U.S. COTTON: AREA INFESTED, AREA TREATED, AND TREATMENT ACRES, 1995

Pest	Area Infested (1,000 Acres)	Area Treated[a] (1,000 Acres)	Average Number of Applications[a]	Treatment Acres (1,000)
Bollworm/Budworm	12,552.1	9,260.0	2.4	22,223.9
Boll Weevil	9,544.1	7,030.3	2.0	14,060.5
Aphids	13,838.3	5,254.9	0.6	3,153.0
Lygus Bugs	8,287.8	4,493.4	0.5	2,246.7
Thrips	11,958.5	4,143.8	0.3	1,243.2
Beet Armyworm	6,803.0	2,617.8	0.3	785.3
Spider Mites	2,945.6	1,392.8	0.1	139.3
Fleahoppers	3,151.3	1,180.1	0.1	118.0
Sweet Potato Whitefly	906.5	522.2	0.2	104.4
Fall Armyworm	3,136.9	689.7	0.1	69.0
Pink Bollworm	508.3	457.0	0.1	45.7
Stink Bug	3,529.0	525.8	< 0.1	26.3
Soybean Looper	1,581.0	480.5	< 0.1	24.0
Cabbage Looper	3,586.0	404.1	< 0.1	20.2
Cutworms	1,240.2	318.3	< 0.1	15.9
Banded Wing Whitefly	1,578.0	46.5	< 0.1	2.3
Salt Marsh Caterpillar	466.0	45.6	< 0.1	2.3
Grasshoppers	194.0	20.1	< 0.1	1.0
White Flower Thrips	2,125.2	20.0	< 0.1	1.0
Leaf Perferator	239.7	16.0	< 0.1	0.8
European Corn Borer	398.5	10.6	< 0.1	0.5

[a]Includes spot applications; < 0.1 is assumed to equal 0.05.

Source: *Proceedings, 1996 Beltwide Cotton Conference*, National Cotton Council of America

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The boll weevil has been eradicated in the Southeast from North Carolina to Alabama and the Florida panhandle; the tobacco budworm (TBW) and the cotton bollworm (CBW) are now the two primary insect pests for cotton grown in the Southeast. North Carolina growers apply no more than three foliar sprays per season to control TBW and CBW, and Georgia growers typically apply 4 to 5 insecticide sprays per crop, of which 3 to 4 are targeted for TBW/CBW control.

Before the federal government's Boll Weevil Eradication Program, cotton growers in southeastern states commonly applied 6 to 12 insecticide sprays per crop. Since boll weevil eradication, however, most have become very integrated pest managemen (IPM)-oriented and are interested in preserving beneficials for biological control of pests such as the beet armyworm. Thus, safety to beneficials is an important consideration in selecting insecticide products. In this regard, aphid sprays are rarely used because they disrupt the natural biological control system.

The boll weevil is the key insect pest of cotton grown in Mississippi and Louisiana and typically requires 5 to 8 treatments per season. The TBW/CBW complex is next in importance. Lygus, tarnished plant bug, cotton aphid, beet armyworm, fall armyworm, and loopers are usually secondary pests. Most cotton growers in these states are advised by private IPM consultants, and pesticides are typically applied on a "prescription" basis. Bts-based products have been an integral part of TBW/CBW resistance management programs in the Mid-South, although their use has declined substantially in recent years because of the availability of synthetic pyrethroids. Accurate timing of Bt applications is critical for effectiveness, and they are more expensive than pyrethroid products.

Major insect pests of Texas cotton include thrips, fleahoppers, boll weevils, and the CBW/TBW complex. The rank in importance of these pests and control programs employed vary by growing region within the state. In some years, the beet armyworm is also a major economic pest. The pink bollworm (PBW) can also be a problem in West Texas, primarily in the Pecos and El Paso areas.

The boll weevil has also been eradicated from Arizona. The PBW is a major pest in that state, and in recent years the silverleaf whitefly (strain B of the sweet potato whitefly) has been a major problem. Cotton grown in California's Southern Interior region is also affected by the silverleaf whitefly and the PBW. Spider mites and Lygus bugs are the major pests of cotton grown in the San Joaquin Valley, California's principal growing region. The PBW is controlled there with sterile male releases.

Table 13 lists the leading insecticides used for cotton in 1995 by chemical class and indicates the target pests of each product. Synthetic pyrethroids are the primary class of insecticides used for cotton in North Carolina and Georgia because they are economical and efficacious. In these states, the TBW and CBW are still susceptible to pyrethroids. Other products such as Curacron®, Larvin®, and Lannate®, although more expensive, have some use in tank mixes with pyrethroids. The specific products used by individual growers vary from year to year.

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Table 13
PRINCIPAL INSECTICIDES USED TO CONTROL MAJOR INSECT PESTS OF U.S. COTTON, 1995

Product Class/ Common Name	Trade Name	Cotton Bollworm	Tobacco Budworm	Boll Weevil	Aphids	Plant Bugs	Thrips	Beet Armyworm	Other Pests
Biological/ Biologically-Based									
Bts	Various		X						Loopers
Microbially-Derived Toxins									
abamectin	Zepher®								Spider Mites
Conventional Chemistry									
Carbamate									
aldicarb	Temik®						X		Nematodes
carbofuran	Furadan®				X				
methomyl	Lannate®	X	X			X			Fleahoppers Fall armyworm
oxamyl	Vydate®			X		X			
thiodicarb	Larvin®	X	X	X				X	Fall armyworm Loopers
Chlorinated Hydrocarbon									
endosulfan	Phaser®, Thiodan®						X		
Organophosphate									
acephate	Orthene®		X	X		X	X		Fleahoppers Fall armyworm
azinphos-methyl	Guthion®			X		X			

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Table 13 (Continued)
PRINCIPAL INSECTICIDES USED TO CONTROL MAJOR INSECT PESTS OF U.S. COTTON, 1995

Product Class/ Common Name	Trade Name	Cotton Bollworm	Tobacco Budworm	Boll Weevil	Aphids	Plant Bugs	Thrips	Beet Armyworm	Other Pests
Organophosphate (Continued)									
chlorpyrifos	Lorsban®		X	X	X	X		X	Spider Mites Fleahoppers Fall armyworm Cutworms
dicrotophos	Bidrin®			X	X	X	X		Fleahoppers
dimethoate	Cygon®, Dimethoate					X	X		
malathion	Malathion			X					
methyl parathion	Penncap® M, Methyl Parathion			X	X	X	X		Fleahoppers
profenofos	Curacron®	X	X		X	X			Spider Mites Fleahoppers Fall armyworm
Synthetic Pyrethroid									
bifenthrin	Capture®	X	X	X	X	X		X	Spider Mites Fleahoppers Whiteflies Loopers
cyfluthrin	Baythroid®	X	X	X	X	X	X	X	Fleahoppers Whiteflies Loopers Cutworms
cypermethrin	Fury®, Mustang®	X	X	X		X	X	X	Fall armyworm Cutworms

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Table 13 (Continued)
PRINCIPAL INSECTICIDES USED TO CONTROL MAJOR INSECT PESTS OF U.S. COTTON, 1995

Product Class/ Common Name	Trade Name	Cotton Bollworm	Tobacco Budworm	Boll Weevil	Aphids	Plant Bugs	Thrips	Beet Armyworm	Other Pests
Synthetic Pyrethroid (Continued)									
esfenvalerate	Asana®	X	X	X	X	X	X	X	Fleahoppers Whiteflies Loopers Cutworms
fenpropathrin	Danitol®								
lambda-cyhalothrin	Karate®								Cutworms
tralomethrin	Scout®								Cutworms
Other Organic									
amitraz	Ovasyn®	X	X	X					
diflubenzuron	Dimilin®			X				X	Fall armyworm Loopers
New Chemistry									
imidacloprid	Admire®, Provado®				X	X	X		Whiteflies

Source: SRI Consulting

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Insecticide Use and Market Value, 1995

In 1995, an estimated 80% of the U.S. cotton acreage received at least one insecticide application, and an average of 7.4 applications were made per treated acre (see Table 14). In terms of treatments, the cotton insecticide market amounted to 99.9 million treatment acres. The Mid-South region accounted for 46% of the cotton insecticides market, based on treatment acres. On average, 10.4 applications were made on 91% of the planted acres in that region.

Table 14
INSECTICIDE USE FOR U.S. COTTON BY REGION, 1995

Region/State	Planted Acres (1,000)	Treated Acres: Percent of Planted Acres	Treated Acres: 1,000 Acres	Average Number of Applications[a]	Insecticide Treatment Acres (1,000)
Southeast	3,460.0	92	3,183.2	6.9	22,035.7
Mid-South	4,877.0	91	4,438.1	10.4	46,133.5
Southern Plains	6,819.8	61	4,160.1	5.0	20,800.4
West	1,774.6	96	1,703.6	6.4	10,940.4
United States, Total	16,931.4		13,485.0		99,910.0
Average		80		7.4	

[a]Components of tank mixes and premixes are counted as separate applications.
Source: SRIC estimates.

U.S. cotton growers spent an estimated $592 million for the insecticide products they applied in 1995. Figure 6 shows the breakdown of the cotton insecticides by product class in terms of both treatment acres and grower expenditures, and Table 15 provides a further breakdown by individual insecticide active ingredient within each class.

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Figure 6

U.S. COTTON MARKET FOR INSECTICIDES BY PRODUCT CLASS, 1995

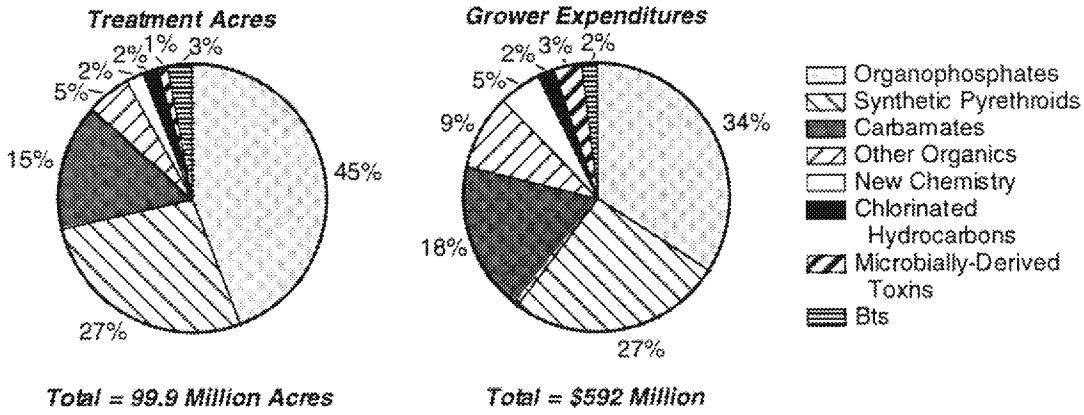

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Table 15
U.S. COTTON INSECTICIDE MARKET BY PRODUCT CLASS, 1995

Product Class/ Active Ingredient	Treatment Acres[a] 1,000 Acres	Class/ Product Share (%)	Grower Expenditures (1,000 Dollars)	Class/ Product Share (%)
Biological/Biollogically Based				
Bacillus thuringiensis	3,343.7	3.3	12,137.1	2.1
Microbially Derived Toxin				
abamectin	680.0	0.7	16,723.5	2.8
Total	4,023.7	4.0	28,860.6	4.9
New Chemistry				
imidacloprid	1,800.0	1.8	21,285.0	3.6
tebufenozide	600.0	0.6	8,415.0	1.4
Total	2,400.0	2.4	29,700.0	5.0
Conventional Chemistry				
Carbamate				
aldicarb	2,790.3	2.8	34,144.9	5.8
thiodicarb	4,673.1	4.7	24,680.8	4.2
oxamyl	3,521.7	3.5	20,338.0	3.4
methomyl	2,587.1	2.6	17,745.1	3.0
carbofuran	1,777.8	1.8	6,655.0	1.1
Subtotal	15,350.0	15.4	103,563.8	17.5
Chlorinated Hydrocarbon				
endosulfan	1,168.3	1.2	7,412.7	1.3
dicofol	450.0	0.5	6,323.9	1.1
Subtotal	1,618.3	1.6	13,736.5	2.3
methyl parathion	17,168.4	17.2	46,140.2	7.8
profenofos	4,622.3	4.6	44,204.6	7.5
chlorpyrifos	3,489.6	3.5	30,367.6	5.1
acephate	4,825.4	4.8	20,521.2	3.5
azinphos-methyl	3,115.4	3.1	13,084.6	2.2
malathion	3,555.6	3.6	11,925.5	2.0
others[b]	2,763.2	2.8	15,815.4	2.7
Subtotal	44,382.3	44.4	202,273.6	34.2

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Table 15 (Concluded)

Product Class/ Active Ingredient	Treatment Acres[a] 1,000 Acres	Class/ Product Share (%)	Grower Expenditures (1,000 Dollars)	Class/ Product Share (%)
Conventional Chemistry (Concluded)				
Synthetic Pyrethroid				
lambdacyhalothrin	7,822.3	7.8	47,070.0	8.0
cypermethrin/ zeta-cypermethrin	6,095.3	6.1	31,305.5	5.3
cyfluthrin	5,689.0	5.7	24,661.6	4.2
bifenthrin	1,354.5	1.4	22,500.3	3.8
fenpropathrin	1,117.5	1.1	14,422.1	2.4
tralomethrin	2,370.4	2.4	12,378.7	2.1
esfenvalerate	2,251.9	2.3	6,399.8	1.1
Subtotal	26,700.8	26.7	158,738.0	26.8
Other Organic				
diflubenzuron	1,676.2	1.7	26,819.3	4.5
propargite	507.9	0.5	9,827.8	1.7
amitraz	948.2	0.9	6,343.2	1.1
others[c]	2,302.7	2.3	12,158.1	2.1
Subtotal	5,435.0	5.4	55,148.4	9.3
Total	93,486.4	93.6	533,460.3	90.1
Total, All Classes	99,910.1	100.0	592,020.9	100.0

[a]Treatment acres for each product include applications alone and in tank mixes and premixes.

[b]Dicrotophos, phorate, naled, and others.

[c]Includes pheromone-based products (about 20 thousand treatment acres) and some other products in the major chemical classes.

Source: SRIC estimates based on USDA data.

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MARKET TRENDS AND ISSUES

New Technologies

Transgenic Insect-Resistant Plants

The first Bt cotton varieties developed by Monsanto and Delta & Pineland Co. were launched in 1996. Table 16 lists the insect-resistant cotton technologies that are expected to be on the market by 2002.

Table 16
TRANSGENIC INSECT RESISTANT COTTON PLANTS AVAILABLE OR UNDER DEVELOPMENT IN THE UNITED STATES

Technology	Trade Name	Target Pest(s)[a]	Developing Company	Year on the Market
Bt Cotton	Bollgard®	TBW CBW PBW	Monsanto/Delta & Pine Land	1996
Bt Cotton	NA	CBW	Mycogen	2000-2002
Dual Gene Bt Cotton	NA	TBW CBW PBW	Monsanto	1999
Cholesterol Oxidase Cotton	NA	BW	Monsanto	2000-2002
Bt + Bromoxynil-Tolerant Cotton	STN474 Bollgard® + BXN®	TBW CBW	Calgene/Stonevil le Pedigreed Seed Company	998
Bt + Glyphosate-Tolerant Cotton	Bollgard® + Roundup® Ready	TBW CBW PBW	Monsanto	1998-1999

[a]BAW = beet armyworm; BW = boll weevil, CBW = cotton bollworm, CL = cabbage looper; PBW = pink bollworm, TBW = tobacco budworm.

Sources: Communications with industry and university pest management specialists and trade literature.

Other companies have conducted field trials and/or are developing insect-resistant cotton plants (see Tables A-3 and A-4 in the Appendix). Northrup King (now Novartis Seeds) field tested glyphosate-tolerant/Lepidopteran-resistant cotton in 1990, and American Cyanamid and Bayer both conducted field trials of Coleopteran-resistant/Lepidoptern-resistant and bromoxynil-tolerant/Lepidopteran-resistant cotton plants in 1993.

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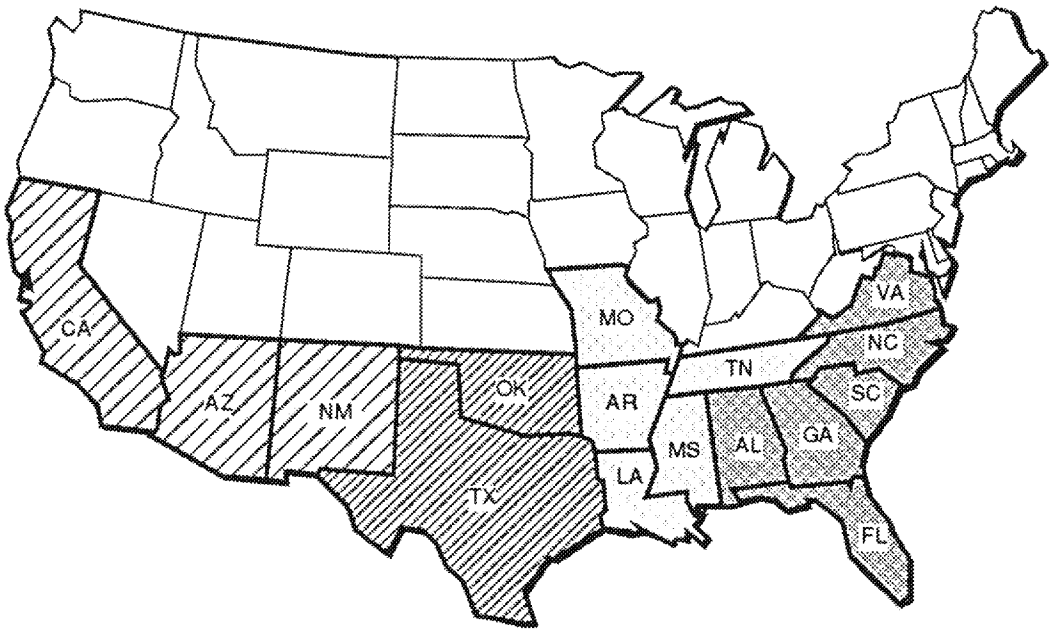
Three Bt cotton varieties containing Monsanto's Bollgard® gene were marketed in 1996 by Delta & Pineland Co. under the trade name NuCOTN™. On the basis of seed sales and the technology licensing contracts signed by growers who purchased NuCOTN™ seed, Delta & Pineland estimates that the transgenic seed was planted on 1,821,000 acres, equivalent to about 12% of the U.S. planted cotton crop acreage.

Figure 7 shows the distribution of U.S. Bt cotton plantings in 1996 and Table 17 presents a breakdown of the Bt cotton plantings by individual state.

Figure 7
BT COTTON PLANTINGS BY REGION, 1996



REGION	Planted Acres (1,000)	BT Cotton Acres (1,000)	BT Cotton Acres Percent of Planted Acres
Southeast	3,098	868	28
Mid-South	3,940	745	19
Southern Plains	6,032	140	2
West	1,596	68	4
Total	14,666	1,821	12

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Table 17
U.S. BT COTTON PLANTINGS BY REGION AND STATE, 1996

Region/State	Total Cotton Plantings (1,000 Acres)	Bt Cotton Plantings: 1,000 Acres	Bt Cotton Plantings: Percent of Total Cotton Plantings
Southeast			
Georgia	1,350.0	358	27
North Carolina	721.0	21	3
Alabama	540.0	430	80
South Carolina	284.0	48	17
Virginia	103.0	--	--
Florida	100.0	11	11
Subtotal/Average	3,098.0	868.0	28
Mid-South			
Mississippi	1,120.0	440	39
Arkansas	1,000.0	156	16
Louisiana	890.0	138	16
Tennessee	540.0	10	2
Missouri	390.0	1	NEG
Subtotal/Average	3,940.0	745.0	19
Southern Plains			
Texas	5,737.0	118	2
Oklahoma	290.0	22	8
Kansas	4.5	NA	NA
Subtotal/Average	6,031.5	140.0	2
West			
California	1,165.0	1	NEG
Arizona	357.0	64	18
New Mexico	74.0	3	4
Subtotal/Average	1,596.0	68.0	4
Total/Average	14,665.5	1,821	12

Sources: Delta & Pineland Company (data for NuCOTN Acres)and USDA (data for Total U.S. Cotton Plantings)

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Mississippi State University cotton insect control specialists have rated Bollgard® cotton's effectiveness against major cotton insect pests. They found that the transgenic cotton provides excellent control of TBW and good control of CBW (see Table 18).

Table 18
RELATIVE ACTIVITY OF BOLLGARD® COTTON AGAINST SPECIFIC COTTON INSECT PESTS

Pest	Activity
Tobacco Budworm	Excellent
Cotton Bollworm	Good
Loopers	Good
Beat Armyworm	Suppression
Fall Armyworm	Little activity
Cutworms	Little activity
Noncaterpillar Pests	None

Source: Publication 2108, 1996, Mississippi State University, Cooperative Extension Service

The initial target markets for Bt cotton are states that have a history of problems with insecticide-resistant TBW—Alabama, parts of Arkansas, Mississippi, Louisiana, and Texas—and with PBW control in Arizona. TBW is expensive to control—the cost can be as high as $200 per acre. Growers will plant Bt cotton to avoid incurring TBW control costs and/or potential yield losses.

Most of the Bt cotton plantings in 1996 were in the Southeast and Mid-South regions. Bt cotton accounted for 80% of Alabama's total cotton crop acreage and for 39% of Mississippi's total planted acreage in 1996. Although they do not have TBW/CBW-resistance problems, Georgia growers planted Bt cotton on 27% of their total crop acreage because the varieties available were well adapted to growing conditions in the state.

Adoption of Bt cotton in other cotton growing regions will be limited until the cost of the technology is reduced and/or until stacked gene varieties with multiple resistance traits become available.

Georgia growers who planted Bt cotton in 1996 were generally pleased with the results, although it is not yet clear if the technology provides an economic advantage over conventional varieties treated with insecticides. A small percent of the Bt cotton acreage had to be sprayed for CBW control. In most cases, only one application was needed, but a few growers had to apply two or three bollworm sprays. Overall, about 20% of the Georgia Bt cotton acreage had to be sprayed at least once for CBW control.

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Georgia's non-Bt cotton plantings received fewer than 3 insecticide application in 1996, with an average cost of about $10 per acre, including $7 for the insecticide and $3 for application. Thus, non-Bt cotton growers' season-long cost for insect control was less than the cost of the Bt cotton ($32 to use the technology, plus a seed premium).

Nevertheless, about 90% of growers in the southeastern part of the state who planted Bt cotton in 1996 will grow it again in 1997. However, a smaller percentage of repeat users is expected in the southwest part of the state, which was a problem area in 1996. Overall, a slight increase in Bt cotton plantings is expected in Georgia in 1997.

Bollgard® cotton's immediate adoption in Alabama (80% of planted acres in 1996) is attributed to the state's severe problems with insecticide-resistant TBW. The problem occurred mainly in the areas that received area-wide malathion sprays for boll weevil eradication and affected both the 1994 and 1995 crops. Some areas of the state suffered two years of almost total crop losses; no existing insecticide would control the TBW. Alabama cotton growers, therefore, had a real need for new technology and readily adopted it as insurance against TBW losses. Most planted Bt cotton on 96% of their cotton land.

According to results of a grower survey conducted by Auburn University, 93% of those who planted Bt cotton were satisfied or very satisfied with the new technology and stated that their yields were as good as or better than yields of non-Bt cotton varieties. The other 7% of growers, mostly in the southern part of the state near the Gulf Coast, were dissatisfied because they had to spray for bollworms and fall armyworms.

CBW infested all Alabama cotton growing areas in 1996, and escapes (from control by Bt cotton) were numerous and most prevalent in areas that had no beneficials in the system (i.e., where sprays for Lygus or other plant bugs had been applied). Bt cotton needs beneficials to help control CBW. When no beneficials exist, even with Bollgard® technology, spraying may be required for CBW control. However, because inexpensive synthetic pyrethroid insecticides are still quite effective against CBW, the total control costs will be affordable.

Alabama growers are expected to plant somewhat fewer acres of Bt cotton in 1997 than in 1996, despite their high level of satisfaction with the new technology. In 1996, most Alabama growers who planted Bt cotton elected the "96-4" refuge option, as opposed to the "80-20" option. Under the 96-4 option, 4% of each grower's cotton acreage must be non-Bt cotton, and it may not be sprayed with any insecticide. Because 1996 was a year of generally low insect pressure, cotton yields were high, even on the 4% refuge acres. Consequently, in 1997, many growers are expected to choose the 80-20 refuge option, under which they will plant Bt cotton on 80% of their acreage and conventional cotton on 20%, and be allowed to treat the 20% refuge acreage with insecticides, but not foliar Bts.

Most Alabama growers also found some negative aspects of using the Bollgard®, including:

- "Up front" payment for the technology.

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- Preferred varieties not having the Bollgard® gene incorporated (This problem will be solved in 1998, however.)
- Requirement for signing a licensing agreement prepared by attorneys that specified potential fines of thousands of dollars should they save seed to plant the following year.

Nonetheless, Alabama cotton pest managers state that the availability of Bt cotton has enabled the state's growers to grow cotton at a profit again. In 1994 and 1995, they typically spent from $75 to $150 per acre for insecticides. In 1996, however, most of those who planted Bt cotton spent only about $10 per acre for insecticides in addition to the $32 per acre license fee for Bollgard® and the $4–6 per acre seed cost premium, for a total of $46–48 per acre.

Bt cotton accounted for about 16% of Louisiana's total cotton acreage in 1996. Growers' level of satisfaction with the technology varied. Yields were generally favorable—up to 33% above the average yields for non-Bt varieties. However, 1996 was not a typical season. Weather conditions were unusually favorable, allowing the long-season, late-maturing Bt cotton varieties to achieve yields as good as those with the conventional shorter season cotton varieties that are normally grown in the state. Late maturity is a serious issue in Louisiana cotton production. In typical seasons, late-maturing varieties incur increased production costs and are susceptible to weather-induced losses.

The use of Bt cotton constitutes preventative control, whereas application of foliar insecticides constitutes reactive control. Many growers would rather not pay the up-front cost for Bt cotton, preferring instead to take the chance that their spraying costs will be less than the cost of Bt cotton. However, annual plantings of Bt cotton will reflect growers' experience in the previous season. Large fluctuations in Bt cotton plantings from year to year are thus likely, but state cotton insect control specialists predict that Bt cotton will increase to 20–33% of Louisiana's total cotton plantings in 1997.

Results achieved with the available late-maturing Bt cotton varieties in Arkansas in 1996 were poor. Late rains caused the Bt cotton plants to keep growing too long. Thus plantings in the state are unlikely to increase until shorter season varieties are available.

Bt cotton accounted for just 2% of Texas' cotton crop acreage in 1996 and for 8% of Oklahoma's much less extensive cotton acreage. Oklahoma and Central and North Texas do not constitute a large potential market for Bt cotton, given that TBW and CBW infestations in these areas are usually not heavy.

In the Coastal Bend area (around Corpus Christi), Bt cotton accounted for 5-6% of the total cotton plantings. Plantings in this area will increase in 1997, primarily because Delta and Pineland Company has offered to pay a $500 incentive to any producer who plants 50 acres of Bt cotton next to non-Bt cotton of any variety, and provides the company with yield comparison data. Consultants in the area expect 75–80% of growers to plant at least 50 acres of Bt cotton. For the entire area, Bt cotton is expected to account for 10% or more of the total cotton plantings.

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Except when cotton is planted late, TBW resistance to insecticides is not a problem in this area. Consultants emphasize that IPM and most insect control for cotton is finished by July 1, before TBW resistance problems develop. Before July 1, TBW/CBW infestations are controlled economically with foliar insecticide applications. However, when cotton is planted late or has to be replanted for some reason, insecticide-resistant TBW can be a major problem.

In addition, growers are aware of favorable results achieved with a Bollgard® variety in a 1996 variety testing program. The Bt cotton variety ranked the highest in average yield against all non-Bt varieties tested at seven locations. The principal benefits to growers of Bt cotton in this area are:

- Higher yield
- A higher level of caterpillar control, including substantially less damage from cabbage loopers
- Somewhat less damage from beet armyworms
- A very significant reduction in damage from tobacco budworms in late-planted cotton.
- Significantly less damage from CBW, although insecticide treatments will be required for heavy infestations
- Reduced concerns about the consequences of treating for aphids, boll weevil, and fleahoppers. The insecticides used against these pests destroy the natural enemies that help control TBW/CBW.
- Fewer insecticide sprayings overall and reduced insecticide costs.

As in the Mid-South, the lack of shorter season, early maturing Bt cotton varieties is a current problem in the Coastal Bend area. The "steep" up-front cost of the Bollgard® technology is also viewed as a problem in this area.

Little Bollgard® seed was available in Central and West Texas in 1996, but where it was planted, it performed well. Throughout Texas, growers of irrigated cotton are expected to be more inclined to plant Bt cotton than growers of dryland cotton. Irrigation promotes more rank growth in cotton plants and more problems with insect infestations.

Bt cotton accounted for 18% of Arizona's total cotton acreage in 1996, and is expected to account for a higher percentage in 1997. The PBW is the target pest in Arizona. The Bollgard® varieties available in 1996 were well-suited for Arizona growing conditions. Overall, this state had the greatest success of all U.S. states with the Bt cotton technology. It performed extremely well against heavy PBW infestations and provided both substantial pesticide cost savings and yield improvements. Beneficials were preserved in the Bollgard® acreage and they kept whiteflies under control.

Bt cotton is not a "fit" for California, except perhaps on the small portion of the state's cotton acreage found in the Southern Interior region where PBW infestations occur. California does not have serious budworm/bollworm problems and sterile male releases are used to control PBW in the major San Joaquin Valley growing region.

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Biological/Biologically Based Insect Control Products

Table 19 lists new biological or biologically based insect control products that have been launched in the U.S. cotton market since 1995 or that are expected to be commercialized before 2005.

Table 19
NEW BIOLOGICAL/BIOLOGICALLY BASED COTTON INSECT CONTROL TECHNOLOGIES AND PRODUCTS

Technology/ Product	Trade Name	Target Pest(s)[a]	Developing Company	Year on the Market
Bts				
Nonrecombinant				
Bt var. kurstaki, Strain M-200	Able®	Lepidoptera	Novartis	1996
Bt var. kurstaki, Strain EG2371	Condor® XL	Lepidoptera	Ecogen	1996
Bt var. kurstaki	CoStar®	Lepidoptera	Novartis	1997
Bt var. kurstaki	Troy Bt	Lepidoptera	Troy Biosciences	1996
Recombinant				
ABG-6413	--	Lepidoptera	Abbott Laboratories	NA
Bt var. kurstaki, Strain EG 7841 Crymax™		Lepidoptera	Ecogen	1996
Encapsulated delta endotoxins of Bt var. aizawai	M/C	BAW	Mycogen	1997
Encapsulated blend of CryIA(c) and Cry IC derived delta endotoxins of Bt	Mattch®	Armyworms CBW/TBW Loopers	Mycogen	1996
Encapsulated delta endotoxin of Bt var. kurstaki	MVP II	Armyworms CBW/TBW Loopers	Mycogen	1996
Viruses				
Naturally Occurring				
Helicoverpa zea NPV	GemStar®	CBW/TBW	Thermo Trilogy	1996
Spodoptera exigua NPV	Spod-X®	BAW	Thermo Trilogy	1995

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Table 19 (Concluded)

Technology/ Product	Trade Name	Target Pest(s)[a]	Developing Company	Year on the Market
Viruses (Continued)				
Recombinant				
Autographa californica (AcNPV)	--	CBW/TBW	American Cyanamid	NA
Autographa californica (AcMNPV)	--	BAW CL CBW/TBW	DuPont	NA
Heliothis zea NPV	--	CBW		NA
Fungi				
Beauvaria bassiana, Strain GHA	Mycotrol™	Aphids Lygus Thrips Whiteflies Others	Mycotech Corporation	1996
Beauvaria bassiana, Strain JW-1	Naturalis® L	All major cotton pests except PBW	Troy Biosciences	1996
Botanical Insecticides				
azadirachtin	Neemix®	Broad spectrum	Thermo Trilogy	NA
Pheromone-Based Products				
Mating Disruptant	Frustrate® PBW	PBW	Thermo Trilogy	1996
Microbially -Derived Toxins				
emamectin, MK-244	Proclaim®	BAW CL CBW/TBW	Merck AgVet	1998
spinosad	Tracer®	BAW Boll Weevil CL CBW/TBW PBW	DowElanco	1997

[a]BAW = beet armyworm; BW = boll weevil, CBW = cotton bollworm, CL = cabbage looper; PBW = pink bollworm, TBW = tobacco budworm.

Sources: Communications with industry and university pest management specialists and trade literature.

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Although the cotton market for Bt-based products is expected to continue to decline, several new Bt-based products have been launched in this market since 1995 or are scheduled to be launched in 1997. Their success will depend on their cost-effectiveness versus existing Bt products for use on conventional (non-Bt) cotton.

Thermo Trilogy produces and markets naturally occurring virus-based insecticides (GemStar® and Spod-X®), which are distributed by Helena Chemical Company. American Cyanamid and Du Pont are working with recombinant baculoviruses, which are very safe, target-specific, and moderately efficacious. Problems associated with both naturally occurring and recombinant viruses for crop insect control include:

- Slowness to kill
- Lack of persistence in the field
- High production costs; they currently are produced *in vivo*.

Viruses that kill in hours instead of days have been evaluated in recent field trials; if the persistence problem can be solved, new recombinant virus-based products could be on the market within 2 to 3 years.

Two new insecticides based on microbially derived toxins will compete with Bt cotton for TBW/CBW control. DowElanco's spinosad (Tracer®) received its first U.S. crop registration for cotton in March 1997. The company expects to sell enough product in the U.S. cotton market in 1997 to treat about 1 million acres. Emamectin benzoate (Proclaim®) has been under development for cotton for several years and is expected to be commercialized in 1998.

New Chemistry

Table 20 lists 10 insecticides based on novel chemistries that are under development for U.S. cotton, identifies their target pests, the developing companies, and when the information was available, indicates the expected year of market launch. One of the new products, imidacloprid (Admire®, Provado®), has been sold for cotton since 1995.

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Table 20
NEW CHEMICAL INSECTICIDES RECENTLY LAUNCHED OR UNDER DEVELOPMENT FOR U.S. COTTON

Product	Trade Name	Target Pest(s)[a]	Developing Company	Year on the Market
acteamiprid	Mospilan®	Whiteflies	Rhone-Poulenc	NA
buprofezin	Applaud®	Whiteflies	AgrEvo	1999
chlorfenpyr	Pirate®, Alert®	BAW CBW Spider mites	American Cyanamid	1998
DPX-KN 128	--	Lepidoptera	DuPont	NA
fenoxycarb[b]	Precision®	Aphids Whiteflies	Novartis	1998-1999
fipronil	Regent®	BW Plant bugs Thrips	Rhône-Poulenc	1998 (EUP 1996)
imidacloprid[b]	Admire®, Provado®	Aphids Plantbugs Whiteflies	Bayer	1995
pymetrozine (CG 215944)	Fulfil®	Aphids Whiteflies	Novartis	1999
pyriproxyfen	Knack®	Aphids Whiteflies	Valent	1997
methoxyfenozide (RH 2485)	Intrepid®	AW CL CBW/TBW PBW	Rohm and Haas	1998
tebufenozide	Confirm®	CBW/TBW	Rohm and Haas	1997
vanilprole	Evaluation®	Broad spectrum; insects and mites	Rhône-Poulenc	NA

[a]BAW = beet armyworm; BW = boll weevil, CBW = cotton bollworm, CL = cabbage looper; PBW = pink bollworm, TBW = tobacco budworm.

[b]Cotton will be a new U.S. crop market for this product.

Sources: Communications with industry and university pest management specialists and trade literature.

Issues

Boll Weevil Eradication

In 1973, it was estimated that insecticides applied to control the cotton boll weevil accounted for about one-third of the total volume of insecticides applied for all U.S.

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agricultural crops. The success of a 1971–1973 cooperative boll weevil eradication experiment involving federal and state agencies and grower associations in portions of Mississippi, Louisiana, and Alabama led to two 3-year demonstration projects. One was an optimum pest management trial in Mississippi, and the other was an eradication trial in North Carolina and Virginia. The Mississippi trial demonstrated the feasibility of boll weevil eradication using existing technology, and in 1980 the eradication trial was proclaimed an overwhelming success; boll weevil control costs were reduced by a factor of 7–8, and cotton acreage and related industries increased.

Since 1980, the program has undergone regular incremental expansion, with the eventual goal of eradicating the boll weevil from the United States. The present program is a cooperative program of the USDA's Animal and Plant Health Inspection Service (APHIS), the Cooperative Extension Services, state departments of agriculture, and cotton producers. The producers vote on a region-by-region basis to approve the program. In each region, the program is administered and partially (30%) funded by APHIS, but grower assessments and/or state appropriations provide most (70%) of the funding.

In the program, insecticides are applied on the basis of the number of adult weevils trapped around cotton fields. One to three pheromone and insecticide baited traps are placed per acre and are checked weekly. Pesticides are applied only to fields where trapped weevil counts reach a predetermined number, thereby minimizing treatments. After several seasons, boll weevils are eradicated within the defined program area and additional spraying for the pest is unnecessary.

Successful eradication efforts have virtually eliminated the boll weevil from Virginia, North Carolina, South Carolina, Georgia, Florida, south Alabama, and middle Tennessee. Less than 10% of the cotton acreage in these states required program treatment for boll weevil reproduction in 1996.

Benefits to cotton growers of boll weevil eradication include reduced crop production costs, increased yields, and the ability to better address increasing public concerns about the effect of agricultural pesticides on the environment. When eradication has been accomplished, insecticide use for cotton has been reduced by 40–90%, and cotton acreage has increased dramatically. For example:

- North Carolina's cotton plantings increased from about 40,000 acres per year before its boll weevil program began in 1978 to 805,000 acres in 1995.
- Cotton plantings in Georgia increased five-fold—from 275,000 acres in 1987 when that state's eradication program began to 1.5 million in 1995,
- Boll weevil eradication eliminates the need for early season insecticide applications in many areas and allows beneficial insects to increase to levels that provide biological control of secondary cotton pests.

Despite the benefits of boll weevil eradication, the program has been controversial in some areas of Texas and Mississippi—area-wide sprays of malathion used to kill boll weevils also eliminate beneficial insects that normally help control secondary pests. In

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1995, severe crop losses occurred in Texas's Lower Rio Grande Valley because of uncontrollable beet armyworm infestations, which some attribute to the use of malathion. In eastern Mississippi, other areas of the Mid-South, and Alabama, uncontrollable TBW infestations reduced yields significantly and were blamed on malathion sprays for the boll weevil.

Growers in these regions are thus considering whether they can survive potentially destructive outbreaks of secondary pests during the first year or two of boll weevil eradication to achieve the economic and environmental benefits of eradication in the years that follow.

Resistance Management

Monsanto received conditional approval to market cotton plants containing the Bollgard® gene in 1995, subject to the development of an effective resistance management plan. Monsanto has developed three resistance management strategies. The 2 basic strategies are the 96–4% (96% Bollgard® cotton and 4% conventional cotton) and 80–20% strategies. The third is planting soybeans and corn near the cotton as a refuge strategy.

Monsanto sampled fields of about 25% of Bollgard® growers in summer 1996, sampling leaf tissue to verify that fields that were supposed to be refuges were not planted with Bt cotton. Results of the sampling indicated greater than 98% compliance with the licensing agreement.

Monsanto and the USDA's Agricultural Research Service will undertake cooperative research on strategies to prevent the build-up of resistance to Bt toxins in transgenic cotton plants. The USDA will evaluate cotton plants carrying two Bt genes rather than a single gene, and assess the effect of mixing transgenic and conventional cotton plants.

The concurrent development and commercialization of Bt cotton, new biologically based insecticides, and new chemistry will also allow cotton growers more options to minimize insect resistance problems.

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MARKET PROJECTIONS, 2000 AND 2005

Total Market

Table 21 presents projections for the U.S. cotton insect control market in 2000 and 2005, in terms of product treatment acres and type of technology.

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Table 21
U.S. COTTON INSECT CONTROL MARKET BY TYPE OF TECHNOLOGY, 1995-2005[a]
(Thousands of Acres)

Technology/ Product Group	1995	2000	2005
Transgenic Insect-Resistant Plants	--	4,000-5,000	5,000-6,000
Applied Pest Control Products			
Biological/Biologically Based			
Bts	3,343.7	2,500-3,000	2,000-3,000
Viruses	NEG	300-900	500-1,000
Nematodes	--	0-10	0-20
Botanicals	--	0-150	150-300
Pheromone-Based Products	--[b]	20-30	20-30
Microbially derived toxins	680.0	2,500-3,000	3,500-4,500
Total	4,023.7	5,320-7,090	6,170-8,850
New Chemistry	2,400.0	5,000-6,000	7,000-9,000
Conventional Chemistry			
Carbamates	15,350.0	11,000-12,000	9,250-10,000
Chlorinated Hydrocarbons	1,618.3	1,200-1,500	950-1,100
Organophosphates	44,382.3	32,000-34,000	27,000-29,000
Synthetic Pyrethroids	26,700.8	21,000-23,000	18,000-20,000
Other Organic	5435.0	3,500-4,000	2,000-4,000
Subtotal	93,486.4	68,700-74,500	57,200-64,100
Total	99,910.1	79,020-87,590	70,370-81,950
Total, All Products	99,910.1	83,020-92,590	76,540-90,800

[a]Based on an assumed total planted acreage of 14 million acres in both 2000 and 2005. Data for transgenic insect-resistant plants are for planted acres; data for applied pest control products are for treatment acres.

[b]In 1995, pheromone-based products (about 20 thousand treatment acres) are included with "Other Organic" insecticides under Conventional Chemistry.

Source: SRI Consulting

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Transgenic Insect-Resistant Plants

Table 22 summarizes estimates and projections for the U.S. market for transgenic insect-resistant cotton seed. In 1997, Bt cotton plantings will be limited by seed availability but are expected to increase by about 32% to about 2.4 million acres. NuCOTN™ 33 and NuCOTN™ 35 will remain the two major Bollgard® varieties, but enough seed to plant about 100,000 acres of new varieties will be available.

Delta and Pineland Co. is concentrating on building up a supply of seed for new Bollgard® varieties in 1997. In 1998, it will market three new varieties with both Bollgard® and Roundup-Ready® genes. The company's Paymaster subsidiary will also have 10 new Bollgard® varieties in 1998, 5 with single Bt genes and 5 with stacked Bollgard® and Roundup Ready® genes. In 1998, Bt cotton varieties are expected to be planted on some 3.5 million acres and account for 25% of U.S. cotton crop acreage. By 2000, insect-resistant cotton varieties will account for 29–36% of U.S. cotton plantings, and by 2005, they will account for 36–43%.

Table 22
U.S. MARKET FOR TRANSGENIC INSECT-RESISTANT COTTON, 1995-2005

Year	Planted Acres (Thousands)	Grower Expenditures (Millions of Dollars)
1995	--	--
1996	1,821	65
1997	2,400	84
1998	3,500	119
2000	4,000-5,000	120-150
2005	5,000-6,000	140-165

Source: SRIC estimates

A considerable amount of R&D is under way for stacked-gene, multiple resistance trait cotton varieties. A Texas cotton consultant remarked that when Bollgard®+ Roundup Ready® varieties become available, they will be "hard not to buy."

Entomologists at the USDA's Western Cotton Research Laboratory in Arizona are considering the feasibility of inserting insecticidal genes of plants that are sources of botanical insecticides (e.g., *Nicotiana*, neem) into cotton plants.

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Applied Insect Control Products

On the basis of treatment acres, the U.S. cotton insecticides market will decline by at least 18% and as much as 30% by 2005. Insecticide treatments will drop from 99.9 million treatment acres in 1995 to 79.0 million–87.6 million treatment acres in 2000, and to 70.4 million–82.0 million treatment acres by 2005. Market acceptance of transgenic insect-resistant cotton, which requires substantially fewer insecticide applications than conventional cotton varieties, and replacement of conventional chemical insecticides with new biologically based and novel chemical insecticides will be the two major causes of the projected decline in insecticide use for cotton. Many of the new products are effective for extended periods, and thus they will not need to be applied as frequently as conventional chemical insecticides.

Biological/Biologically Based Products

Use of biological and biologically based insecticides for cotton will increase by 53–120% between 1995 and 2005, led by rapid adoption expected for two new products based on microbially derived toxins. Spinosad (Tracer®), was launched in time for the 1997 cotton season, whereas emamectin (Proclaim®) is not expected on the market until 1998.

As Bt cotton plantings increase and novel new insecticides for TBW and CBW control are launched in the cotton market, the use of applied Bt-based insecticides for cotton is expected to continue to decline. Applied Bts are expected to be less cost-effective than the newer technologies for Lepidoptera control in cotton.

Assuming that recombinant virus-based products are commercialized, use of virus-based insecticides (both natural and recombinant) for U.S. cotton will amount to 300,000–900,000 treatment acres in 2000 and 500,000–1 million treatment acres by 2005. Use of pheromone-based products for control of PBW and mites in cotton will amount to 20,000–30,000 treatment acres in both 2000 and 2005. Botanical insecticides based on azidarachtin may be on the market for cotton by 2000; by 2005, they are expected to be applied on 150,000-300,000 treatment acres.

New Chemistry

New insecticides based on novel chemistry will account for 6–7% of the U.S. cotton market for insecticides by 2000 and for 10–11% by 2005. New chemical insecticide treatments will increase from 2.4 million treatment acres in 1995 to 5–6 million treatment acres in 2000, to 7–9 million treatment acres in 2005.

Conventional Chemical Insecticides

An overall decline of 31–39% is projected for conventional chemical insecticides in the cotton market by 2005 as they are displaced by transgenic insect-resistant plants and new biologically based and chemical insecticides.

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POTATOES

INSECT CONTROL MARKET 1995

Crop Area and Major Growing Regions

In 1995, potatoes were planted on nearly 1.8 million acres in the United States and Canada. Canada had 253.3 thousand acres and the United States had 1,398.2 thousand acres. Figure 8 and Table 23 show the regional distribution of each country's potato plantings in 1995.

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Figure 8

NORTH AMERICAN POTATO ACREAGE BY COUNTRY AND REGION, 1995

	Planted Acres (1,000)	Percent of Country's Planted Acres	Percent of North America's Planted Acres
Canada			
East	253.3	70.8	14.4
West	104.5	29.2	6.0
United States			
Northeast	139.4	10.0	7.9
Upper N. Central	345.0	24.7	19.6
Northwest	601.0	43.0	34.2
Other Regions	312.8	22.4	17.8

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Table 23
NORTH AMERICAN POTATO ACREAGE
BY COUNTRY AND REGION, 1995

Country/Region	Planted Acres (1,000)	Percent of Country's Planted Acres	Percent of North America's Planted Acres
Canada			
East			
Prince Edward Island	108.0	30.2	6.2
New Brunswick	54.0	15.1	3.1
Québec	46.9	13.1	2.7
Ontario	38.4	10.7	2.2
Other Provinces	6.0	1.7	0.3
Subtotal	253.3	70.8	14.4
West			
Manitoba	60.0	16.8	3.4
Alberta	30.0	8.4	1.7
Other Provinces	14.5	4.1	0.8
Subtotal	104.5	29.2	6.0
Total	357.8	100.0	20.4
United States			
Northeast			
Maine	78.0	5.6	4.4
New York	29.0	2.1	1.7
Pennsylvania	18.0	1.3	1.0
Other States	14.4	1.0	0.8
Subtotal	139.4	10.0	7.9
Upper North Central			
North Dakota	125.0	8.9	7.1
Minnesota	83.0	5.9	4.7
Wisconsin	82.0	5.9	4.7
Michigan	55.0	3.9	3.1
Subtotal	345.0	24.7	19.6
Northwest			
Idaho	400.0	28.6	22.8
Washington	147.0	10.5	8.4
Oregon	54.0	3.9	3.1
Subtotal	601.0	43.0	34.2

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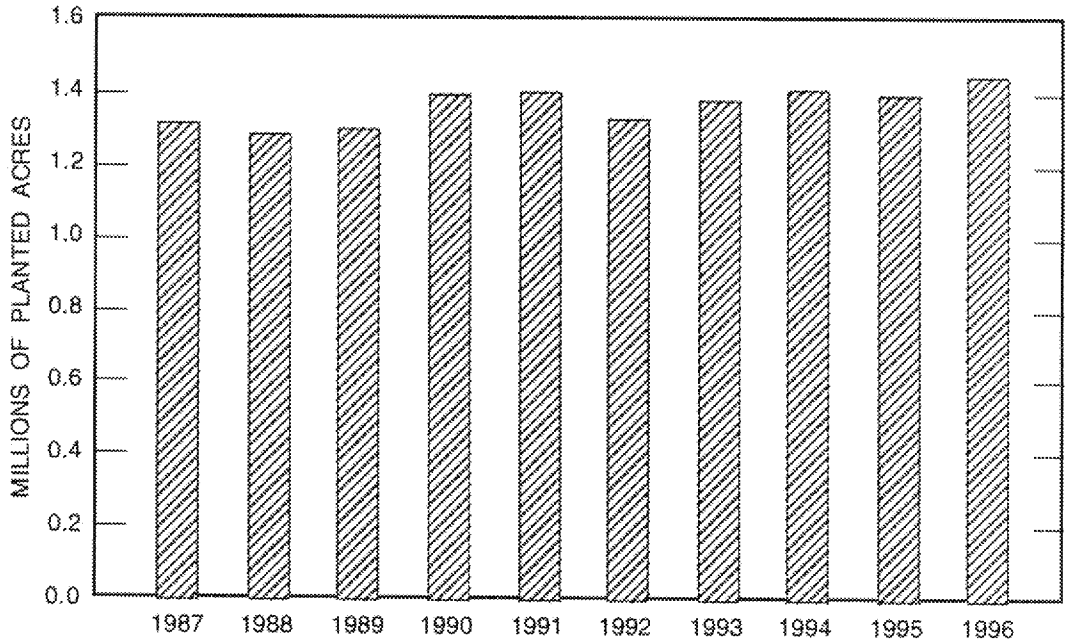
Table 23 (Concluded)

Country/Region	Planted Acres (1,000)	Percent of Country's Planted Acres	Percent of North America's Planted Acres
Other Regions			
Colorado	86.3	6.2	4.9
Florida	46.8	3.3	2.7
California	41.5	3.0	2.4
Other States	138.2	9.9	7.9
Subtotal	312.8	22.4	17.8
Total	1,398.2	100.0	79.6
North America, Total	1,756.0	N/A	100.0

Sources: Statistics Canada and USDA.

Canada's potato crop acreage has been increasing since the late 1980s. Figure 9 shows the trend in planted potato acreage in the United States over the past decade. U.S. potato plantings fluctuated from year to year in the 1987-1995 period—ranging from 1.28 million to 1.42 million acres; however, the planted acreage in 1995 was 6% greater than that in 1987. In 1996, U.S. potato plantings increased by 4% to about 1.46 million acres.

Figure 9
U.S. PLANTED POTATO ACREAGE, 1987-1996



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Major Pests and Control Practices

The Colorado potato beetle—CPB— (*Leptinotarsa decemlineata*) is the primary insect pest for potatoes in Canada, the U.S. Northeast region, and the Great Lakes States. Aphids, primarily the green peach aphid *(Myzus persicae)*, are the primary insect pests for potatoes grown in North Dakota and the U.S. Northwest. The CPB, leafhoppers, potato flea beetles, and wireworms are other economically important potato pests in all regions. The European corn borer—ECB—*(Ostrinia nubilalis)*. is an occasional pest problem for potatoes grown in the Great Lakes States.

Bayer's imidocloprid (Admire®) became available for potatoes in 1995, and in its first year on the market became the leading insecticide used against the CPB. Because CPB has developed resistance to nearly all other insecticides, integrated pest management (IPM) programs are being employed to prevent or delay development of CPB resistance to imidacloprid.

Michigan's IPM program, for example, incorporates both chemical and nonchemical methods. Nonchemical methods include burning with propane gas flames, surrounding fields with plastic-lined ditches to trap incoming CPBs and allow them to be eaten by predators, and crop rotation. Admire® is applied in the furrow at planting to control both CPBs and aphids, and a spray program is employed to control leafhoppers. Some Michigan growers use *Bacillus thuringiensis* var. *tenebrionis* (Btt)-based biological insecticides for early season control of CPB. Correct timing for Btt applications is critical, however, for effective control.

Before the initiation of IPM, Michigan growers typically used the systemic carbamate insecticide/nematicide product aldicarb (Temik®) to control their entire pest spectrum, including for many both insects and lesion nematodes.

Table 24 lists the principal insecticides used for U.S. potatoes in 1995 and indicates the major target pests of each product.

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Table 24
PRINCIPAL INSECTICIDES USED TO CONTROL MAJOR INSECT PESTS OF U.S. POTATOES, 1995

Insecticide		Target Pest(s)		
Product Class/ Common Name	Trade Name	Aphids	CPB	Other Pests
Biological				
pyrethrins	Various	X	X	Leafrollers Potato leafhopper Others
Conventional Chemistry				
Carbamate				
carbaryl	Sevin®, Carbaryl	X	X	Leafhoppers Others
carbofuran	Furadan®	X	X	ECB Potato flea beetle Potato leafhopper
oxamyl	Vydate®	X	X	Flea beetles Potato leafhopper Nematodes Tarnished plant bug
Chlorinated Hydrocarbon				
endosulfan	Phaser®, Thiodan®	X	X	ECB Potato flea beetle Potato leafhopper Others
Organophosphate				
azinphos-methyl	Guthion	X	X	ECB Flea beetles Leafhoppers Leafminers Tarnished plant bug Others
dimethoate	Dimethoate	X		Leafhoppers Leafminers Grasshoppers
disulfoton	DiSyston®	X	X	Flea beetles Leafhoppers Southern potato wireworm
ethoprop	Mocap®			Nematodes Symphylans Wireworms
fonofos	Dyfonate®			Symphylans Wireworms

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Table 24 (Concluded)

Insecticide		Target Pest(s)		
Product Class/ Common Name	**Trade Name**	**Aphids**	**CPB**	**Other Pests**
Conventional Chemistry				
methamidophos	Monitor®	X	X	Flea beetles Potato leafhopper ECB Others
methyl parathion	Penncap-M®, Methyl Parathion	X		Flea beetles Leafhoppers Others
phorate	Thimet®	X	X	Flea beetles Leafhoppers Leafminers Wireworms
phosmet	Imidan®		X	Potato flea beetle Potato leafhopper
Synthetic Pyrethroid				
esfenvalerate	Asana®	X	X[a]	Flea beetle Leafhoppers Tarnished plant bug Others
permethrin	Ambush®, Pounce®	X	X[a]	Potato flea beetles Potato leafhopper Tarnished plant bug Others
Other Organic				
propargite	Comite® Omite®			Two-spotted spider mite
Inorganic				
cryolite	Kryocide®		X	
New Chemistry				
imidacloprid	Admire®, Provado®	X	X	Flea beetles Potato leafhopper

[a]Potato aphid.

Source: University extension and private pest management consultants.

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Insecticide Use and Market Value, 1995

Canadian potato growers spent an estimated US$7 million for insecticides in 1995, and U.S. growers spent an estimated $50.4 million. Table 25 summarizes insecticide use for U.S. potatoes in 1995 by region and state. Overall, 87% of the United States' planted potato acreage received at least 1 insecticide treatment, and on average, 2.7 applications were made per treated acre. The Northwest region, with 43% of the crop acreage, accounted for 34% of the U.S. potato insecticides market in terms of treatment acres. The Upper North Central region, with about 25% of the crop acreage, accounted for 33% of the total insecticide treatments.

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Table 25
INSECTICIDE USE FOR U.S. POTATOES BY REGION, 1995
(Thousands of Planted Acres)

Region/State	Planted Acres [a] (1,000)	Treated Acres: Percent of Planted Acres	Treated Acres: 1,000 Acre	Average Number of Applic-ations [b]	Insecticide Treatment Acres (1,000)
Northeast					
Maine	78.0	100	78.0	2.1	161.8
New York	29.0	93	27.0	3.1	82.4
Pennsylvania	18.0	91	16.4	2.9	47.1
Other s	14.4	97	14.0	2.4	33.5
Total	139.4		135.3		324.8
Average		97.1		2.4	
Upper North Central					
North Dakota	125.0	100	125.0	3.1	391.4
Minnesota	83.0	90	74.7	2.4	179.9
Wisconsin	82.0	94	77.1	4.8	367.9
Michigan	55.0	100	55.0	2.5	138.6
Total	345.0		331.8		1,077.8
Average		96.2		3.2	
Northwest					
Idaho	400.0	76	304.0	1.5	452.0
Washington	147.0	93	136.7	3.9	527.7
Oregon	54.0	92	49.7	2.8	140.7
Total	601.0		490.4		1,120.4
Average		81.6		2.3	
Other Regions	312.8	82.8	258.9	2.9	743.2
United States, Total	1,398.2		1,216.4		3,266.2
Average		87.0		2.7	

Source: SRIC estimates

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Figure 10 shows the breakdown of the 1995 U.S. potato insecticides market by product class, in terms of both treatment acres and grower expenditures. Table 26 presents a further breakdown of the market by product within each class. Conventional chemical insecticides accounted for about 92% of the market on the basis of treatment acres and for 80.5% of the market on the basis of grower expenditures. Organophosphate products are the most widely used conventional insecticides in this crop market.

Bayer's imidacloprid (Admire®, Provado®), registered for U.S. potatoes in 1995, accounted for 7.7% of the total insecticide treatments, and achieved a 19.2% market share, based on grower expenditures in its first year on the market.

Figure 10

U.S. POTATO MARKET FOR INSECTICIDES BY PRODUCT CLASS, 1995

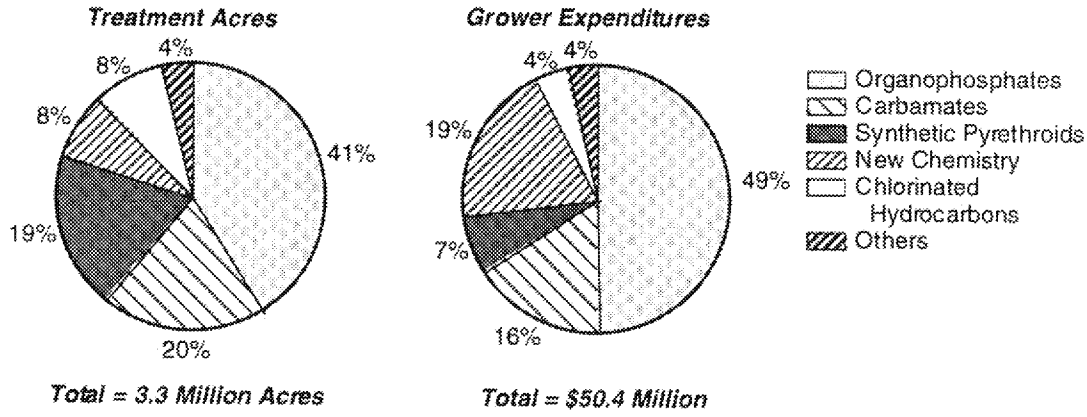

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Table 26
U.S. POTATO INSECTICIDE MARKET BY PRODUCT CLASS, 1995

Class/ Product	Treatment Acres: 1,000 Acres	Treatment Acres: Class/ Product Share (%)	Volume Applied (1,000 lb, A.I.)	Grower Expenditures: (1,000 dollars)	Grower Expenditures: Class/ Product Share (%)
Biologicals[a]					
Botanicals					
pyrethrins	14.0	0.4	0.3	125.8	0.2
Conventional Chemistry					
Carbamates					
carbofuran	570.5	17.5	479.2	7,034.5	14.0
oxamyl	36.4	1.1	30.2	792.0	1.6
carbaryl	54.5	1.7	45.3	264.8	0.5
Subtotal	661.3	20.2	554.6	8,091.3	16.1
Chlorinated Hydrocarbon					
endosulfan	274.0	8.4	202.8	2,230.7	4.4
Organophosphates					
methamidophos	546.7	16.7	475.6	7,610.0	15.1
phorate	293.6	9.0	784.0	6,797.0	13.5
ethoprop	107.7	3.3	471.6	6,366.0	12.6
disulfoton	78.3	2.4	186.4	1,362.2	2.7
azinphos-methyl	156.6	4.8	70.5	1,112.7	2.2
fonofos	41.9	1.3	110.7	941.3	1.9
dimethoate	67.1	2.1	28.2	184.3	0.4
phosmet	19.6	0.6	16.6	133.1	0.3
methyl parathion	23.8	0.7	16.6	93.7	0.2
Subtotal	1,335.3	40.9	2,160.2	24,600.4	48.8
Synthetic Pyrethroids					
permethrin	290.8	8.9	37.8	1,871.5	3.7
esfenvalerate	327.2	10.0	9.8	1,829.2	3.6
Subtotal	618.0	18.9	47.6	3,700.7	7.3
Other Products					
propargite	50.3	1.5	87.6	1,167.5	2.3
cryolite	7.0	0.2	78.2	255.0	0.5
others	54.5	1.7	51.8	518.0	1.0
Subtotal	111.9	3.4	217.6	1,940.5	3.9
Total	3,000.5	91.9	3,182.8	40,563.7	80.5

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Table 26 (Concluded)

Class/ Product	Treatment Acres: 1,000 Acres	Treatment Acres: Class/ Product Share (%)	Volume Applied (1,000 lb, A.I.)	Grower Expenditures: (1,000 dollars)	Grower Expenditures: Class/ Product Share (%)
New Chemistry					
imidacloprid	251.7	7.7	35.2	9,689.5	19.2
Total, All Products	3,266.2	100.0	3,218.3	50,379.0	100.0

[a]*Bacillus thuringiensis* var. *tenebrionis* (Btt)-based products are included with others under "Other Products".

[b]Includes Btts, rotenone, and other products in the listed conventional chemical classes (diazinon, fenvalerate, malathion, methomyl and others), none of which were applied on more than 0.5% of the total planted acres.

Source: SRIC estimates.

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MARKET TRENDS AND ISSUES

New Technologies and Products

Trangenic Insect-Resistant Potatoes

Monsanto commercialized the first transgenic insect-resistant potatoes in the United States in May 1995, following EPA registration of the *Bacillus thuringiensis* subspecies *tenebrionis* (Btt) protein that is produced in the company's NewLeaf® Russet Burbank potatoes. The Btt protein is selectively active against the CPB and certain other Coleopteran insects.

Only 1,800 acres of NewLeaf® potatoes were planted in the United States in 1995. However, in 1996, about 10,000 acres were planted for seed and commercial use in 11 U.S. states and 6 Canadian provinces. Limited amounts of seed for two more NewLeaf® varieties were also available in 1996—NewLeaf® Atlantic, a chipping variety, and NewLeaf® Superior, a round white potato for the fresh market. Monsanto anticipates that enough seed will be available to plant NewLeaf® varieties on 50,000–100,000 acres in 1997.

NatureMark™, Monsanto's seed potato division, is responsible for seed production, marketing, and development of resistance prevention and management strategies for NewLeaf® potatoes. NatureMark™, headquartered in Boise, Idaho, and its subsidiary, NatureMark™ Canada., sell seed to a group of about 100 contracted growers designated as Authorized NatureMark™ Producers (ANPs). ANPs, who are assessed a one-time $500 entry fee to produce the seed potatoes—according to NatureMark™'s standards—sell the seed to commercial growers.

Prices for the seed potatoes are negotiated between the ANPs and individual growers. NatureMark™ charges the commercial growers a regional "trait premium" of $1.50 to $2.50 per cwt of seed, depending on the severity of beetle infestations, and licenses them for a single year's production.

The cost per acre for the NewLeaf® technology—generally in the range of $25 to $50 per acre—is intended to be competitive with traditional CPB insecticide programs. However, the cost depends on both the seeding rate and regional trait premium. For example, in Michigan, where seeding rates range from 16 to 20 cwt per acre, and the trait premium is $2.50 per cwt, the NewLeaf® technology costs growers $40–$50 per acre. In the state of Washington, however, seeding rates are as high as 50 cwt per acre, and the trait premium is $2.00 per cwt. Thus in Washington, growers' cost for NewLeaf® technology may be $100 per acre above the cost of conventional potato seed.

NatureMark™ is also developing stacked gene potato varieties with multiple resistance traits and expects to gain EPA approval to launch the first NewLeaf® Plus varieties with resistance to both the CPB and virus diseases (i.e., potato leaf roll virus and potato virus Y) by 1988 or 1999. Resistance to bacterial soft rot, *Verticillium*, and late blight will also be incorporated into NewLeaf® potato varieties within the next few years. NewLeaf® Plus varieties will be more attractive to potato growers in Idaho and

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Washington, where aphid-transmitted virus diseases are more serious economic problems than CPBs. Before 2005, other Bt proteins that control other potato insect pests, such as wireworms, corn borers, and loopers, are expected to be incorporated in NewLeaf® varieties. Monsanto is also researching glucose oxidase for control of disease causing fungi (*Verticillium* spp.) and bacteria (*Erwinia* spp.).

Michigan potato growers sustained average harvest losses of 12% due to the CPB in 1994; thus, those who planted NewLeaf® potatoes in 1996 did so primarily for insurance against such losses and were generally pleased with the results. They consider the built-in protection from CPB damage to be NewLeaf® potatoes' principal benefit. That resistance provides season-long control and the convenience of not having to spray insecticides to control CPB. Additional benefits are less worker exposure to pesticides and more biological control of other pests, given that without CPB sprays populations of beneficial insects increase.

However, yields of NewLeaf® Russet Burbank varieties grown in both Michigan and Wisconsin were generally lower than yields of conventional (non-Bt) varieties treated with Admire®, and potatoes produced from NewLeaf® varieties were smaller than those from conventional varieties.

Potato growers and research entomologists in the U.S. Northwest have reported increased populations of beneficials and fewer problems with mites, aphids, and other insects in NewLeaf® potato fields than in conventional potato fields. The yields and quality of NewLeaf® varieties were comparable to those of conventional Russet Burbank varieties.

Other organizations that have conducted field trials of potato varieties with genetically engineered resistance to CPB and/or Lepidopteran insects since 1990 include Calgene, Frito-Lay, Plant Genetic Systems, Michigan State University, and the USDA's Agricultural Research Service. Tables A-5 and A-6 in the Appendix summarize insect resistant potato field trial release permits and field trial notifications by company/institution, respectively.

New Insecticides

Imidocloprid (Admire®, Provado®), which was registered for control of the CPB and green peach aphid on potatoes at the beginning of 1995, is very effective against both pests. Its other beneficial attributes include relatively low mammalian toxicity and the application in the furrow at planting. Table 27 lists other insecticides under development that are expected to become available to control of CPB and/or other major pests within the next few years. Because most of these new products are expected to be less expensive than Admire®, they may gain market share at Admire®'s expense.

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Table 27
NEW INSECTICIDES UNDER DEVELOPMENT FOR POTATOES

Technology/ Common Name	Trade Name	Target Pest(s)[a]	Supplier	Year on Market or Expected
Biological/Biologically Based				
Bts, Recombinant				
Bt var. kurstaki, Strain 7673	Raven®	CPB	Ecogen	1995
Microbially Derived Toxins				
abamectin[b]	Agrimek®	CPB Mites	Merck AgVet	1997
spinosad	Tracer®.	CPB Lepidoptera	DowElanco	1998
New Chemistry				
chlorfenpyr	Alert®, Pirate®	CPB Lepidoptera	American Cyanamid	1998
fipronil	Regent®	CPB	Rhône-Poulenc	NA
imidacloprid	Admire®, Provado®	CPB	Bayer	1995
halsflexozide (RH 0345)	NA	Broad spectrum	Rohm and Haas	NA
Insect Growth Regulator				
cyromazine[b]	Trigard®	CPB	Novartis	1997

[a]CPB = Colorado potato beetle

[b]Potatoes will be a new U.S. crop market for this product.

Source: Communications with industry and pest management specialists; trade literature

CPB Resistance

The CPB has developed widespread resistance to all classes of conventional chemical insecticides. The highest levels of CPB resistance are in Canada's eastern provinces and the U.S. Northeast and Upper North Central regions. Because of this pest's history of quickly developing resistance, pest management specialists interviewed in Michigan and Wisconsin predict that within 3-5 years, it will also become resistant to single-Btt-gene NewLeaf® potatoes, as well as imidacloprid.

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However, Monsanto's NatureMark™ has implemented a CPB resistance prevention and management program composed of several elements. NatureMark™ has established a baseline estimate of Btt susceptibility and has genetically engineered potato plants to express a high level of the Btt protein (20-50 times greater than LC_{99}). The company's other responsibilities in the program include communication, training, refuge enforcement and surveillance, and tracking of any occurrences of Btt resistance. Growers licensed to plant NatureMark™ potatoes are required to practice IPM strategies for CPB control, to maintain "refuges" (i.e., plant a maximum of 80% NewLeaf® on any farm, place refuge acres close to NewLeaf® plantings, treat refuge with foliar CPB insecticides as needed, and vinekill NewLeaf® fields before vinekilling non-Bt potato fields), to monitor NewLeaf® fields for CPB larval survival, and to contact NatureMark™ if any CPB larvae are found on NewLeaf® plants.

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MARKET PROJECTIONS, 2000 AND 2005

Total Market

Table 28 summarizes projections for planted acres of transgenic insect-resistant potato plants and treatment acres of biological/biologically based insect control products and new and conventional chemical insecticides.

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Table 28
U.S. POTATO INSECT CONTROL MARKET BY TYPE OF TECHNOLOGY, 1995-2005[a]
(Thousands of Acres)

Technology/ Product Group	1995	2000	2005
Transgenic Insect-Resistant Plants[b]	1.8	800-900	1,350-1,400
Applied Pest Control Products			
Biological/Biologically Based			
Bts	NA	50-100	50-100
Botanicals	14.0	15-20	20-25
Microbially derived toxins	--	50-100	100-125
Subtotal	14.0	115-220	170-250
New Chemistry	251.7	400-500	500-550
Conventional Chemistry			
Carbamates	661.3	430-450	305-350
Chlorinated Hydrocarbons	274.0	175-225	125-150
Organophosphates	1,335.3	870-950	625-675
Synthetic Pyrethroids	618.0	400+500	290-330
Others[c]	111.9	70-100	50-75
Subtotal	3,000.5	1,945-2,225	1,395-1,580
Total	3,266.2	2,460-2,945	2,065-2,380
Total, All Products	3,268.0	3,260-3,845	3,415-3,780

[a]Data for transgenic insect-resistant plants include Canada and the United States; all other data are for the United States only. Projections are based on the assumptions that Canada's potato plantings will amount to about of 0.4 million acres in both 2000 and 2005, and that U.S. plantings will amount to about 1.4 million acres in both years.

[b]Data for 2000 and 2005 Include stacked-gene varieties with multiple resistance traits.

[c]Includes other organic and inorganic insecticides.

Source: SRI Consulting

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Transgenic Insect-Resistant Plants

Transgenic potato varieties with either single or multiple resistance traits are expected to account for 45–50% of U.S. and Canadian potato plantings by 2000 and for 75–80% by 2005. Table 29 presents estimates and projections of planted acres and U.S. and Canadian grower expenditures for transgenic insect resistant potato technology from 1995–2005.

Table 29
NORTH AMERICAN MARKET FOR TRANSGENIC INSECT-RESISTANT POTATOES, 1995-2005

Year	Planted Acres (Thousands)	Grower Expenditures (Millions of Dollars)
1995	1.8	< 0.1
1996	10	0.4
1997	75	2.8
1998	100	3.5
2000	800-900	30.0-35.0.
2005	1,350-1,440	50.0-55.0

Source: SRIC estimates

In the Upper North Central States, in particular, potato growers typically have long-term relationships with their seed distributors and as a result, may be reluctant to buy NewLeaf® potatoes from one of Monsanto's ANPs. This factor could impede the rapid market penetration projected for the new transgenic plant technology.

Applied Insect Control Products

The U.S. potato market for applied insect control products is expected to decline by 27–37% between 1995 and 2005, on the basis of treatment acres, as a result of the replacement of conventional potato varieties by transgenic insect resistant and multiple resistance trait varieties. However, the new biological/biologically based and novel chemical insecticides under development for potatoes, assuming they are successfully launched, will create competition for NewLeaf® potatoes and could constrain market penetration of the transgenic plant technology.

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Biological and Biologically Based Technologies

Biological and biologically based insecticides will account for about 5–7.5% of U.S. potato insecticide treatments by 2000 and for about 8–10.5% by 2005.

New Chemistry

Use of new chemical insecticides for potatoes will increase from 251,700 treatment acres in 1995 to 400,000–500,000 treatment acres in 2000, and to 500,000–550,000 treatment acres in 2005. By 2005, new chemistry will account for 10–21% of the total insecticide treatments applied for U.S. potatoes.

Conventional Chemistry

Conventional chemical insecticides will be displaced in the potato market not only by transgenic insect-resistant plants but by new biologically based and novel chemical insecticides. Imidocloprid (Admire®, Provado®) has already largely displaced the inorganic insecticide, cryolite (Kryocide®), for CPB control. Between 1995 and 2005, treatments of potatoes with conventional chemical insecticides are expected to decline by 4.5–16%. Conventional products will account for 51–66% of the total potato insecticide treatments in 2005.

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VEGETABLES

INSECT-CONTROL MARKET, 1995

Crop Area and Major Growing Regions

In 1995, two eastern provinces, Ontario and Quebec, together accounted for 87% of Canada's 136.3 thousand planted acres of cucurbit crops (cucumbers, pumpkins, squash, and zucchini), lettuce, sweet corn, and tomatoes, and two western provinces, Alberta and British Columbia, together accounted for 9%. Sweet corn accounted for 63% of Canada's total acreage of the vegetable crops selected for this study, tomatoes accounted for 20%, cucurbits for 11%, and lettuce for 6%.

Figure 11 shows the major vegetable-growing regions in the United States and the share of the nation's total planted acreage of sweet corn, cucurbits, lettuce, and tomatoes that each region accounted for in 1995. The Southwest region (California and Arizona) and the North Central region accounted for 39% and 22%, respectively, of the total selected vegetable crop acreage. No other region had more than 7% of the total acreage. The Southwest leads the nation in acreage and production of tomatoes, lettuce, and cucurbits, and the North Central is the dominant region in sweet corn acreage and production. Table 30 summarizes the U.S. planted acreage for the selected vegetables in 1995 by crop and region.

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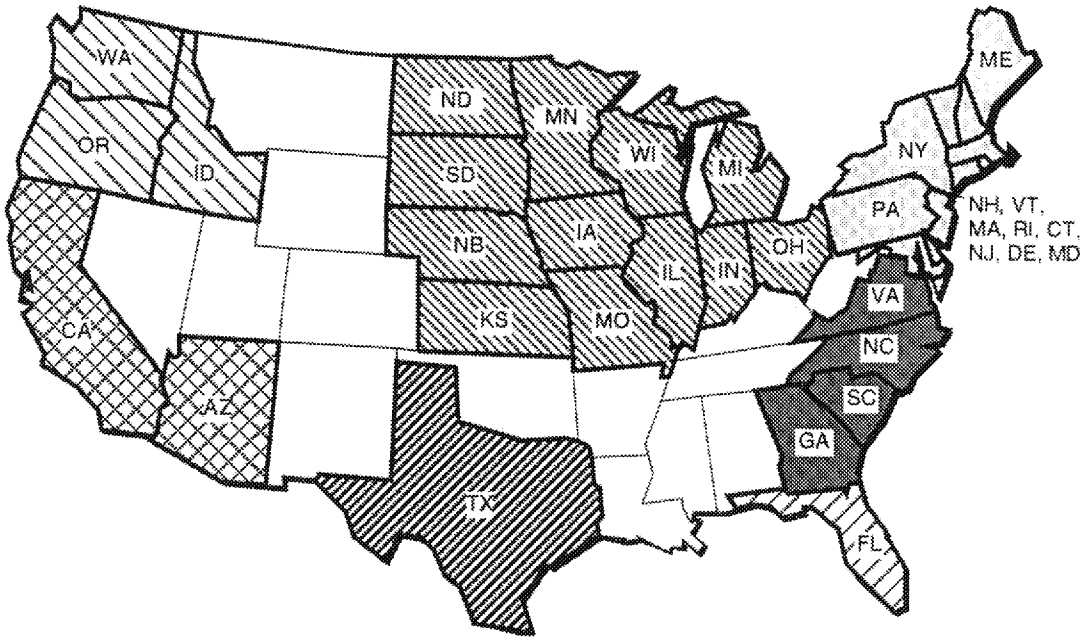
Figure 11
PRINCIPAL U.S. VEGETABLE GROWING REGIONS



REGION	Sweet Corn	Cucurbits	Lettuce	Tomatoes	All
	Percent of U.S. Planted Acres of Selected Vegetable Crops, 1995				
Northeast	16	3	—	—	6
South Atlantic	4	18	—	3	7
Florida	5	10	3	10	7
North Central	47	12	—	6	22
Texas	—	16	—	—	4
Northwest	20	—	—	—	7
Southwest	3	30	92	74	39
Others[b]	6	11	4	7	7
Total[a]	**100**	**100**	**100**	**100**	**100**

[a] Data may not add to 100% because of rounding.
[b] Includes acreage in states within the major regions for which acreage data is not reported separately.

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Table 30
PLANTED AREA OF SELECTED U.S. VEGETABLE CROPS, 1995
(Thousands of Acres)

Region	Sweet Corn			Cucurbits	Lettuce	Tomatoes			Total
	Fresh Market	Proces-sing	Total			Fresh Market	Proces-sing	Total	
Northeast	75.5	43.4	118.9	15.2	–	–	–	–	134.1
South Atlantic	34.2	–	34.2	98.3	–	12.7	–	12.7	145.2
Florida	38.1	–	38.1	56.1	9.5	48.6	–	48.6	152.3
North Central	51.3	308.5	359.8	63.6	–	7.6	22.5	30.1	453.5
Texas	–	–	0.0	85.7	–	–	–	–	85.7
Northwest[a]	–	150.0	150.0	–	–	–	–	–	150.0
Southwest[b]	22.3	–	22.3	164.5	255.0	38.0	331.0	369.0	810.8
Other Regions [c]	13.9	29.5	43.4	61.1	11.3	29.9	6.0	35.9	151.7
Total	235.3	531.4	766.7	544.5	275.8	136.9	359.5	496.4	2,083.2

[a] Washington, Oregon, and Idaho.
[b] California and Arizona
[c] Also includes some minor acreage in the regions listed.
Source: USDA.

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Major Pests

Table 31 indicates the major insect and mite pests that attack U.S. sweet corn, cucurbit crops, lettuce, and tomatoes. The major insect pests affecting U.S. sweet corn are armyworms, corn earworms, corn rootworms, and cutworms. The European corn borer is also a major pest in the Northeast and North Central region. Silkflies, aphids, and wireworms are additional pests in Florida.

The most widely treated insect pests affecting cucurbits are aphids, whiteflies, and armyworms, followed by loopers, leafminers, and the cucumber beetle. In Florida, cutworms, leafhoppers, and wireworms often require treatment, as do rindworms in Texas and loopers and spider mites in California.

Loopers, aphids, armyworms, leafminers, thrips, whiteflies, and corn earworms rank as the most widely treated insect pests for U.S. lettuce. Armyworms and whiteflies are the most widely treated insect pests for tomatoes, followed by the tomato pinworm, tomato fruitworm, and aphids. Leafminers and loopers are also major pests attacking Florida tomatoes, and stink bugs commonly require treatment in California's tomato fields. Flea beetles are additional tomato pests, primarily in the North Central states and California.

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Table 31
MAJOR VEGETABLE CROP INSECT AND MITE PESTS

Pest	Sweet Corn	Cucurbits	Lettuce	Tomatoes
Aphids		X	X	X
Armyworms	X	X	X	X
Corn earworms/ Tomato fruitworms	X	X	X	X
Corn rootworms	X			
Cucumber beetles		X		
Cutworms	X	X		
European corn borers	X			
Flea beetles				X
Leafhoppers		X		
Leafminers		X	X	X
Loopers	X	X	X	X
Mites		X		
Pickleworms		X		
Rindworms		X		
Seed corn maggots		X		
Silkflies	X			
Spider mites		X		
Squash bugs		X		
Squash vine borers		X		
Stink bugs				X
Thrips			X	
Tomato pinworms				X
Whiteflies		X	X	X
Wireworms		X		

Source: SRI Consulting

Recent Trends in Insect Control for Florida Vegetables

Sweet Corn

The major insect pests attacking Florida sweet corn are the fall armyworm, the corn earworm, and the silkfly. Lannate®, Larvin®, and some Lorsban® are used to control the fall armyworm. The silkfly is an increasingly prevalent pest treated mainly with lambda-cyhalothrin (Warrior®), tank mixes of Warrior® and methyl parathion (Penncap-M®), or Lorsban®. The corn earworm is a problem mainly in Northern Florida.

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Cucurbits

The leading insecticides used on Florida cucurbit crops are Bts, crop oils, and abamectin (Agrimek®). Agrimek® has been available since the end of 1995 for control of thrips, mites, and leafminers. Although imidacloprid (Admire®, Provado®) has been used for aphid and whitefly control on California cucurbit crops under a Section 18 registration, it is not yet available to Florida cucurbit growers, who would especially like to be able to use it for watermelons.

Lettuce

Florida lettuce crops receive weekly applications of a Bt-based product tank-mixed with a synthetic pyrethroid. Insecticidal soaps are applied for aphid control. Merck's new microbially-derived toxin product, Proclaim®, is under evaluation for worm control in Florida lettuce.

Tomatoes

The beet armyworm, southern armyworm, tomato fruitworm, looper, tomato pinworm, and sweet potato whitefly are principal insect pests for tomatoes grown in Florida.

The introduction of imidacloprid (Admire®, Provado®) for whitefly control in tomatoes has resulted in significant changes in Florida growers' insect-control programs. The availability of this new systemic product for control of the sweet potato whitefly has greatly reduced the number of insecticide applications per season. Admire®, which is also used to treat tomato transplants in greenhouses, is applied when the transplants are planted in the field. The single soil application at planting provides control for 6-8 weeks. Provado® is used for late-season foliar treatments for whitefly control. Imidacloprid also controls tomato mottle virus, a disease vectored by the sweet potato whitefly.

Conventional insecticides still used for whitefly control in Florida tomatoes include endosulfan (Thiodan®, Phaser®), methamidophos (Monitor®), and Monitor®/pyrethroid tank mixes. Insecticidal soaps are also used for whitefly control.

Additional insecticide applications are made at least weekly to larvae of the armyworm, tomato fruitworm, and looper. Conventional chemical products such as chlorpyrifos (Lorsban®), methomyl (Lannate®), and synthetic pyrethroids are being displaced by Bts—now the principal larvicides used. The conventional insecticides are still used when there is heavy worm pressure or mixed populations of instars. They usually are tank-mixed with Bts.

Tomato pinworm infestations occur mainly on Florida's spring tomato crops. Pheromone mating-disruptant products are used to control pinworm infestations that occur early in the growing season. One or two applications (of a tag or sprayable pheromone formulation) per crop are made. If pinworm infestations occur late in the season, they are treated with Lannate® or Monitor®.

Until imidacloprid became available, Florida tomato growers applied conventional insecticides three times per week, on average, to control whiteflies and worms. They typically rotated endosulfan, chlorpyrifos, methomyl, synthetic pyrethroids, and

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insecticidal soaps. The major benefits of imidacloprid to Florida tomato growers are reduced insecticide costs, fewer trips across the field, less environmental impact, and the survival of more beneficials to help control other pests such as leafminers.

In 1996, the most widely used insecticides for Florida tomatoes were imidacloprid, Bts, lambda-cyhalothrin (Warrior®), Lannate®, and Monitor®. Warrior, registered in 1996, is displacing esfenvalerate (Asana®) because it is considered to be more efficacious for tomato fruitworm control. Problems with this pest have increased recently.

Insecticide Use and Market Value

Table 32 summarizes insecticide use for sweet corn, cucurbit crops, lettuce, and tomatoes in 1995 in terms of treated acres, average number of applications, and insecticide treatment acres. Of the vegetable crops selected for this study, sweet corn is the largest market for insecticides on the basis of treatment acres, closely followed by tomatoes. Sweet corn accounted for 30% of the total insecticide-treated acreage of selected vegetable crops, tomatoes accounted for 29%, lettuce for about 26%, and cucurbits for 15%. Vegetables grown for the fresh market are treated much more intensively than those grown for processing.

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Table 32
INSECTICIDE USE FOR SELECTED U.S. VEGETABLE CROPS, 1995

Crop	Planted Acres (thousands)	Treated Acres: Percent of Planted Acres	Treated Acres: Thousands	Average Number of Applications	Insecticide Treatment Acres (thousands)
Sweet Corn					
Fresh Market	235.3	85	199.4	10.5	2,089.4
Processing	531.4	65	345.8	2.6	882.9
Total	766.7		545.2		2,972.3
Average		71		5.5	
Cucurbits					
Cucumbers					
Fresh Market	62.7	79	49.6	4.0	200.7
Processing	122.4	65	79.0	2.8	220.3
Subtotal	185.1		128.6		421.0
Average		69		3.3	
Muskmelons					
Cantaloupes	104.7	94	98.6	4.1	406.1
Honeydew	26.3	91	23.9	4.2	100.9
Subtotal	131.0		122.5		507.0
Average		94		4.1	
Watermelons	228.4	70	159.6	3.7	593.1
Total	544.5		410.7		1,521.1
Average		75		3.7	
Lettuce[a]	275.8	98	271.2	9.3	2,523.9
Tomatoes					
Fresh Market	136.9	97	132.4	18.1	2,399.9
Processing	359.5	73	262.9	1.9	491.7
Total	496.4		395.3		2,918.1
Average		80		7.4	
Total, Selected Crops	2,083.4		1,622.4		9,934.5
Average		78		6.1	

[a]Head lettuce, leaf lettuce, and romaine.

Source: SRIC estimates

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Table 33 provides a breakdown of the selected U.S. vegetable crop markets for insecticides by product class, based on estimated treatment acres in 1995. Conventional chemical insecticides accounted for 85.5% of the total vegetable crop treatment acres, biological and biologically based products accounted for 12.5%, insecticidal soaps accounted for 1.3%, and novel chemical insecticides accounted for less than 1%.

Table 33
INSECTICIDE USE FOR SELECTED U.S. VEGETABLE CROPS BY PRODUCT CLASS, 1995
(thousands of treatment acres)

Technology/ Product Group	Sweet Corn[a]	Cucurbits[b]	Lettuce[c]	Tomatoes[d]	Total	Percent of Total
Biological/Biologically-Based						
Bts	160.0	173.4	155.5	370.0	864.9	8.7
Botanical Insecticides	1.8	4.7	195.0	25.0	226.5	2.3
Pheromones	--	2.5	--	2.5	5.0	NEG
Microbially-Derived Toxins	--	10.0	70.0	60.0	140.0	1.4
Total	167.8	190.6	420.5	457.5	1,236.4	12.4
Insecticidal Soaps	0.5	30.0	5.5	94.0	130.0	1.3
New Chemistry	--	33.0	20.0	20.0	73.0	0.7
Conventional Chemistry						
Carbamates	1,405.0	410.0	410	330.0	2,555.0	25.7
Chlorinated Hydrocarbons	20.0	305.0	67.0	326.0	718.0	7.2
Organophosphates	383.0	268.0	650.0	725.0	2,026.0	20.4
Synthetic Pyrethroids	990.0	282.0	950.0	960.5	3,182.5	32.0
Other Organic	6.0	0.5	NEG	0.1	6.6	0.1
Inorganic	--	2.0	--	5.0	7.0	0.1
Total	2,804.0	1,267.5	2,077.0	2,346.6	8,495.1	85.5
Total, All Products	2,972.3	1,521.1	2,523.0	2,918.1	9,934.5	100.0

[a]Fresh market and processing sweet corn.
[b]Cucumbers, muskmelons, and watermelons.
[c]Head lettuce and leaf lettuce.
[d]Fresh market and processing tomatoes.

Source: SRIC estimates

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Reported data for 1995 insecticide use for the selected vegetable crops are summarized by product class in Table 34. California is the leading U.S. state in vegetable crop acreage and production. In 1995, it accounted for 33% of the total insecticide treatments made nationwide for sweet corn, cucurbit crops, lettuce, and tomatoes.

Table 34
INSECTICIDE USE BY CLASS FOR SELECTED CALIFORNIA VEGETABLE CROPS, 1995
(thousands of treatment acres)

Technology/ Product Group	Sweet Corn[a]	Cucurbits[b]	Lettuce[c]	Tomatoes[d]	Total	Percent of Total
Biological/Biologically-Based						
Bts	4.0	55.8	93.0	85.1	237.8	7.2
Botanical Insecticides	0.1	2.2	116.0	6.8	125.1	3.8
Pheromones	--	0.5	0.0	0.7	1.2	NEG
Microbially-Derived Toxins	--	2.9	66.8	2.0	71.6	2.2
Total	4.1	61.3	275.8	94.5	435.7	13.3
Insecticidal Soaps	0.2	0.6	3.6	6.0	10.3	0.3
New Chemistry	0.0	26.6	53.0	6.8	86.4	2.6
Conventional Chemistry						
Carbamates	69.0	79.2	263.4	156.1	567.6	17.3
Chlorinated Hydrocarbons	14.8	68.4	38.5	21.6	143.3	4.4
Organophosphates	57.5	87.3	570.3	262.5	977.6	29.7
Synthetic Pyrethroids	93.2	64.4	689.8	212.5	1,059.9	32.3
Other Organic	NEG	0.2	0.0	NEG	0.2	NEG
Inorganic	--	1.3	0.0	4.2	5.5	0.2
Total	234.4	300.8	1,562.0	656.9	2,754.1	83.8
Total, All Products	238.8	389.3	1,894.4	764.2	3,286.6	100.0

[a]Fresh market sweet corn.
[b]Cucumbers, muskmelons, and watermelons.
[c]Head lettuce and leaf lettuce.
[d]Fresh market and processing tomatoes.
Source: California Department of Pesticide Regulations

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MARKET TRENDS AND ISSUES

New Technologies and Products

Transgenic Insect-Resistant Plants

Several companies are developing transgenic insect-resistant sweet corn and tomatoes in the United States. The potential advantages of insect-resistant vegetable plants to growers include insurance against crop losses and reduced chemical and application costs.

Companies working with insect-resistant sweet corn include Novartis Seeds' Rogers Seed Co. subsidiary, Harris Moran Seeds (owned by Limagrain), Pillsbury, and Seminas Vegetable Seeds. Target pests of the first insect-resistant sweet corn varieties will be the European corn borer and other Lepidopteran pests. Monsanto, Mycogen, Novartis, and Seminas Vegetable Seeds are working on insect-resistant tomatoes. Target pests of the first Bt tomatoes are various Lepidoptera, including the tomato fruitworm, armyworm, and tomato pinworm. Leafminers may also be targeted by some Bt tomato varieties.

The first insect-resistant sweet corn varieties are expected to be on the market in 1998-2000, and the first insect-resistant tomatoes, in 1998-1999. AgrEvo announced in late 1996 that it expects to launch unspecified insect-resistant vegetables (presumed to be sweet corn) in 1999.

Biological or Biologically Based Products

Table 35 identifies the new biological or biologically based insect-control products that have become available for U.S. vegetable crops since 1995 or that are expected to obtain vegetable crop registrations before 2005.

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Table 35
NEW BIOLOGICAL OR BIOLOGICALLY-BASED VEGETABLE CROP INSECT-CONTROL TECHNOLOGIES AND PRODUCTS

Technology/ Product	Trade Name	Target Pests[a]	Developing Company	Year on the Market
Bts				
Nonrecombinant				
Bt var. kurstaki, Strain M-200	Able®	Lepidoptera	Novartis	1996
Bt var. kurstaki	CoStar®	Lepidoptera	Novartis	1997
Bt var. kurstaki Strain 2348	Condor™	Lepidoptera	Ecogen	1996
Bt var. kurstaki	Troy-Bt	Lepidoptera	Troy Biosciences	1996
Recombinant				
AVG-6413	--	Lepidoptera	Abbott Laboratories	NA
Bt var. kurstaki, Strain EG7841	Crynax™	Lepidoptera	Ecogen	1996
Bt var. kurstaki, Strain 7826	Lepinox®	Fall armyworm	Ecogen	1997
Encapsulated blend of CryIA(c) and CryIC derived delta endotoxins of Bt	Mattch™	BAW Looper TFW Diamondback moth	Mycogen	1996
Encapsulated delta endotoxin of Bt var. aizawai	M/C	BAW	Mycogen	1997
Encapsulated delta endotoxin of Bt var. kurstaki	MVP II	Lepidoptera	Mycogen	1996
Viruses				
Naturally-Occurring				
Helicoverpa zea NPV	GemStar®	CEW/TFW	Thermo Trilogy	1996
Spodoptera exigua NPV	Spod-X®	BAW	Thermo Trilogy	1995
Recombinant				
Autographa californica (AcNPV)	--	CEW/TFW	American Cyanamid	NA
Autographa californica (AcMNPV)	--	BAW CL CEW/TFW	DuPont	NA
Heliothis zea NPV	--	CEW/TFW	DuPont	NA

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Table 35 (Concluded)

Technology/ Product	Trade Name	Target Pests[a]	Developing Company	Year on the Market
Fungi				
Beauvaria bassiana, Strain GHA	Mycotrol®	Aphids Thrips Whiteflies	Mycotech Corp.	1996
Botanical Insecticides				
azadirachtin	Neemix®	Aphids Fall armyworm Leafminers Melonworm Pickleworm Rindworm Squash bug Squash vine borer Whiteflies	Thermo Trilogy	1996
Microbially -Derived Toxins				
emamectin benzoate	Proclaim®	BAW CL CEW/TFW	Merck AgVet	1998
spinosad	Spintor®, Success®	BAW CL CEW/TFW Leafminers Thrips	DowElanco	1998

[a]BAW = beet armyworm; CEW/TFW = corn earworm/tomato fruitworm (*Helicoverpa zea*), CL = cabbage looper.

Sources: Trade literature and communications with industry and university pest management specialists

The two new microbially-derived toxin products, emamectin (Proclaim®) and spinosad (Spintor®, Success®) will compete in vegetable crop insect-control markets with Bt-based products. In Florida, they may be used in rotation with Bts. Spinosad is expected to have an advantage over Bts and Proclaim® in vegetable crop markets because it is effective against leafminers and thrips as well as Lepidopteran pests.

New Chemical Insecticides

Table 36 lists new chemical insecticides recently launched or under development for U.S. vegetable crops.

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Table 36
NEW CHEMICAL INSECTICIDES RECENTLY LAUNCHED OR UNDER DEVELOPMENT FOR U.S. VEGETABLE CROPS

Product	Trade Name	Target Pest(s)[a]	Developing Company	Year on the Market
acteamiprid	Mospilan®	Whiteflies	Rhone-Poulenc	NA
chlorfenpyr	Alert®	BAW CEW/TFW Spider mites	American Cyanamid	1997
cyromazine[b]	Trigard®	Leafminers	Novartis	1996
DPX-KN 128	--	Lepidoptera	DuPont	NA
fipronil	Regent®	Thrips	Rhône-Poulenc	1998
Halsflexozide (RH 0345)	--	Broad spectrum	Rohm and Haas	NA
imidacloprid	Admire®, Provado®	Aphids Whiteflies	Bayer	1995
methoxyfenozide (RH 2485)	Intrepid®	Lepidoptera	Rohm and Haas	1998
pymetrozine (CG 215944)	Fulfil®	Aphids Whiteflies	Novartis	1999
pyriproxyfen	Knack®	Aphids Whiteflies	Valent	1998
vanilprole	Evaluation®	Broad spectrum; insects and mites	Rhône-Poulenc	NA

[a] BAW = beet armywormCEW/TFW= corn earworm/tomato fruitworm (*Helicoverpa zea*).

[b] Cucurbits, lettuce, and tomatoes are new vegetable crop registrations for cyromazine, which has been used for leafminer control in celery for a number of years.

Sources: Trade literature and communications with industry and university pest management specialists

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MARKET PROJECTIONS, 2000 AND 2005

Total Market

Table 37 presents projections for insecticide use in 2000 and 2005, for the selected major U.S. vegetable crops by type of technology. Overall, an 11-22% decline in the use of applied insect-control products is projected by 2005, due both to the availability of more effective new products and increasing emphasis on IPM for vegetable crops.

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Table 37
SELECTED U.S. VEGETABLE CROPS INSECT-CONTROL MARKET BY TYPE OF TECHNOLOGY, 1995-2005[a]
(thousands of acres)

Technology/ Product Group	1995	2000	2005
Transgenic Insect-Resistant Plants[b]	--	45-50	300-350
Applied Insect-Control Products			
Biological/Biologically based			
Bts	864.9	1,100-1,200	1,200-1,350
Viruses	NEG	200-300	400-500
Pheromone-Based Products	5.0	10-20	10-20
Botanicals	226.5	250-300	300-350
Microbially-Derived toxins	140.0	250-350	300-400
Subtotal	1,236.4	1,810-2,170	2,210-2,620
Insecticidal Soaps	130.0	130-150	130-150
New Chemistry	73.0	200-250	400-500
Conventional Chemistry			
Carbamates	2,555.0	2,050-2,200	1,500-1,700
Chlorinated Hydrocarbons	718.0	550-600	450-500
Organophosphates	2,026.0	1,600-1,700	840-950
Synthetic Pyrethroids	3,182.5	2,550-2,750	2,200-2,400
Other[b]	13.6	10-20	10-20
Subtotal	8,495.1	6,760-7,270	5,000-5,570
Total	9,934.5	8,900-9,840	7,740-8,840
Total, All Products	9,934.5	8,945-9,890	8,040-9,190

[a]Planted acres for transgenic insect-resistant plants; treatment acres for applied insect-control products. It is assumed that the total planted acreage of the selected vegetable crops will be approximately 2.1 million acres in 2000 and 2005.

[b]Other organic and inorganic insecticides.

Source: SRI Consulting

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Transgenic Insect-Resistant Plants

Seed for transgenic insect-resistant sweet corn and tomatoes is expected to be on the market in the United States by 1998 or 1999, and in 2000, it will be planted on an estimated 45,000-50,000 acres. By 2000, the transgenic vegetable seed market will expand to 300,000-350,000 planted acres. Transgenic sweet corn will account for the larger portion of the total insect-resistant seed plantings.

Applied Insect Control Products

Biological and Biologically Based Products

Bts

Use of Bt-based insecticides for vegetable crops will increase by 39-56% between 1995 and 2005. Bts will account for about 12% of the total vegetable crop market for applied insect-control products in 2000 and for 15-16% by 2005.

Viruses

Virus-based insecticides are expected to account for 2-3% of the insecticide treatments applied to vegetable crops in 2000 and for 5-6% by 2005.

Microbially Derived Toxins

The one product in this class in 1995 was applied to 140,000 acres that year, mainly for lettuce and tomatoes. Two new microbially-derived toxin products, Merck's emamectin (Proclaim®) and DowElanco's spinosad (Success®, Spintor®) are expected to be launched for vegetable crops in 1988. Both new products will compete with Bt-based products for control of Lepidopteran pests in vegetable crops. Spinosad's advantage is its wider vegetable pest spectrum; it controls leafminers and thrips as well as worms. By 2000, the use of microbially-derived toxins for the selected vegetable crops will grow to 250,000-350,000 treatment acres, and by 2005, to 300,000-400,000 treatment acres.

New Chemistry

The share of total applied insect-control product treatment acres accounted for by products based on new chemistry will increase from less than 1% in 1995 to 2-2.5% in 2000 and to 5-6% by 2005.

Conventional Chemical Products

Use of conventional chemical insecticides for vegetable crops is expected to decline by 11-22% during 1995-2005 because of the availability of new, effective, safer, and more environmentally compatible biological/biologically based insecticides and novel chemical insecticides, as well as transgenic sweet corn and tomato plants with built-in resistance to key insect pests. Conventional insecticides' share of the declining total selected vegetable crops market, based on treatment acres, will decrease from 85.5% in 1995 to about 75% in 2000, and to 63-65% by 2005.

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APPENDIX

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Table A-1

U.S. TRANSGENIC INSECT RESISTANT CORN FIELD TRIAL RELEASE PERMITS BY COMPANY, 1991-1995

Company or Institution	Number of Sites	Site Location(s)	Issue Date	Phenocat Category[a]	Phenotype[b]	Gene Category[c]
Companies						
Crop Genetics[d]	10	IA, MD, NE	4/8/93	IR	Lepidopteran resistant	Not SM-CryIA(c)-Btk/ Not SM-Tetracycline binding protein-
DeKalb	1	HI	9/29/92	IR	Lepidopteran resistant	SM-B-glucuronidase-/ SM-Phosphinothricin acetyl transferase-/ not SM-CryIA(c)-Bt
Dow	2	IL, IN	4/30/93	IR	CBI	SM-B-glucuronidase-E. coli/ not SM-CBI-CBI
Monsanto	1	IL	5/10/91	IR	Lepidopteran resistant	SM-Acetolactate synthase-/ SM-Luciferase-/ SM-NptII-E. coli/ not SM-CryIA(c)-Btk
Monsanto	1	IL	5/19/92	HT/IR	Herbicide tolerance/Lepidopteran resistant	SM-NptII-E. coli/ not SM-CBI-CBI
Monsanto	1	FL	9/29/92[e]	HT/IR	Glyphosate tolerant/Insecticidal protein	Not SM-Cry-/ Not SM-EPSPS-
Monsanto	1	HI	11/2/92	HT/IR	Coleopteran resistant/Lepidopteran resistant	SM-CBI-/ SM-NptII-E. coli/ not SM-CryIA(b)-Bt
Monsanto	1	HI, PR	11/2/92	IR	Lepidopteran resistant	SM-Acetolactate synthase-/ SM-B-glucuronidase-E. coli/ SM-EPSPS-/ SM-NptII-E. co
Monsanto	1	HI	11/2/92	IR	Lepidopteran resistant	SM-CBI-/ not SM-CBI-CBI
Monsanto	1	HI	11/17/92	IR	Lepidopteran resistant	SM-CBI-/ not SM-CBI-CBI
Monsanto	1	HI	12/4/92	HT/IR	Herbicide tolerance/Lepidopteran resistant	SM-CBI-/ not SM-CBI-CBI

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Table A-1 (Continued)

Company or Institution	Number of Sites	Site Location(s)	Issue Date	Phenocat Category[a]	Phenotype[b]	Gene Category[c]
Monsanto	1	MI, PR	12/17/92	HT/IR	Phosphinothricin tolerant/Lepidopteran resistant	SM-B-glucuronidase-E. coli/ SM-EPSPS-/ SM-NptII-E. coli/ not SM-CryIA(c)-Btk/ no
Monsanto	3	IL, OH	4/30/93[e]	HT/IR/IR/PQ	Glyphosate tolerant/Insecticidal protein/Lepidopte	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-Cry-CBI/ not SM-EPSPS-CBI
Monsanto	1	IL	4/30/93[e]	IR	Lepidopteran resistant	SM-CBI-CBI/ not SM-CryIA(b)-Btk
Monsanto	2	IA	4/30/93[e]	IR	Lepidopteran resistant	SM-CBI-CBI/ not SM-CryIA(b)-Btk
Monsanto	1	IL	4/30/93[e]	IR	Lepidopteran resistant	SM-CBI-CBI/ not SM-CryIA(b)-Btk
Monsanto	1	IL	4/30/93[e]	IR	Lepidopteran resistant	SM-CBI-CBI/ not SM-CryIA(b)-Btk
Monsanto	1	MD	4/30/93[e]	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CBI-CBI
Monsanto	1	IL	4/30/93[e]	IR/IR	Coleopteran resistant/Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Bt
Monsanto	1	IL	4/30/93[e]	IR/IR	Coleopteran resistant/Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(c)-Bt
Monsanto	1	IA	4/30/93[e]	IR/IR	Coleopteran resistant/Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(c)-Bt
Monsanto	1	MN	4/30/93[e]	IR/IR	Insecticidal protein/Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(c)-Bt
Monsanto	2	IN, NE	4/30/93[e]	IR/IR	Insecticidal protein/Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(c)-Bt
Novartis (Ciba-Geigy)	1	IL	5/27/92	HT/IR	Lepidopteran resistant/Lepidopteran resistant	SM-B-glucuronidase-E. coli/ SM-Phosphinothricin acetyl transferase-/ not SM-Cryl

Table A-1 (Continued)

Company or Institution	Number of Sites	Site Location(s)	Issue Date	Phenocat Category[a]	Phenotype[b]	Gene Category[c]
Novartis (Ciba-Geigy)	1	HI	9/1/92	IR	Lepidopteran resistant	SM-B-glucuronidase-E. coli/ SM-Phosphinothricin acetyl transferase-/ not SM-CryI
Novartis (Ciba-Geigy)	1	FL	9/11/92	IR	Lepidopteran resistant	SM-B-glucuronidase-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydros
Novartis (Ciba-Geigy)	9	NC	4/13/93	HT/IR	Herbicide tolerance/Lepidopteran resistant	SM-B-glucuronidase-E. coli/ SM-Phosphinothricin acetyl transferase-/ not SM-CryI
Novartis (Ciba-Geigy)	1	HI	4/30/93[e]	IR/IR	Coleopteran resistant/Lepidopteran resistant	SM-B-glucuronidase-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hygros
Novartis (Ciba-Geigy)	1	NC	3/28/95[e]	IR	Coleopteran resistant	SM-Phosphinothricin acetyl transferase-/ not SM-CBI-CBI
Novartis (Northrup King)	4	IL, MN	5/14/92	HT/IR	Phosphinothricin tolerant/European corn borer resistant	Not SM-CryIA(b)-Btk/ Not SM-Phosphinothricin acetyl transferase-Strep. viridochr
Novartis (Northrup King)	2	PR	10/13/92	IR/VR	Lepidopteran resistant/MDMV resistant	SM-NptII-E. coli/ SM-Phosphinothricin acetyl transferase-/ not SM-Coat protein-M
Novartis (Northrup King)	22	IA, IL, KY, MN, NE, OH, PA	4/26/93	HT/IR/VR	Phosphinothricin tolerant/Lepidopteran resistant/M	SM-NptII-E. coli/ SM-Phosphinothricin acetyl transferase-/ not SM-Coat protein-M
Novartis (Northrup King)	41	CA, CO, CT, DE, GA, HI, IA	1/31/95[e]	HT/IR	Phosphinothricin tolerant/Lepidopteran resistant	Not SM--
Novartis (Northrup King)	1	MN	3/16/95[e]	IR	n.a.	Not SM--
Pioneer	1	HI	9/24/91	IR	European corn borer resistant	SM-Phosphinothricin acetyl transferase-/ not SM-Lectin-Wheat

Table A-1 (Concluded)

Company or Institution	Number of Sites	Site Location(s)	Issue Date	Phenocat Category[a]	Phenotype[b]	Gene Category[c]
Pioneer	1	FL	9/24/91	IR	European corn borer resistant	SM-Phosphinothricin acetyl transferase-/ not SM-Wheat germ agglutinin-Wheat
Pioneer	1	IA	5/4/92	HT/IR	Phosphinothricin tolerant/European corn borer resistant	Not SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus/ Not SM-Wheat ge
Pioneer	1	HI	6/1/92	HT/IR	Phosphinothricin tolerant/European corn borer resistant	Not SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus/ Not SM-Wheat ge
Pioneer	1	HI	10/21/92	IR	Lepidopteran resistant	SM-Phosphinothricin acetyl transferase-/ not SM-Wheat germ agglutinin-Wheat
Pioneer	2	HI, IA	4/13/93	IR	Lepidopteran resistant	SM-Acetolactate synthase-/ SM-Phosphinothricin acetyl transferase-/ not SM-CBI-C
Pioneer	1	IA	4/22/93	HT/IR	Phosphinothricin tolerant/Lepidopteran resistant	Not SM-Phosphinothricin acetyl transferase-Strep. hygroscopicus/ Not SM-Wheat ge
Universities						
Michigan State U	1	MI	6/13/94[e]	HT/IR	Phosphinothricin tolerant/Insect predator resistant	Not SM-Phosphinothricin acetyl transferase-

[a] HT = herbicide tolerance; IR = insect resistance; PQ = product quality' VR = virus resistance.

[b] CBI = confidential business information.

[c] CBI = confidential business information; SM = selectable marker.

[d] Crop Genetics International was acquired by biosys, Inc. om 1995; biosys was acquired by Thermo Trilogy in January 1997.

Source: Biotechnology Permits Data Base, USDA.

Table A-2
U.S. INSECT RESISTANT CORN FIELD TRIAL NOTIFICATIONS BY COMPANY, JANUARY 1995 - AUGUST 1996

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Asgrow	NA	30-Mar-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Asgrow	NA	30-Mar-95	IA, IN, NE, PR	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Asgrow	1.5	11-Apr-95	IA, IN, NE	IR	Lepidopteran resistant	CBI-Btk/ SM-CBI-
Asgrow	1.0	09-Jun-95	PR	IR	Lepidopteran resistant	CBI-CBI/ SM-CBI-
Asgrow	NA	20-Sep-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Asgrow	NA	26-Feb-96	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Asgrow	450.0	15-Mar-96	IA, IL, IN, MD, MI, MN, MO, NE, OH, PR, TX, WI	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Asgrow	NA	15-Mar-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Becks Superior Hybrids	0.2	22-May-96	IN	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-
Cargill	2.0	04-Apr-95	HI, IL	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Cargill	NA	04-Apr-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Cargill	NA	04-Apr-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Cargill	NA	03-Apr-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Cargill	NA	03-Apr-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA

Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Cargill	NA	03-Apr-96	NA	IR	Lepidopteran resistant	CBI-Btt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Cargill	17.0	04-Apr-96	HI, IA, IL	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Cargill	14.0	04-Apr-96	HI, IA, IL	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Cargill	NA	04-Apr-96	HI, IA, IL	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Cargill	NA	06-Aug-96	NA	IR	Lepidopteran resistant	-
Ciba-Geigy[c]	NA	19-Jan-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Ciba-Geigy[c]	NA	24-Jan-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Ciba-Geigy[c]	NA	24-Jan-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Ciba-Geigy[c]	NA	27-Feb-95	NC	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Ciba-Geigy[c]	NA	27-Feb-95	NC	IR	Lepidopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Ciba-Geigy[c]	NA	27-Feb-95	NC	IR	Lepidopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes

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Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Ciba-Geigy[c]	6,330.6	06-Mar-95	AL, AR, CA, CO, DE, FL, GA, HI, IA, IL, IN, KS, KY, MD, MI, MN, MO, NC, NE, NY, OH, PA, SD, TN, TX, VA, WI	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Ciba-Geigy[c]	NA	07-Mar-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Ciba-Geigy[c]	NA	27-Mar-95	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Ciba-Geigy[c]	51.0	28-Mar-95	FL, HI, IA, IL, NC	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Ciba-Geigy[c]	NA	06-Apr-95	IA	IR	Lepidopteran resistant	-Bt/ SM-Phosphinothricin acetyl transferase-
Ciba-Geigy[c]	2.9	11-Apr-95	FL, HI, IL, NC	IR	Coleopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Ciba-Geigy[c]	NA	13-Apr-95	NA	IR/IR	European Corn Borer resistant/Lepidopteran resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Ciba-Geigy[c]	NA	14-Aug-95	NC	IR/IR	European Corn Borer resistant/Lepidopteran resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-
Ciba-Geigy[c]	NA	19-Sep-95	NA	IR/IR	European Corn Borer resistant/Lepidopteran resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes

Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Ciba-Geigy[c]	NA	03-Jan-96	NA	IR	Lepidopteran resistant	CryIA(b)-Bt/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Ciba-Geigy[c]	150.0	28-Feb-96	NC	IR/IR	European Corn Borer resistant/Lepidopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Ciba-Geigy[c]	150.0	28-Feb-96	NC	IR/IR	European Corn Borer resistant/Lepidopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Ciba-Geigy[c]	NA	21-Mar-96	IL, NC	IR	Coleopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Ciba-Geigy[c]	NA	28-Mar-96	HI, IA, IL, IN, MN, NC, NE, TX	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Ciba-Geigy[c]	2.0	12-Apr-96	IL	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-
Ciba-Geigy[c]	NA	12-Apr-96	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Ciba-Geigy[c]	0.1	03-May-96	MN	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-
Ciba-Geigy[c]	NA	06-Jun-96	IL	IR	Lepidopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Crows	0.51	10-Apr-96	FL, IL, PR	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-
DeKalb	NA	04-Mar-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
DeKalb	NA	17-Apr-96	NA	IR	European Corn Borer resistant	Phosphinothricin acetyl transferase-Strep. hydroscopicus

Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
DeKalb	NA	30-May-96	NA	IR	Coleopteran resistant	CBI-CBI/ Phosphinothricin acetyl transferase-Strep. hydroscopicus/ SM-Phosphinothricin acetyl transferase-
DeKalb	NA	03-Jun-96	NA	IR	European Corn Borer resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-
DeKalb	NA	01-Aug-96	NA	IR	European Corn Borer resistant	CBI-CBI/ Phosphinothricin acetyl transferase-Strep. hydroscopicus
Dow	2.2	29-Mar-95	IA, IL, IN, MN	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-
Dow	NA	29-Mar-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-
Dow	NA	29-Mar-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-
Dow	NA	29-Mar-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-
Dow	0.2	03-Apr-95	IL	IR	Lepidopteran resistant	CBI-CBI/ SM-B-glucuronidase-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Dow	NA	03-Apr-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-B-glucuronidase-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Genetic Enterprises	1.0	17-Apr-95	IA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Genetic Enterprises	NA	17-Apr-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Genetic Enterprises	NA	17-Apr-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Golden Harvest Seeds	1.4	29-Sep-95	HI, IA, IL, MO, NE, WI	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus

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Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Golden Harvest Seeds	NA	29-Sep-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Golden Harvest Seeds	NA	29-Sep-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Golden Harvest Seeds	0.85	28-Feb-96	HI, IA, KS, MO, NE	IR	Lepidopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-Bt
Golden Harvest Seeds	NA	28-Feb-96	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-Bt
Golden Harvest Seeds	4.0	10-Apr-96	HI	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-
Great Lakes Hybrids	0.15	17-Oct-95	PR	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Great Lakes Hybrids	NA	17-Oct-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Holdens	NA	11-Apr-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Holdens	NA	11-Apr-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Holdens	NA	11-Apr-95	HI, IA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Holdens	5.0	02-May-96	HI, IA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-
Holdens	NA	02-May-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-
Hunt-Wesson	NA	03-Mar-95	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
ICI	0.9	16-Nov-95	CO, HI, IA, IL, IN, MN, MO, NE, WI	IR	Lepidopteran resistant	CBI-CBI
ICI	0.55	04-Mar-96	IA, MO, NE	IR	Lepidopteran resistant	CBI-CBI/ SM-CBI-

Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
ICI	0.55	04-Mar-96	IA, MO, NE	IR	Lepidopteran resistant	CBI-CBI/ SM-CBI-
ICI	0.2	26-Mar-96	IA, IL	IR	Lepidopteran resistant	CBI-CBI/ SM-CBI-
Limagrain	12.0	04-Mar-96	IA, IL, IN, NE	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Limagrain	NA	04-Mar-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Limagrain	1.0	24-May-96	IA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-
Limagrain	NA	24-May-96	IN	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-
Monsanto	NA	06-Jan-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-CBI-
Monsanto	NA	26-Jan-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-CBI-
Monsanto	1.79	31-Jan-95	NC	IR	Lepidopteran resistant	CBI-/ CBI-CBI
Monsanto	0.7	14-Feb-95	MD, VA	IR	Lepidopteran resistant	CBI-CBI/ SM-EPSPS-Agrobacterium
Monsanto	5.0	15-Feb-95	IL	IR	Lepidopteran resistant	CBI-CBI/ SM-EPSPS-Agrobacterium
Monsanto	1.67	15-Feb-95	IA, IL, IN, MN	IR	Lepidopteran resistant	CBI-CBI/ SM-EPSPS-Agrobacterium
Monsanto	NA	15-Feb-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-EPSPS-Agrobacterium
Monsanto	NA	01-Mar-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-EPSPS-Agrobacterium
Monsanto	NA	03-Mar-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-EPSPS-Agrobacterium
Monsanto	12.0	06-Mar-95	IA, IL, IN, MD, NE	IR	Lepidopteran resistant	-
Monsanto	2.1	13-Mar-95	IL	IR	Lepidopteran resistant	CBI-CBI/ EPSPS-Arab. thaliaNA
Monsanto	1.5	13-Mar-95	IL	IR	Lepidopteran resistant	CBI-CBI/ EPSPS-Arab. thaliaNA
Monsanto	NA	13-Mar-95	IL, MO, NE, WI	IR	Lepidopteran resistant	CBI-CBI/ EPSPS-Arab. thaliaNA
Monsanto	NA	13-Mar-95	IL, OH	IR	Lepidopteran resistant	CBI-CBI/ EPSPS-Arab. thaliaNA
Monsanto	12.6	15-Mar-95	HI, IA, IL, MN, NE	IR	Lepidopteran resistant	CBI-CBI/ EPSPS-Arab. thaliaNA

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Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Monsanto	7.6	16-Mar-95	IA, IL, IN, KS, MD	IR	Lepidopteran resistant	CBI-CBI/ SM-EPSPS-Agrobacterium
Monsanto	NA	16-Mar-95	MO, NE, NY, OH, PA, WI	IR	Lepidopteran resistant	CBI-CBI/ SM-EPSPS-Agrobacterium
Monsanto	4.86	21-Mar-95	CO, IA, IL, IN, KS, KY	IR	Lepidopteran resistant	CBI-CBI/ SM-EPSPS-Agrobacterium
Monsanto	2.74	21-Mar-95	MI, MN, MO, NE, OH, PA, WI	IR	Lepidopteran resistant	CBI-CBI/ SM-EPSPS-Agrobacterium
Monsanto	2.0	22-Mar-95	IA, IL, IN, MN, MO, NE, WI	IR	Lepidopteran resistant	CBI-CBI/ SM-EPSPS-Agrobacterium
Monsanto	1.5	24-Mar-95	IA, IL, IN, NE	IR	Lepidopteran resistant	CBI-CBI/ SM-EPSPS-Agrobacterium
Monsanto	16.3	28-Mar-95	AL, IL, NE	IR	Lepidopteran resistant	CBI-CBI/ SM-EPSPS-Agrobacterium
Monsanto	0.5	28-Mar-95	ID, MN	IR	Lepidopteran resistant	CBI-CBI/ SM-EPSPS-Agrobacterium
Monsanto	3.17	30-Mar-95	HI, IA, IL, IN, MO, OH	IR	Lepidopteran resistant	CBI-CBI/ SM-EPSPS-Agrobacterium
Monsanto	NA	01-May-95	IL, IN, MO, PA	IR	Lepidopteran resistant	CBI-CBI
Monsanto	NA	03-May-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-EPSPS-
Monsanto	1.75	09-May-95	IL, IN, MI, OH, TN, WI	IR	Lepidopteran resistant	CBI-CBI/ SM-EPSPS-Agrobacterium
Monsanto	NA	26-Jun-95	NA	IR	Lepidopteran resistant	CBI-CBI/ EPSPS-Arab. thaliaNA
Monsanto	1.0	16-Aug-95	HI	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Monsanto	2.0	31-Aug-95	HI	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Monsanto	NA	31-Aug-95	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-
Monsanto	12.0	05-Sep-95	HI, PR	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA

Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Monsanto	6.0	12-Sep-95	PR	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Monsanto	NA	12-Sep-95	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Monsanto	NA	21-Sep-95	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Monsanto	12.0	22-Sep-95	HI	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Monsanto	2.5	25-Sep-95	HI, PR	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Monsanto	0.2	25-Sep-95	HI	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Monsanto	1.5	04-Oct-95	HI	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Monsanto	0.8	07-Nov-95	HI, PR	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Monsanto	0.1	07-Nov-95	HI, PR	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Monsanto	NA	07-Nov-95	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Monsanto	NA	07-Nov-95	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Monsanto	180.0	13-Nov-95	PR	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Monsanto	2.0	01-Dec-95	PR	IR/IR	Coleopteran resistant/Lepidopteran resistant	CBI-CBI/ SM-NptII-E. coli
Monsanto	NA	17-Jan-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium

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Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Monsanto	NA	01-Feb-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Monsanto	NA	20-Feb-96	NA	IR/IR	Coleopteran resistant/Lepidopteran resistant	CBI-CBI/ SM-NptII-E. coli
Monsanto	NA	20-Mar-96	DE, IL, IN, MD, OH	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Monsanto	NA	20-Mar-96	IA, KS, MI, MO	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Monsanto	NA	21-Mar-96	MN, NE, NY, PA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Monsanto	NA	28-Mar-96	IA, IL, MD, MN, NC, TN, VA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Monsanto	NA	04-Apr-96	HI, IA, IL	IR/IR	Coleopteran resistant/Lepidopteran resistant	CBI-CBI/ SM-NptII-E. coli
Monsanto	NA	04-Apr-96	IL, MD, NC, TN, VA	IR/IR	Coleopteran resistant/Lepidopteran resistant	CBI-CBI/ SM-NptII-E. coli
Monsanto	0.5	09-Apr-96	HI	IR/IR	Coleopteran resistant/Lepidopteran resistant	CBI-CBI/ SM-NptII-E. coli
Monsanto	0.5	09-Apr-96	HI	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-
Monsanto	NA	12-Apr-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-
Monsanto	0.1	30-Apr-96	IA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-
Monsanto	0.1	25-Jun-96	AL, PR	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-

Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Mycogen	226.38	13-Mar-95	CO, DE, GA, IA, IL, IN, KS, KY, LA MD, MI, MO, NC, NE, OH, OK PA, PR, SC SD, TN, TX, WI	IR/IR	European Corn Borer resistant/Lepidopteran resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Mycogen	NA	11-Apr-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
NC+ Hybrids	1.0	07-Apr-95	NE	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
NC+ Hybrids	NA	07-Apr-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
NC+ Hybrids	0.9	11-Oct-95	HI, NE	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
NC+ Hybrids	0.5	09-Apr-96	NE	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-
NC+ Hybrids	NA	09-Apr-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Northrup King[c]	NA	24-Jan-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	50.0	21-Feb-95	HI	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	2.0	27-Feb-95	TX	IR	Not specified	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes

Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Northrup King[c]	NA	27-Feb-95	NA	IR	Not specified	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	0.2	01-Mar-95	MS	IR	Not specified	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	NA	01-Mar-95	NA	IR	Not specified	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	2,256.0	06-Mar-95	IA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	40.0	06-Mar-95	KS	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	32.0	06-Mar-95	MO	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	12.0	06-Mar-95	KY	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	10.0	06-Mar-95	TX	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	3.0	06-Mar-95	NC	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	1.0	06-Mar-95	GA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes

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Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Northrup King[c]	1.0	06-Mar-95	TN	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	470.0	09-Mar-95	IL	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	210.0	09-Mar-95	WI	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	65.0	09-Mar-95	NE	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	55.0	09-Mar-95	MN	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	28.0	09-Mar-95	SD	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	25.0	09-Mar-95	HI	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	25.0	09-Mar-95	IN	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	25.0	09-Mar-95	OH	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	15.0	09-Mar-95	MI	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes

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Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Northrup King[c]	10.0	09-Mar-95	NY	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	8.0	09-Mar-95	CO	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	7.0	09-Mar-95	PA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	5.0	09-Mar-95	ID	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	5.0	09-Mar-95	PR	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	3.0	09-Mar-95	VA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	2.0	09-Mar-95	DE	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	2.0	09-Mar-95	MD	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	2.0	09-Mar-95	MT	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	2.0	09-Mar-95	OR	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes

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Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Northrup King[c]	1.0	09-Mar-95	ND	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	1.0	09-Mar-95	NJ	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	1.0	09-Mar-95	WA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	NA	13-Mar-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	0.5	15-Mar-95	MN	IR	Not specified	CBI-/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	NA	22-Mar-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	NA	23-Mar-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	NA	12-Apr-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	NA	12-Apr-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Northrup King[c]	NA	12-Apr-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Northrup King[c]	NA	12-Apr-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus

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Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Northrup King[c]	NA	25-Apr-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	NA	17-Jul-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	NA	19-Jul-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	NA	19-Jul-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	NA	20-Jul-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	NA	09-Aug-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	NA	10-Aug-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	NA	23-Aug-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-
Northrup King[c]	NA	29-Aug-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	40.0	01-Sep-95	HI	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes

Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Northrup King[c]	NA	07-Sep-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	5.0	12-Sep-95	FL	IR	European Corn Borer resistant	CBI-CBI/ CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	NA	12-Sep-95	NA	IR	European Corn Borer resistant	CBI-CBI/ CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	20.0	18-Sep-95	HI, PR	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	0.6	18-Sep-95	HI, PR	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Northrup King[c]	0.2	18-Sep-95	HI, PR	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Northrup King[c]	0.2	18-Sep-95	HI, PR	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Northrup King[c]	NA	20-Sep-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	NA	21-Sep-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Northrup King[c]	NA	21-Sep-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Northrup King[c]	NA	21-Sep-95	NA	IR	Lepidopteran resistant	CBI-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Northrup King[c]	NA	02-Oct-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes

Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Northrup King[c]	NA	05-Dec-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Northrup King[c]	NA	12-Dec-95	NA	IR	Not specified	Not specified
Northrup King[c]	NA	12-Dec-95	FL, HI, IA, ID, IL, IN, KY, MN, OH, PR	IR	Not specified	Not specified
Northrup King[c]	5.0	15-Mar-96	HI, IA, IL, MN, NE	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Northrup King[c]	0.29	15-Mar-96	HI, IL, MN	IR	Lepidopteran resistant	CBI-Btt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Northrup King[c]	0.29	15-Mar-96	HI, IL, MN	IR	Lepidopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Northrup King[c]	NA	15-Mar-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Pioneer	0.5	01-Feb-95	NC	IR	Lepidopteran resistant	CBI-CBI/ SM-B-glucuronidase-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	0.5	06-Feb-95	KY	IR	Lepidopteran resistant	CBI-CBI/ SM-B-glucuronidase-E. coli/ SM-CBI-/ SM-NptII-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	0.5	06-Feb-95	GA	IR	Lepidopteran resistant	CBI-CBI/ SM-B-glucuronidase-E. coli/ SM-CBI-/ SM-NptII-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	4.5	08-Feb-95	IL	IR	Lepidopteran resistant	CBI-CBI/ SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus

Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Pioneer	1.5	08-Feb-95	NE	IR	Lepidopteran resistant	CBI-CBI/ SM-B-glucuronidase-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	1.25	08-Feb-95	PA	IR	Lepidopteran resistant	CBI-CBI/ SM-B-glucuronidase-E. coli/ SM-CBI-/ SM-NptII-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	1.25	08-Feb-95	WI	IR	Lepidopteran resistant	CBI-CBI/ SM-B-glucuronidase-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	1.25	08-Feb-95	IN	IR	Lepidopteran resistant	CBI-CBI/ SM-B-glucuronidase-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	1.0	08-Feb-95	MO	IR	Lepidopteran resistant	CBI-CBI/ SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	1.0	08-Feb-95	SD	IR	Lepidopteran resistant	CBI-CBI/ SM-B-glucuronidase-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	0.75	08-Feb-95	MI	IR	Lepidopteran resistant	CBI-CBI/ SM-B-glucuronidase-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	0.25	08-Feb-95	ND	IR	Lepidopteran resistant	CBI-CBI/ SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	0.08	08-Feb-95	MN	IR	Lepidopteran resistant	CBI-CBI/ SM-B-glucuronidase-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	NA	21-Feb-95	NA	IR	Lepidopteran resistant	-

Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Pioneer	NA	01-Mar-95	NA	IR/IR	Coleopteran resistant/Lepidopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	13.5	15-Mar-95	IA	IR	Lepidopteran resistant	CBI-CBI/ SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	NA	22-Mar-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-CBI-
Pioneer	0.8	03-Apr-95	IA	IR	Lepidopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	NA	03-Apr-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	0.5	06-Apr-95	IA	IR	Lepidopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	2.0	25-May-95	HI	IR	Lepidopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-
Pioneer	3.0	05-Sep-95	HI	IR	Coleopteran resistant	CBI-CBI
Pioneer	NA	05-Sep-95	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Pioneer	NA	05-Sep-95	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Pioneer	15.0	18-Sep-95	HI	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium/ SM-NptII-E. coli
Pioneer	15.0	18-Sep-95	PR	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium/ SM-NptII-E. coli
Pioneer	NA	18-Sep-95	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Pioneer	50.0	17-Jan-96	HI	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA

Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Pioneer	0.1	26-Jan-96	TX	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Pioneer	NA	30-Jan-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium
Pioneer	10.0	23-Feb-96	HI	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA/ SM-NptII-E. coli
Pioneer	NA	23-Feb-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA/ SM-NptII-E. coli
Pioneer	NA	26-Feb-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Pioneer	7.1	20-Mar-96	IL	IR	Lepidopteran resistant	CBI-CBI/ CryIA(b)-Btk
Pioneer	2.9	20-Mar-96	IN	IR	Lepidopteran resistant	CBI-CBI/ CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Pioneer	1.5	20-Mar-96	SD	IR	Lepidopteran resistant	CBI-CBI/ CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Pioneer	0.9	20-Mar-96	MN	IR	Lepidopteran resistant	CBI-CBI/ CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Pioneer	0.8	20-Mar-96	PA	IR	Lepidopteran resistant	CBI-CBI/ CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Pioneer	0.8	20-Mar-96	WI	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Pioneer	0.5	20-Mar-96	NE	IR	Lepidopteran resistant	CBI-CBI/ CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Pioneer	0.5	20-Mar-96	MO	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Pioneer	0.4	20-Mar-96	MI,	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA

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Table A-2 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Pioneer	NA	20-Mar-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA/ SM-Phosphinothricin acetyl transferase-/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	13.5	01-Apr-96	IA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Pioneer	2.0	10-Apr-96	IA	IR	Coleopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-
Pioneer	1.0	10-Apr-96	NE	IR	Coleopteran resistant	CBI-CBI/ SM-Phosphinothricin acetyl transferase-
Pioneer	NA	12-Apr-96	NA	IR	Coleopteran resistant	CBI-CBI/ Phosphinothricin acetyl transferase-Strep. viridochromogenes
Pioneer	10.0	14-Jun-96	HI	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-NptII-E. coli
Pioneer	NA	14-Jun-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-NptII-E. coli
Pioneer	NA	18-Jul-96	NA	IR	Lepidopteran resistant	CryIA(b)-Bt/ CryIA(b)-Btk/ SM-EPSPS-Arab. thaliaNA
Pioneer	NA	18-Jul-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-
Pioneer	30.0	23-Jul-96	HI	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium/ SM-NptII-E. coli
Pioneer	30.0	23-Jul-96	PR	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-Agrobacterium/ SM-NptII-E. coli
Pioneer	NA	25-Jul-96	NA	IR	Lepidopteran resistant	CryIA(b)-Btk/ SM-EPSPS-/ SM-NptII-E. coli
Rogers[d]	NA	21-Apr-95	NA	IR	European Corn Borer resistant	-Strep. viridochromogenes/ SM-Phosphinothricin acetyl transferase-
Rogers[d]	NA	21-Apr-95	CA, MN	IR	European Corn Borer resistant	-Btk/ SM-Phosphinothricin acetyl transferase-

Table A-2 (Concluded)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Rogers[d]	NA	24-Nov-95	NA	IR	European Corn Borer resistant	CryIA(b)-Btk/ SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
USDA/ARS	0.1	15-Mar-95	IL	IR/IR	European Corn Borer resistant/Lepidopteran resistant	CryIA(b)-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
USDA/ARS	0.1	07-Feb-96	IL	IR	Lepidopteran resistant	CryIA(b)-Bt/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
USDA/ARS	0.1	13-Feb-96	IL	IR	Lepidopteran resistant	CryIA(b)-Bt/ SM-Phosphinothricin acetyl transferase-

NA = not available.

[a] IR = insect resistant.

[b] CBI = confidential business information.

[c] Ciba and Northrup King are now Novartis Seeds.

[d] Field trials conducted by Rogers Seeds, also part of Novartis Seeds, were probably sweet corn trials.

Source: Biotechnology Permits Data Base, USDA.

Table A-3
U.S. TRANSGENIC INSECT RESISTANT COTTON FIELD TRIAL RELEASE PERMITS BY COMPANY, 1989-1993

Institution	Number of Sites	Site Location(s)	Issue Date	Phenocat Category[a]	Phenotype	Gene Category
Agracetus	1	MS	4/13/89	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(a)-Btk
American Cyanamid	2	AZ, LA	4/30/93[b]	HT/IR	Bromoxynil tolerant/ Lepidopteran resistant	not SM-CryIA(c)-Btk/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	1	HI	9/12/90	HT/IR	Bromoxynil tolerant/ Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(c)-Btk/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	1	MS	3/6/91	HT/IR	Bromoxynil tolerant/ Lepidopteran resistant	SM-NptII-E. coli/ not SM-Cry-Btk/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	4	AZ, MS, SC	4/17/92	HT/IR	Bromoxynil tolerant/ Lepidopteran resistant	not SM-CryIA(c)-Btk/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	1	MS	4/20/92	HT/IR	Bromoxynil tolerant/ Lepidopteran resistant	not SM-CryIA(c)-Btk/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	3	AZ, MS, SC	3/18/93	HT/IR	Bromoxynil tolerant/ Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(c)-Btk/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	1	MS	4/8/93	HT/IR	Bromoxynil tolerant/ Lepidopteran resistant	not SM-CryIA(c)-Btk/ not SM-Nitrilase-Klebsiella ozaenae
Miles[c]	2	GA, MS	4/30/93[b]	HT/IR	Coleopteran resistant/ Lepidopteran resistant	not SM-CryIA(c)-Bt/ not SM-Nitrilase-Klebsiella ozaenae
Monsanto	1	HI	10/11/89	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk
Monsanto	2	AZ, IL	4/16/90	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk
Monsanto	6	AL, AZ, CA, LA, MS, TX	4/27/90	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk
Monsanto	1	HI	9/20/90	HT/IR	Glyphosate tolerant/ Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk/ not SM-EPSPS-Arab. t
Monsanto	2	CA ,MS	4/2/91	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk

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Table A-3 (Concluded)

Institution	Number of Sites	Site Location(s)	Issue Date	Phenocat Category[a]	Phenotype	Gene Category
Monsanto	5	AL, AZ, LA, MS, TX	4/12/91	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk
Monsanto	1	AL	5/2/91	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(c)-Btk
Monsanto	1	HI	9/16/91	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk
Monsanto	2	NC	4/14/92	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk
Monsanto	19	AL, AR, AZ, CA, GA, LA, MS	4/15/92	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk
Monsanto	3	NC	4/5/93	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk
Monsanto	26	AL, AR, AZ, CA,GA, LA, MS	4/30/93	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk
Monsanto	1	MD	4/30/93[b]	IR/IR	Insecticidal protein/ Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(c)-Bt
Northrup King[d]	1	MS	4/5/90	HT/IR	Glyphosate tolerant/ Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk/ not SM-EPSPS-

a IR = insect resistant; HT = herbicide tolerant.

b Withdrawn.

c Now Bayer Corporation.

d Now part of Novartis Seeds.

Source: Biotechnology Permits Data Base, USDA.

Table A-4
INSECT RESISTANT COTTON FIELD TRIAL NOTIFICATIONS, JANUARY 1995 TO AUGUST 1996

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype[b]	Gene Type[b]
Agracetus[c]	NA	30-Aug-95	NA	IR	CBI	-
Delta and Pine Land	NA	10-Feb-95	NA	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Delta and Pine Land	34,350	10-Feb-95	AZ, MS	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Delta and Pine Land	20.00	10-Feb-95	NC	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Delta and Pine Land	1,500	10-Feb-95	AL, AR AZ, CA, FL, GA, LA, MO, MS, SC, TN, TX	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Delta and Pine Land	369.0	23-Feb-95	AL, AR, AZ, FL, GA, LA, MS, SC, TX	IR	Lepidopteran resistant	CryIA(c)-Bt/ CryIIA-Bt/ SM-NptII-E. coli
Delta and Pine Land	10.00	23-Feb-95	NC	IR	Lepidopteran resistant	CryIA(c)-Bt/ SM-NptII-E. coli
Delta and Pine Land	NA	25-Sep-95	PR	IR	Lepidopteran resistant	Cry-Bt/ SM-NptII-E. coli
Delta and Pine Land	NA	06-Oct-95	PR	IR	Lepidopteran resistant	CryIIA-Bt/ SM-NptII-E. coli
Delta and Pine Land	NA	14-Feb-96	AZ	IR	Lepidopteran resistant	CryIIA-Bt/ SM-NptII-E. coli
Delta and Pine Land	NA	14-Feb-96	SC	IR	Lepidopteran resistant	CryIIA-Bt/ SM-NptII-E. coli
Delta and Pine Land	NA	14-Feb-96	MS	IR	Lepidopteran resistant	CryIIA-Bt/ SM-NptII-E. coli
Jacob Hartz	1.50	12-Jan-95	TX	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	NA	12-Jan-95	NA	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	NA	13-Jan-95	NA	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	12.15	19-Jan-95	NC	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	14.20	20-Jan-95	NC	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	NA	23-Jan-95	AL, AR, AZ, CA, FL	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli

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Table A-4 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype[b]	Gene Type[b]
Monsanto	NA	23-Jan-95	TX	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	297.2	25-Jan-95	GA, LA, MS, SC, TN	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	NA	31-Jan-95	NA	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	122.0	06-Feb-95	AL, AR, AZ, FL, GA	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	42.35	06-Feb-95	LA, MO, MS, SC, TN	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	15.0	06-Feb-95	TX	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	NA	22-Feb-95	NA	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	NA	22-Feb-95	NA	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	290.0	22-Feb-95	AZ	IR	Lepidopteran resistant	CryIA(c)-Btk/ CryIIA-Btk/ SM-NptII-E. coli
Monsanto	NA	22-Feb-95	NA	IR	Lepidopteran resistant	CryIA(c)-Btk/ CryIIA-Btk/ SM-NptII-E. coli
Monsanto	NA	01-Mar-95	NA	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	NA	06-Mar-95	NA	IR	Lepidopteran resistant	-
Monsanto	15.0	09-Mar-95	MS	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	115.0	20-Mar-95	AZ	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	NA	20-Mar-95	NA	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
	NA	31-Mar-95	NA	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	560.0	31-Mar-95	AZ	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	50.0	04-Apr-95	AZ	IR	Lepidopteran resistant	CryIA(c)-Btk/ CryIIA-Btk/ SM-NptII-E. coli

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Table A-4 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype[b]	Gene Type[b]
Monsanto	NA	04-Apr-95	NA	IR	Lepidopteran resistant	CryIA(c)-Btk/ CryIIA-Btk/ SM-NptII-E. coli
Monsanto	NA	13-Apr-95	NA	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	3,150	13-Apr-95	AR, MS	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	NA	13-Apr-95	NA	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	1.0	13-Apr-95	MS	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	NA	13-Apr-95	NA	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	3.0	21-Apr-95	FL	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	NA	21-Apr-95	NA	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	0.5	27-Apr-95	VA	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	NA	12-Jun-95	NA	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Monsanto	15.0	04-Aug-95	PR	IR	Lepidopteran resistant	CryIIA-Btk/ SM-NptII-E. coli
Monsanto	4.0	23-Aug-95	NA	IR	Lepidopteran resistant	CryIIA-Btk/ SM-NptII-E. coli
Monsanto	NA	01-Mar-96	NA	IR	Coleopteran resistant	CBI-CBI
Monsanto	1.0	01-Mar-96	AR	IR	Coleopteran resistant	CBI-CBI/ SM-CBI-
Monsanto	50.0	07-Mar-96	AR	IR	Lepidopteran resistant	CryIIA-Btk/ SM-NptII-E. coli
Monsanto	NA	15-Mar-96	NA	IR	Coleopteran resistant	CBI-CBI/ EPSPS-Arab. thaliana
Monsanto	NA	15-Mar-96	AR	IR	Coleopteran resistant	CBI-CBI/ EPSPS-Arab. thaliana
Monsanto	NA	28-Mar-96	AL, AR, MS, NC	IR	Lepidopteran resistant	CryIIA-Btk/ SM-NptII-E. coli
Monsanto	NA	28-Mar-96	AZ, TX	IR	Lepidopteran resistant	CryIIA-Btk/ SM-NptII-E. coli
Monsanto	NA	03-Apr-96	NA	IR	Lepidopteran resistant	CryIIA-Btk/ SM-NptII-E. coli
Monsanto	1.0	04-Apr-96	MS	IR	Coleopteran resistant	CBI-CBI/ SM-EPSPS-Arab. thaliana
Monsanto	25.0	06-Aug-96	PR	IR	Lepidopteran resistant	CryIIA-Btk/ SM-NptII-E. coli
Monsanto	NA	13-Aug-96	PR	IR	Coleopteran resistant	CBI-CBI/ SM-CBI-

Table A-4 (Concluded)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype[b]	Gene Type[b]
Mycogen	0.25	01-Mar-95	MS	IR	Insect resistant general	CryIA(c)-Btk/ SM-Phosphinothricin acetyl transferase-
Mycogen	NA	07-Apr-95	NA	IR	Not Specified	CBI-CBI/ SM-CBI-
Mycogen	0.25	28-Feb-96	MS	IR	Insect resistant general	CryIA(c)-/ SM-NptII-E. coli/ SM-Phosphinothricin acetyl transferase-
Mycogen	NA	28-Feb-96	NA	IR	Insect resistant general	CryIA(c)-/ SM-NptII-E. coli/ SM-Phosphinothricin acetyl transferase-

NA = Not available.

[a] IR = Insect resistant.

[b] CBI = Confidential business information.

[c] Acquired by Monsanto.

Source: Biotechnology Permits Data Base, USDA.

Table A-5

U.S. TRANSGENIC INSECT RESISTANT POTATO FIELD RELEASE PERMITS, 1990-1996

Institution	Number of Sites	Site Location(s)	Issue Date[a]	Phenocat Category[b]	Phenotype	Gene Category[c]
Companies						
Calgene	2	ID	4/15/92	IR/VR	Coleopteran resistant/PLRV resistant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-Coat protein-PLRV/ not SM-C
Frito Lay	1	WI	2/28/92	IR	Coleopteran resistant	SM-NptII-E. coli/ not SM-CryIIIA-Btt
Frito Lay	3	WI	4/30/93	IR/VR	Coleopteran resistant/PLRV resistant	SM-NptII-E. coli/ not SM-Chitinase-PVY/ not SM-Coat protein-Btt/ not SM-CryIIIA-
Monsanto	1	IL	4/19/90	IR/VR/VR	Coleopteran resistant/PLRV resistant/PVY resistant	SM-NptII-E. coli/ not SM-Coat protein-PLRV/ not SM-Coat protein-PVX/ not SM-Coat
Monsanto	1	WA	5/8/90	IR/VR/VR	Coleopteran resistant/PVX resistant/PVY resistant	SM-NptII-E. coli/ not SM-Coat protein-PVX/ not SM-Coat protein-PVY/ not SM-CryII
Monsanto	3	ID, ME, MI	4/26/91	IR/VR	Coleopteran resistant/PLRV resistant	SM-NptII-E. coli/ not SM-Coat protein-PLRV/ not SM-CryIIIA-Btk
Monsanto	3	OR, WA ,WI	5/14/91	IR	Coleopteran resistant	SM-NptII-E. coli/ not SM-CryIIA-Btk
Monsanto	1	ME	6/5/91	IR	Coleopteran resistant	SM-NptII-E. coli/ not SM-CryIIIA-Btt
Monsanto	1	WA	6/25/91	IR/VR/VR	Coleopteran resistant/PVX resistant/PVY resistant	SM-NptII-E. coli/ not SM-Coat protein-PVX/ not SM-Coat protein-PVY/ not SM-CryII
Monsanto	7	ID, ME,MI,OR, WA	4/20/92	IR/PQ/VR/ VR	Coleopteran resistant/Tuber solids increased/PVX r	SM-B-glucuronidase-E. coli/ SM-EPSPS-/ SM-NptII-E. coli/ not SM-CBI-CBI/ not SM-
Monsanto	2	NY	4/29/92	IR/PQ	Coleopteran resistant/Solids increased	SM-NptII-E. coli/ not SM-CBI-CBI/ not SM-CryIIIA-Btt

Table A-5 (Continued)

Company or Institution	Number of Sites	Site Location(s)	Issue Date[a]	Phenocat Category[b]	Phenotype	Gene Category[c]
Monsanto	2	FL, HI	11/23/92	IR/VR/VR/ VR	Coleopteran resistant/PLRV resistant/PVX resistant	SM-EPSPS-Arab. thaliana/ not SM-Coat protein-PLRV/ not SM-Coat protein-PVX/ not
Monsanto	38	CO, ID, MD, ME, MI,MT, ND	4/16/93	IR/PQ/VR/ VR	Coleopteran resistant/Auxin metabolism and increas	SM-B-glucuronidase-/ SM-CBI-/ SM-NptII-/ not SM-CBI-CBI/ not SM-CBI-PLRV/ not SM
Monsanto	1	WI	4/27/93	IR/PQ/VR/ VR	Coleopteran resistant/Tuber solids increased/PLRV	SM-B-glucuronidase-/ SM-CBI-/ SM-NptII-/ not SM-CBI-CBI/ not SM-CBI-PLRV/ not SM
Monsanto	1	MD	4/30/93a	IR	Coleopteran resistant	SM-NptII-E. coli/ not SM-CryIIIA-Btk
Monsanto	4	ID, ME, OR,WA	5/4/94	IR/VR	Coleopteran resistant/PLRV resistant	SM-NptII-E. coli/ not SM-CBI-CBI/ not SM-Coat protein-PLRV/ not SM-CryIIIA-Btt
Monsanto	2	CA, FL	10/31/94	IR/VR	Coleopteran resistant/PLRV resistant	SM-NptII-E. coli/ not SM-CBI-PLRV/ not SM-Coat protein-PLRV/ not SM-CryIIIA-Btt
Monsanto	19	CO, ID, ME, MN, MT, ND, OR	4/4/95	IR/VR	Colorado potato beetle resistant/PLRV resistant	SM-EPSPS-PLRV/ SM-NptII-E. coli/ not SM-CBI-Agro. tumefaciens/ not SM-CryIIIA-Bt
Monsanto	2	CA ,FL	9/15/95	IR/VR	Coleopteran resistant/PLRV resistant	SM-NptII-E. coli/ not SM-CBI-PLRV/ not SM-Coat protein-PLRV/ not SM-CryIIIA-Btt
Monsanto	13	ID, ME, OR, WA	4/2/96	IR/VR	Colorado potato beetle resistant/PLRV resistant	SM-NptII-/ not SM-Coat protein-PLRV/ not SM-CryIIIA-Btt
Monsanto	17	ID, ME, MN,MT, ND, NE, WA	4/18/96	IR/VR	Colorado potato beetle resistant/PLRV resistant	not SM-Coat protein-PLRV
Monsanto	2	CA, FL	10/29/96	IR/VR	Coleopteran resistant/PLRV resistant	SM-NptII-E. coli/ not SM-CBI-/ not SM-Coat protein-PLRV/ not SM-CryIIIA-Btt

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Table A-5 (Concluded)

Institution	Number of Sites	Site Location(s)	Issue Date[a]	Phenocat Category[b]	Phenotype	Gene Category[c]
Universities/ Government Agencies						
Michigan State University	1	MI	4/30/93a	IR	Lepidopteran resistant	not SM-CryIA(c)-Bt
USDA, ARS	1	WA	5/23/90	IR/IR	Coleopteran resistant/Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(a)-Btt/ not SM-CryIIIA-Btk
USDA, ARS	1	WA	5/14/92	IR	Colorado potato beetle resistant	SM-NptII-E. coli/ not SM-CryIB-Btt

[a] Withdrawn.

[b] IR = insect resistance; PQ = product quality; VR = virus resistance.

[c] CBI = confidential business information; SM = selectable marker.

Source: Biotechnology Permits Data Base, USDA.

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Table A-6
U.S. INSECT RESISTANT POTATO FIELD TRIAL NOTIFICATIONS, JANUARY1995 TO AUGUST 1996

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Companies:						
Frito Lay	0.1	25-Apr-95	WI	IR	Colorado potato beetle resistant	CryIIIA-Btt/ SM-NptII-E. coli
Frito Lay	0.1	16-Apr-96	ME, WI	IR	Colorado potato beetle resistant	CryIIIA-Btt/ SM-NptII-E. coli
Frito Lay	NA	06-Aug-96	NA	IR	Colorado potato beetle resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	26.0	05-Jan-95	MD, NC	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	505.0	09-Jan-95	OR, WA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	11-Jan-95	NA	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	11-Jan-95	NA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	0.1	23-Jan-95	ME, PA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	2,820.0	30-Jan-95	ID, ME, MI	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	2,102.0	30-Jan-95	MN, ND, WI	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	30-Jan-95	NA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	30-Jan-95	NA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	1.3	07-Feb-95	ID, ME, VA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-EPSPS-Arab. thaliana/ SM-NptII-E. coli
Monsanto	0.8	07-Feb-95	NY, PA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-EPSPS-Arab. thaliana/ SM-NptII-E. coli
Monsanto	0.8	07-Feb-95	NY, PA	IR/PQ	Coleopteran resistant/Tuber solids increased	CBI-CBI/ CryIIIA-Btt/ SM-EPSPS-Arab. thaliana
Monsanto	0.1	07-Feb-95	ID, ME, VA	IR/PQ	Coleopteran resistant/Tuber solids increased	CBI-CBI/ CryIIIA-Btt/ SM-EPSPS-Arab. thaliana

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Table A-6 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Companies (Continued)						
Monsanto	103.3	10-Feb-95	ID, ME, OR, RI, WA, WI	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	97.0	10-Feb-95	ID, ME, OR, WA, WI	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	24.0	10-Feb-95	MI, OH	IR	Coleopteran resistant	CryIIIA-Btt/ SM-EPSPS-/ SM-NptII-E. coli
Monsanto	24.0	10-Feb-95	MI, OH	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	9.5	10-Feb-95	MA, MN, ND, NY, VA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-EPSPS-/ SM-NptII-E. coli
Monsanto	9.5	10-Feb-95	MA, MN, ND, NY, VA	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	21-Feb-95	NA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	100.0	23-Feb-95	WA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	2.0	23-Feb-95	NC	IR	Coleopteran resistant	CryIIIA-Btt/ EPSPS-Arab. thaliana/ SM-NptII-E. coli
Monsanto	NA	02-Mar-95	ME, MI, MN, ND, NE, NY	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-Btt/ SM-NptII-E. coli
Monsanto	NA	02-Mar-95	CO, ID, MT, OR, WI	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-/ CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	1,700.0	03-Mar-95	ME, MI, MN, ND, NE, NY	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	03-Mar-95	CO, ID, MT, OR, WI	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	23-Mar-95	NA	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ CryIIIA-Btt/ SM-NptII-E. coli

Table A-6 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Companies (Continued)						
Monsanto	NA	23-Mar-95	NA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-EPSPS-/ SM-NptII-E. coli
Monsanto	NA	04-Apr-95	NA	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	04-Apr-95	NA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-EPSPS-/ SM-NptII-E. coli
Monsanto	NA	01-May-95	WI	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	09-Jun-95	NA	IR	Coleopteran resistant	CBI-CBI/ SM-NptII-E. coli
Monsanto	NA	01-Dec-95	NA	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	01-Dec-95	NA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	14-Dec-95	NA	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	27.0	07-Feb-96	ME, MI, NC, VA, WI	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	07-Feb-96	ID, ME, MI, NC, NE, OR, VA, WA, WI	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-/ CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	400.0	09-Feb-96	ID, MN, OR, WA, WI	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	300.0	09-Feb-96	MA, ME, MI, PA, RI, VA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	150.0	09-Feb-96	MD, NC, NJ NY	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli

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Table A-6 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Companies (Continued)						
Monsanto	NA	22-Feb-96	CO, CT, IL, KY, ME, MI, MN, MT, ND, OH, OK, PA, SC, TX	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	11-Mar-96	NA	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	11-Mar-96	NA	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	11-Mar-96	ID, ME, MI, NC, NE, OR, VA, WA, WI	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	12-Mar-96	NJ	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	12-Mar-96	NJ	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	19-Mar-96	NA	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	19-Mar-96	NA	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	19-Mar-96	ID, ME, MT, NY, WI	IR/VR	Coleopteran resistant/PVY resistant	-
Monsanto	NA	19-Mar-96	CO, DE, ME, MN, ND, NE, OH	IR/VR	Coleopteran resistant/PVY resistant	-
Monsanto	325.0	26-Mar-96	ID, ME, MT, NY, WI	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	300.0	26-Mar-96	CO, DE, ME, MN, ND, NE, OH	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli

Table A-6 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Companies (Continued)						
Monsanto	300.0	26-Mar-96	ID, ME, MT, NY, WI	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ SM-NptII-E. coli
Monsanto	300.0	26-Mar-96	CO, DE, ME, MN, ND, NE, OH	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ SM-NptII-E. coli
Monsanto	NA	28-Mar-96	MA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	28-Mar-96	NA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	28-Mar-96	NA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	28-Mar-96	DE	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	03-Apr-96	NA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	30.0	08-Apr-96	ME	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	30.0	12-Apr-96	ME	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	08-May-96	NA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	10-May-96	ME	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Monsanto	NA	02-Jul-96	NA	IR/VR	Coleopteran resistant/PVY resistant	Coat protein-PVY/ CryIIIA-Btt/ SM-NptII-E. coli
Plant Genetics	NA	01-May-96	NM	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Universities and Government Agencies						
Michigan State U	NA	27-Feb-95	NA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Michigan State U	NA	21-Apr-95	MI	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Michigan State U	NA	21-Apr-95	MI	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Michigan State U	NA	22-Feb-96	CA	IR	Lepidopteran resistant	NA
Michigan State U	NA	29-Apr-96	MI	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli

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Table A-6 (Continued)

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Universities and Government Agencies						
Michigan State U	NA	29-Apr-96	NA	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Michigan State U	NA	29-Apr-96	MI	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Michigan State U	NA	02-May-96	MI	IR	Lepidopteran resistant	Cry-Btk/ SM-NptII-E. coli
Michigan State U	NA	02-May-96	MI	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
Michigan State U	NA	02-May-96	MI	IR	Lepidopteran resistant	CryIA(c)-Btk/ SM-NptII-E. coli
Michigan State U	NA	02-May-96	MI	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
New Mexico State U	1.0	10-Apr-95	NM	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
New Mexico State U	1.0	02-May-96	NM	IR	Coleopteran resistant	CryIIIA-Btt/ SM-NptII-E. coli
USDA/ARS	NA	20-Feb-96	CA	IR	Lepidopteran resistant	CryIA(a)-Btk/ SM-NptII-E. coli

NA = not available.

[a] IR = insect resistant; PQ = product quality; VR = virus resistant.

[b] CBI = confidential business information.

Source: Biotechnology Permits Data Base, USDA.

Table A-7
U.S. TRANSGENIC INSECT-RESISTANT VEGETABLE PLANT FIELD TRIALS BY COMPANY, MARCH 1988 -JUNE, 1996

Crop	Institution	Issue Date	Phenocat Category[a]	Phenotype	Gene Category
Tomato	Agrigenetics[b]	5/23/88	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(c)-Btk
Tomato	Campbell	5/10/91	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk
Tomato	Campbell	6/5/92	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk
Brassica oleracea	Cornell U	5/9/95	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(c)-Btk
Brassica oleracea	Cornell U	4/16/96	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(c)-Btk
Tomato	Monsanto	3/23/88	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA-Btk
Tomato	Monsanto	5/23/88	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk
Tomato	Monsanto	2/22/89	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk
Tomato	Monsanto	4/26/89	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(c)-Btk
Tomato	Monsanto	4/28/89	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk
Tomato	Monsanto	1/23/90	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk
Tomato	Monsanto	2/2/90	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk
Tomato	Monsanto	5/7/90	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk
Tomato	Northrup King[c]	6/4/91	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk
Tomato	Rogers NK[c]	5/7/92	IR	Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk
Eggplant	Rutgers U	7/1/94	IR	Coleopteran resistant	SM-NptII-E. coli/ not SM-CryIIIA-Btt
Eggplant	Rutgers U	5/31/95	IR	Coleopteran resistant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-CryIIIA-Btt
Eggplant	Rutgers U	6/12/96	IR	Colorado potato beetle resistant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-CryIIIA-Btt

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[a] IR = insect resistant.

[b] Now Mycogen Seeds.

[c] Now part of Novartis Seeds.

Source: Biotechnology Permits Data Base, USDA

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Table A-8
U.S. INSECT RESISTANT TOMATO FIELD TRIAL NOTIFICATIONS BY COMPANY, JANUARY 1995 TO JUNE 1996

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Companies						
Monsanto	NA	12-Apr-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-NptII-E. coli
Monsanto	NA	18-May-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-NptII-E. coli
Monsanto	5.0	18-May-95	CA	IR	Lepidopteran resistant	CBI-CBI/ SM-NptII-E. coli
Monsanto	NA	31-May-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-NptII-E. coli
Monsanto	5.0	31-May-95	CA	IR	Lepidopteran resistant	CBI-CBI/ SM-NptII-E. coli
Monsanto	4.0	04-Aug-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-NptII-E. coli
Monsanto	NA	04-Aug-95	AZ	IR	Lepidopteran resistant	CBI-CBI/ SM-NptII-E. coli
Monsanto	NA	15-Aug-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-NptII-E. coli
Monsanto	NA	15-Aug-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-NptII-E. coli
Monsanto	NA	18-Oct-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-NptII-E. coli
Monsanto	NA	26-Dec-95	NA	IR	Lepidopteran resistant	CBI-CBI/ SM-NptII-E. coli
Monsanto	4.0	11-Jan-96	FL	IR	Lepidopteran resistant	NA
Mycogen	NA	07-Feb-96	NA	IR	Lepidopteran resistant	-Btk/ SM-NptII-E. coli
Mycogen	NA	28-Feb-96	NA	IR	Lepidopteran resistant	-Btk/ SM-NptII-E. coli
Mycogen	NA	28-Feb-96	NA	IR	Lepidopteran resistant	-Btk/ SM-NptII-E. coli
Mycogen	NA	28-Feb-96	NA	IR	Lepidopteran resistant	-Btk/ SM-NptII-E. coli
Petoseed[c]	NA	13-Mar-95	CA	IR	Not specified	Lysozyme-/ Stilbene synthase-Grape/ SM-NptII-E. coli
Petoseed[c]	NA	13-Mar-95	NA	IR	Not specified	Lysozyme-/ Stilbene synthase-Grape/ SM-NptII-E. coli
Petoseed[c]	NA	05-Feb-96	CA	IR	Not specified	Lysozyme-E. coli/ Stilbene synthase-/ SM-NptII-E. coli

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Table A-8

Institution	Acres	Received	Locations	Phenocat Category[a]	Phenotype	Gene Type[b]
Universities						
Ohio State U	0.5	11-Apr-95	OH	IR	Insect resistant,3 general	Anionic peroxidase-Tobacco/ SM-NptII-E. coli
Texas Tech U	NA	10-Jun-96	MD	IR	Not specified	CBI-CBI/ SM-NptII-E. coli

NA = not available

[a] IR = insect resistant.

[b] CBI = confidential business information.

[c] Petoseed is now part of Semi NAs Vegetable Seeds, Inc.

Source: Biotechnology Permits Data Base, USDA.

REPORT II: WEED CONTROL

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INTRODUCTION

This report assesses the North American (U.S. and Canada only) corn, cotton, and soybean markets for herbicides as of 1995, the market potential by 2000 and 2005 for traditionally bred and transgenic herbicide-tolerant plants, and the likely impact of herbicide-tolerant plants on herbicide use and interproduct competition in the three major crop markets. The market data developed in this report are intended to provide a base line for monitoring and reporting year-to-year sales and market penetration of herbicide-tolerant plants and new herbicides. This report is one of six reports issued in 1997 to first-year subscribers to SRI Consulting's new multiclient program, *Biotechnology and New Chemistry: Their Impacts on Agricultural Pest Control.*

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OVERVIEW

WORLD HERBICIDE MARKET, 1995

World agricultural crop markets for herbicides totaled an estimated $14.1 million at the end-user level in 1995. Figure O-1 and Table O-1 indicate the estimated breakdown of the world market by major region and crop sector.

Figure O-1
WORLD CROP MARKETS FOR HERBICIDES, 1995

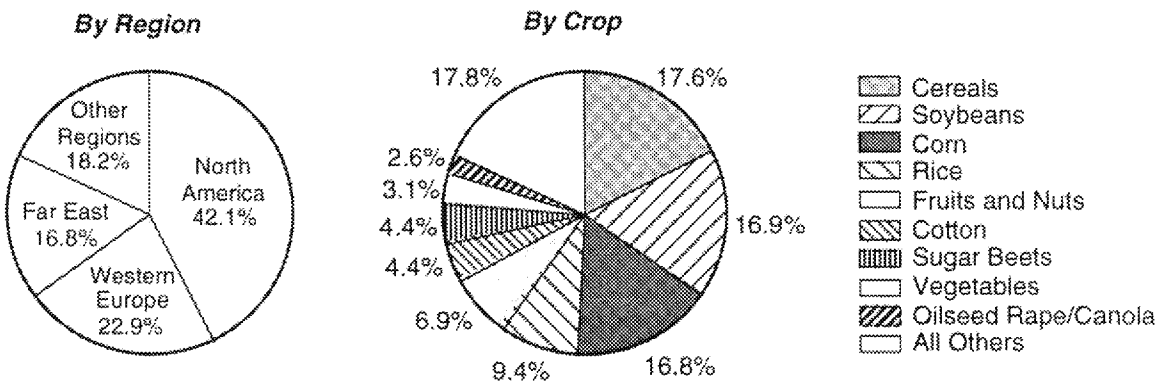

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Table O-1
WORLD CROP MARKETS FOR HERBICIDES BY REGION, 1995
(Millions of Dollars, End-User Sales)

Crop Market	Canada	United States	Total	Western Europe	Far East[a]	Other Regions	Total
Cereals	420	390	810	1,070	298	307	2,485
Soybeans	40	1,590	1,630	55	75	625	2,385
Corn	65	1,625	1,690	405	60	220	2,375
Rice	--	140	140	55	970	155	1,320
Fruits and Nuts[b]	3	170	173	300	330	167	970
Cotton	--	330	330	10	150	135	625
Sugar Beets	7	65	72	435	30	88	625
Vegetables	6	95	101	175	120	44	440
Oilseed Rape/Canola	82	10	92	235	25	18	370
Potatoes	5	30	35	100	55	70	260
Peanuts	--	60	60	--	32	30	122
Others	47	760	807	390	225	701	2,123
Total	675	5,265	5,940	3,230	2,370	2,560	14,100

[a]East Asia and Australia
[b]Citrus, grapes, apples, and other tree and vine crops.

Source: SRIC estimates

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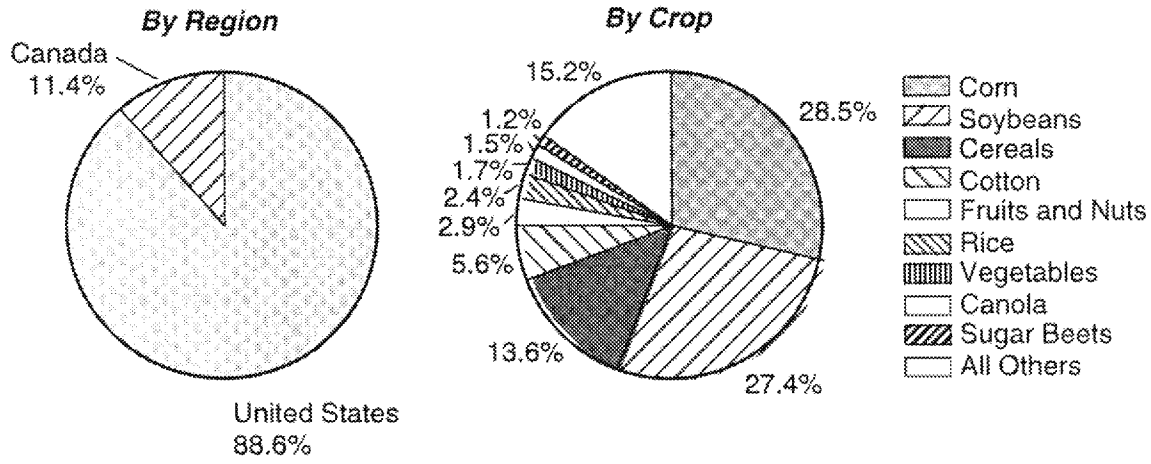
NORTH AMERICAN HERBICIDES MARKET, 1995

Herbicide sales in North American (excluding Mexico) agricultural crop markets totaled more than $5,900 million in 1995, of which the United States accounted for about 89% and Canada for 11% (see Figure O-2).

Figure O-2

NORTH AMERICAN CROP MARKETS FOR HERBICIDES, 1995



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NEW WEED CONTROL TECHNOLOGIES

Herbicide-Tolerant Crops

The most herbicide-intensive crops, including corn, soybeans, and cotton, have been the major targets for herbicide tolerance research. Together, chemical weed control for these crops totaled $3.5 billion for U.S. growers in 1995. Research on the development of herbicide-tolerant crops is dominated by several agricultural chemical companies and crop seed producers, as well as a few biotechnology companies. Commercial herbicide-tolerant crops entered the North American market in 1993. The major developers of transgenic herbicide-tolerant corn, cotton and soybeans are AgrEvo; DuPont; and Monsanto and its subsidiary, Calgene. American Cyanamid and BASF have developed traditionally bred hybrid corn tolerant of imidazolinone herbicides (IMI-Corn™), and sethoxydim (SR-Corn), respectively.

Table O-2 lists major transgenic herbicide-tolerant crops currently available or soon to be commercialized.

Table O-2
TRANSGENIC HERBICIDE-TOLERANT CROPS ON THE MARKET OR UNDER DEVELOPMENT IN NORTH AMERICA

Crop/Herbicide Tolerance	Trade Name	Supplier or Developer	Year on Market
Corn			
glufosinate	Liberty® Link	AgrEvo	1997
glyphosate	Roundup® Ready	Monsanto	1998
Cotton			
bromoxynil	BXN® Cotton	Calgene	1995
glyphosate	Roundup® Ready	Monsanto	1997
Soybeans			
glufosinate	Liberty® Link	AgrEvo	1998-1999
glyphosate	Roundup® Ready	Monsanto	1996
sulfonylurea herbicides	STS Soybeans	DuPont	1993

The appendix lists additional transgenic research known to be under way; we note that a significant portion of the research is unlikely to result in commercial products.

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Table O-3 shows the estimated and projected plantings of herbicide-tolerant corn, cotton, and soybeans in Canada and the United States.

Table O-3
NORTH AMERICAN PLANTINGS OF HERBICIDE-RESISTANT/TOLERANT PLANTS[a]
(Thousands of Acres)

	Corn	Cotton	Soybeans	Total
1995	1,800	—	3,000	4,800
1996	2,700	—	5,400	8,100
1997	4,500	—	15,000	19,500
2000	23,100-31,100	1,800-2,500	37,000-44,000	61,600-77,600
2005	48,000-57,000	2,100-2,700	45,000-53,000	95,100-112,700

[a] Includes traditionally bred and transgenic varieties. Projections for 2000 and 2005 include stacked trait varieties.

Source: SRI Consulting

U.S. and Canadian corn and soybean growers are expected to plant new "high-tech" corn and soybean seeds that have traditionally bred or genetically engineered resistance or tolerance to several postemergence herbicides on about 19.5 million acres in 1997. By 2000, the North American corn, cotton, and soybean markets for herbicide-tolerant plants will more than triple, and by 2005, the combined three-crop market will total 95 million to 113 million planted acres. Figure O-3 shows the percentages of the total corn, cotton, and soybean crop plantings of herbicide-resistant/tolerant seed products in 2000 and 2005.

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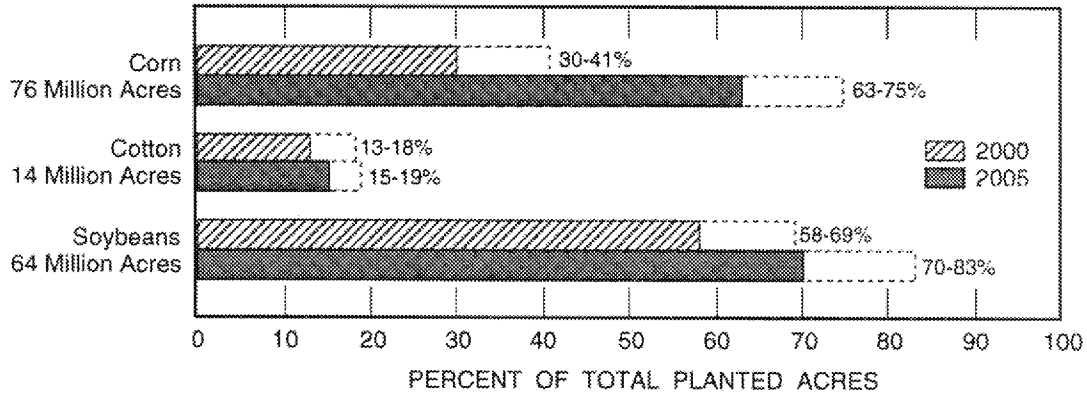
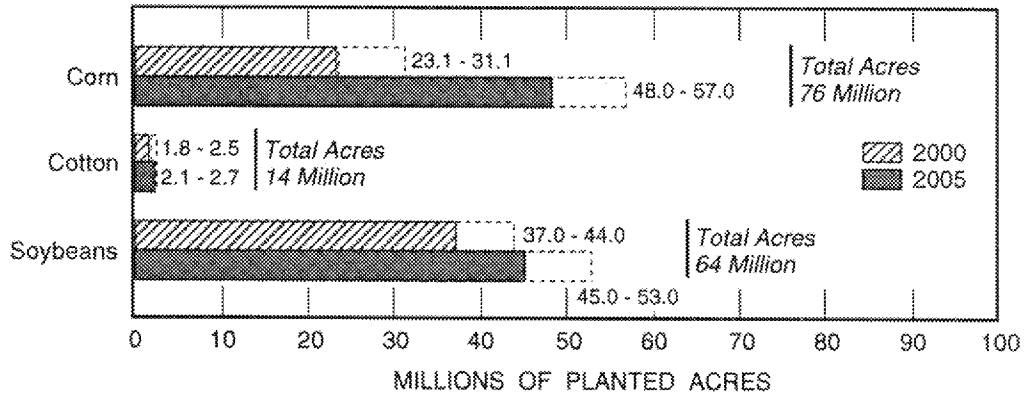
Figure O-3

PROJECTED NORTH AMERICAN PLANTED ACRES OF HERBICIDE RESISTANT/TOLERANT PLANTS





New Herbicides

Many new herbicides are being developed for corn and soybeans in North America, and one new product was launched in the U.S. cotton market in 1996. Several of the new product herbicides are sulfonylureas, and at least one is an imidazolinone. Most, however are novel compounds. Table O-4 lists herbicide products recently launched or expected to be registered within the next few years.

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Table O-4
HERBICIDES RECENTLY LAUNCHED OR UNDER DEVELOPMENT
FOR MAJOR NORTH AMERICAN CROPS

Product	Weeds Controlled	Application Timing[a]	Crop Market(s) (year on market)	Developing Company
carfentrazone	Grasses and broadleaf weeds	Post	corn soybeans	FMC
chloransulam-methyl (First Rate®)	Broadleaf weeds	Pre and Post	soybeans	DowElanco
flumiclorac (Resource®)	Broadleaf weeds	Post	corn (1995) soybeans	Valent
flurtamone (Benchmark®)	Broadleaf weeds' some grasses	Pre and Post		Rhône-Poulenc
fluthiacet-methyl (Action®)	Broadleaf weeds	Post	corn (1997) soybeans (1998)	Novartis (Ciba)[b]
halosulfuron-methyl (Permit®, Battalion®)	Broadleaf weeds, nutsedges	Pre and Post	corn (1995)	Monsanto[c]
imazamox (Raptor®)	Broad spectrum	Pre and Post	corn (1997 or 1998) Soybeans	American Cyanamid
isoxaflutole (Balance®)	Broadleaf weeds and grasses	Pre	corn (1997)	Rhône-Poulenc
metosulam (Eclipse®)	Broadleaf weeds	Pre and Post	corn	DowElanco
oxasulfuron (Expert®)	Broadleaf weeds, some grasses	Post	soybeans (1997)	Novartis (Ciba)
prosulfuron (premix with primisulfuron) (Exceed®)	Broadleaf weeds	Post	corn (1995)	Novartis (Ciba)
pyrithiobac sodium (Staple®)	Broadleaf weeds, some grasses	Pre and Post	cotton (1996)	DuPont[b]
rimsulfuron (premix with thifensulfuron) (Basis®)	Grasses and some broadleaf weeds	Post	corn (1995)	DuPont
sulfentrazone (Authority®)	Broadleaf weeds, some grasses	Pre	soybeans (1997)	FMC
thiafluamide (Axiom®)	Grasses and some broadleaf weeds	Pre and early Post	corn (1997-1998) soybeans	Bayer
thiazopyr (Visor®), RH 123 652	Grasses and broadleaf weeds	Pre	cotton	1997-1998
ZA-1296	Broadleaf weeds	Pre and Post	Corn	Zeneca

[a]PPI = preplant incorporated; Pre = preplant or preemergence; Post = postemergence.
[b] Licensed from Kumiai for development in the United States and Europe.
[c]Licensed from Nissan Chemical Industries, Ltd., Japan.

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EXPECTED MARKET IMPACT OF NEW TECHNOLOGIES

Using the two alternative, "extreme case" scenarios outlined below, we have projected the impacts of transgenic herbicide tolerant plants and new chemistry on the use of conventional chemical herbicides in the U.S. corn, cotton, and soybeans markets from 1995-2005, and on expected trends in consumption of individual herbicide products. Projections based on a "High Inertia/Price War" scenario (Scenario A) are summarized in Table O-5A, and projections under a "New Era" scenario (Scenario B) are provided in Table O-5B. Under both scenarios, we expect U.S. and Canadian crop markets for herbicides to continue to be affected by regulatory pressures, as well as by increasing availability and market acceptance of new weed control technologies. The following events and factors, in particular, will affect the overall market:

- Herbicide-resistant crop plants will not necessarily be treated with the herbicide that is tolerated. A preferred seed variety may "come with" herbicide resistance. Therefore, the grower's seed selection may be based on traits other than weed control, and the tolerated herbicide may not be applied.

- Inexpensive "burn down" products will continue to be used before planting; most growers are not expected to use more expensive herbicides if they can avoid doing so.

- Use of herbicides in the major triazine class for corn will decline as a result of the expected loss of cyanazine (Bladex®) by 2000 and increasing regulatory pressures that negatively affect use of atrazine through 2005. These changes will stimulate the increased use of glyphosate and other "greener" herbicides.

- The U.S. Environmental Protection Agency (EPA) may restrict the use of bromoxynil (Buctril®) because of concerns about possible carcinogenicity. If so, demand for bromoxynil-resistant cotton could be reduced; moreover, Rhône-Poulenc, the producer of Buctril®, might reevaluate the feasibility of continuing to supply the product in the United States. A restriction on Buctril® would affect both the corn and cotton herbicide markets.

- Use of AgrEvo's recently registered herbicide, glufosinate (Liberty®), will be stimulated by the introduction of Liberty® Link corn and Liberty® Link soybeans in 1997 and 1998-1999, respectively. However, glufosinate's growth in the market will depend in large part on its price and ability to compete on a value basis with other herbicides.

- Glyphosate (Roundup®) use will increase substantially because of (1) Monsanto's price-cutting strategy, which has led to greater overall use of the product, and (2) the introduction of Roundup® Ready soybeans in 1996 and Roundup® Ready corn in 1997. Published results of

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surveys of growers who planted Roundup® Ready soybeans in 1996 indicate generally high satisfaction with the new technology.

- Imidazolinone herbicides will benefit from increased plantings of IMI-Corn™; however, competition from glyphosate (Roundup®) will be intense.
- Only moderate overall growth is projected for sethoxydim (Poast®). This herbicide is not expected to benefit greatly from the introduction of SR-Corn because other broader spectrum herbicides—particularly glyphosate—are expected to dominate the corn market.
- Use of sulfonylurea herbicides for corn and soybeans will increase moderately, helped in part by market acceptance and increasing plantings of STS soybeans.

Scenario A: "High Inertia/Price War"

Assumptions:

- Growers resist new technologies
- Weak demand for herbicide-tolerant seed causes transgenic plant technology fees to be discounted or "rolled" into a standard pricing format; that is, premium seed "comes with" herbicide tolerance at no incremental additional cost.
- In response to the release of the new technologies, manufacturers of conventional herbicides reduce prices to maintain market shares. As a result, growers find higher value in managing weeds by conventional methods.
- The least expensive conventional herbicides/weed control methods are used on a significant portion of the acres planted with herbicide tolerant seeds, regardless of herbicide tolerance traits.

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Table O-5A
PROJECTED USE OF CONVENTIONAL CHEMICAL HERBICIDES IN MAJOR U.S. CROP MARKETS, 1995-2005
SCENARIO A: "HIGH INERTIA/PRICE WAR"
(Millions of Treatment Acres)

Crop/Herbicide Product or Class	1995	2000	2005
Corn			
triazines (atrazine, cyanazine)	66.5	45	40
trifluralin	--	--	--
bromoxynil (Buctril®)	5.7	7	8
glufosinate (Liberty®)	--	4	8
glyphosate (Roundup®)	4.7	10	40
imidazolinone herbicides	0.7	3	3
sethoxydim (Poast®)	Neg	0.3	Neg
sulfonylurea herbicides:	13.5	15	15
all others	83.4	90.7	61
Total	174.5	175.0	175.0
Cotton			
triazines (atrazine, cyanazine)	--	--	--
trifluralin (Treflan®)	11.2	12-13	12-13
bromoxynil (Buctril®)	--	2	2
glufosinate (Liberty®)	--	--	--
glyphosate (Roundup®)	1.7	3	4
imidazolinone herbicides	--	--	--
sethoxydim (Poast®)	0.4	1-2	1-2
sulfonylurea herbicides	--	--	--
all others	51.6	45-47	44-46
Total	64.9	65	65

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Table O-5A (Concluded)

Crop/Herbicide Product or Class	1995	2000	2005
Soybeans			
triazines (atrazine, cyanazine)	--	--	--
trifluralin (Treflan®)	12.5	13-14	13-14
bromoxynil (Buctril®)	--	--	--
glufosinate (Liberty®)	--	3	6
glyphosate (Roundup®)	12.5	18	45
imidazolinone herbicides	37.5	38-40	38-40
sethoxydim (Poast®)	4.4	4-5	4-5
sulfonylurea herbicides	17.7	21-22	20-21
all others	86.0	69-74	40-45
Total	170.6	171	171
Total			
triazines (atrazine, cyanazine)	66.5	45	40
trifluralin (Treflan®)	23.7	25-27	25-27
bromoxynil (Buctril®)	5.7	9	10
glufosinate (Liberty®)	--	7	14
glyphosate (Roundup®)	18.9	31	89
imidazolinone herbicides	38.2	41-43	41-43
sethoxydim (Poast®)	4.8	5.3-7.3	5-7
sulfonylurea herbicides	31.2	36-37	35-36
all others	221.0	204.7-211.7	145-152
Total	410.0	411	411

Scenerio B: "New Era"

Assumptions:

- Growers accept new technologies.
- Adequate demand for herbicide tolerant seeds allows technology fees to hold.
- Manufacturers of conventional herbicides do not aggressively reduce prices to preserve market shares in response to release of new technologies

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- Herbicides not used with herbicide tolerant crop plants lose significant market shares.

Table O-5B
PROJECTED USE OF CONVENTIONAL CHEMICAL HERBICIDES IN MAJOR U.S. CROP MARKETS, 1995-2005
SCENARIO B: "NEW ERA"
(Millions of Treatment Acres)

Crop/Herbicide Product or Class	1995	2000	2005
Corn			
triazines (atrazine, cyanazine)	66.5	45	15
trifluralin	--	--	--
bromoxynil (Buctril®)	5.7	7	7-8
glufosinate (Liberty®)	--	7	14
glyphosate (Roundup®)	4.7	15	70
imidazolinone herbicides	0.7	6.5	10
sethoxydim (Poast®)	Neg	0.4	0.4
sulfonylurea herbicides:	13.5	14-15	14-15
all others	83.4	79.1-80.1	42.6-44.6
Total	174.5	175.0	175.0
Cotton			
triazines (atrazine, cyanazine)	--	--	--
trifluralin (Treflan®)	11.2	12-13	12-13
bromoxynil (Buctril®)	--	2	2
glufosinate (Liberty®)	--	--	--
glyphosate (Roundup®)	1.7	5	6
imidazolinone herbicides	--	--	--
sethoxydim (Poast®)	0.4	1-2	1-2
sulfonylurea herbicides	--	--	--
all others	51.6	43-45	42-44
Total	64.9	65	65

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Table O-5B(Concluded)

Crop/Herbicide Product or Class	1995	2000	2005
Soybeans			
triazines (atrazine, cyanazine)	--	--	--
trifluralin (Treflan®)	12.5	13-14	13-14
bromoxynil (Buctril®)	--	--	--
glufosinate (Liberty®)	--	6	8
glyphosate (Roundup®)	12.5	29	55
imidazolinone herbicides	37.5	38-40	38-40
sethoxydim (Poast®)	4.4	4-5	4-5
sulfonylurea herbicides	17.7	21-22	20-21
all others	86.0	55-60	28-33
Total	170.6	171	171
Total			
triazines (atrazine, cyanazine)	66.5	45	15
trifluralin (Treflan®)	23.7	25-27	25-27
bromoxynil (Buctril®)	5.7	9	9-10
glufosinate (Liberty®)	--	13	22
glyphosate (Roundup®)	18.9	49	131
imidazolinone herbicides	38.2	44.5-46.5	48-50
sethoxydim (Poast®)	4.8	5.4-7.4	5.4-7.4
sulfonylurea herbicides	31.2	35-37	34-36
all others	221.0	177.1-185.1	112.6-122.6
Total	410.0	411	411

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Regulatory and Environmental Issues

Regulatory action to restrict or cancel the use of triazine herbicides, particularly atrazine, and DuPont's voluntary phasing out of its widely used triazine herbicide, Bladex® (cyanazine) by 2000 are expected to affect the U.S. corn weed control market over the next decade. These actions will stimulate the consumption of "greener" herbicide alternatives as replacements.

Some environmentalists object to the creation of herbicide-resistant crops because they believe that the resistance genes will inevitably be incorporated into weeds. AgrEvo acknowledges that the glufosinate-resistant gene may migrate to weeds that are closely related to the crop itself, but states that this is not expected to become a problem, because other herbicides will be able to control those glufosinate-resistant weed plants.

Other Issues

Herbicide-tolerant crops provide growers with simplified chemical weed control programs and work well in herbicide-intensive no-till weed control programs. Weed control for herbicide-tolerant crops will still require a variety of herbicides, albeit a much narrower list. For example, if Roundup® Ready corn is grown in rotation with Roundup® Ready soybeans, an herbicide other than glyphosate will be needed to control volunteers from the preceding rotation.

The technology fee charged for herbicide-tolerant and other pest management related traits is expected to cause friction among chemical companies, seed companies, and growers.

Most seed companies view herbicide tolerance (or, for that matter, any pest management related trait) as merely one trait among the many that make up the characteristics of a seed. Seed companies believe that seeds with the most valuable specific traits should be premium priced.

For growers, on the other hand, deciding which seed to purchase entails multiple issues: quality traits—nutritional attributes, fiber length and strength—yield, and drought resistance, to name a few. Even though growers may buy premium-priced, high-yield varieties for their high-yield traits, rather than their pest management traits, seed companies believe that pest management traits will soon become part of growers' expectations about seed products. Such products will then become the "standard" as opposed to a specialty that commands a premium price.

In addition, the technology fee concept may not work well for seeds that incorporate stacked-gene herbicide resistance to multiple, competing herbicides from different chemical producers. Moreover, as pest management traits work their way through seed product lines, growers may increasingly elect not to use the herbicide for which an herbicide-tolerant crop was originally intended.

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CORN

WEED CONTROL MARKET, 1995

Crop Area and Major Growing Regions

Figure 1 indicates the major growing regions for corn in Canada and the United States. Table 1 summarizes reported statistics for 1995 on planted corn acreage by major growing region in both countries. Canada's nearly 3 million acres included about 2.5 million acres of corn planted for grain and about 0.5 million acres of corn planted for forage. The province of Ontario accounted for about 70% of Canada's total corn acreage, and Québec accounted for about 28%. U.S. growers planted 71.2 million acres of corn in 1995. Three North Central U.S. regions—the Corn Belt, the Lake States, and the Northern Plains—together account for more than 80% of annual U.S. corn plantings.

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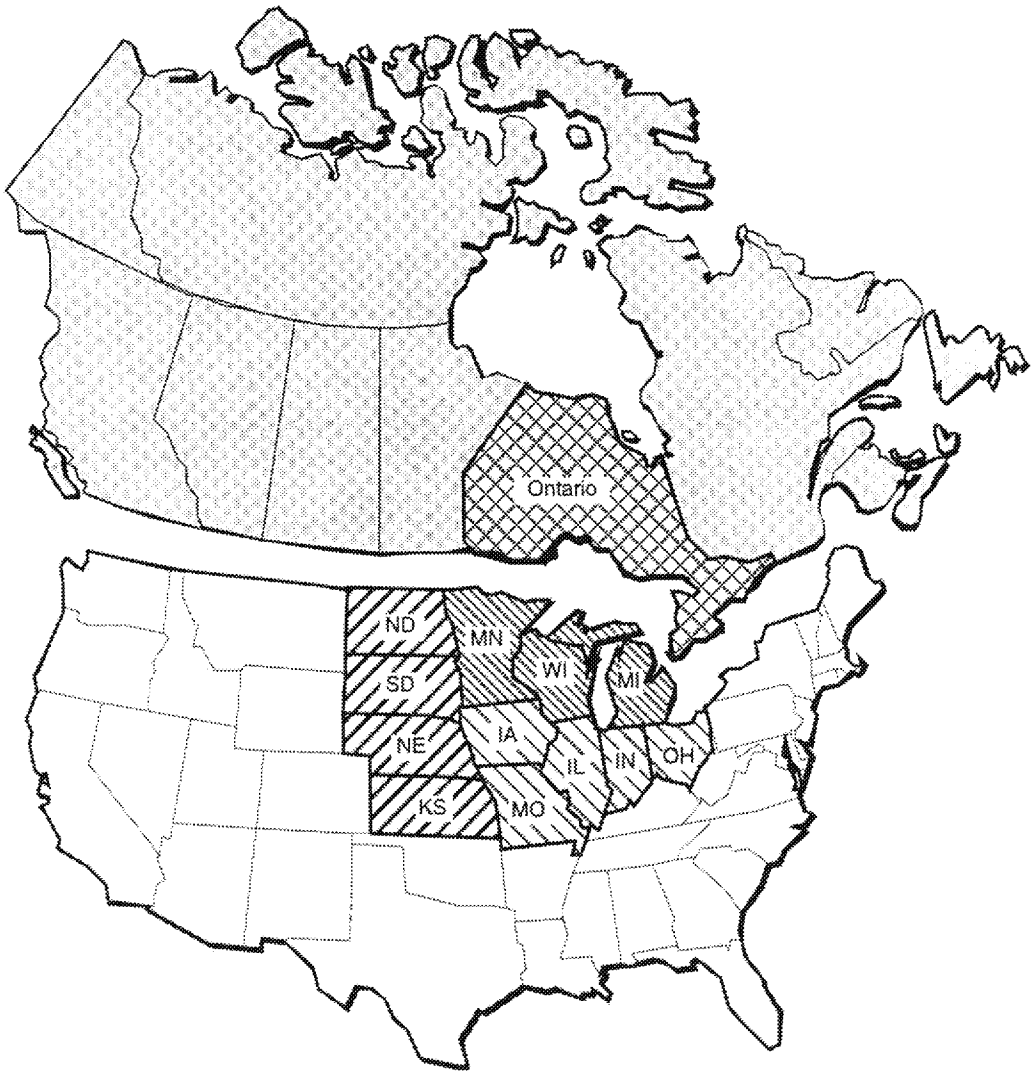
Figure 1

NORTH AMERICAN CORN ACREAGE BY COUNTRY AND REGION, 1995



	Planted Acres (1,000)	Percent of Country's Planted Acres	Percent of North America's Planted Acres
Ontario	2,073	69.6	2.8
Lake States	12,600	18.0	17.2
Corn Belt	32,250	45.3	43.4
Northern Plains	13,650	19.2	18.4
Rest of U.S.	12,545	17.6	16.9
Rest of Canada	906	30.4	2.8

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Table 1
REGIONAL DISTRIBUTION OF NORTH AMERICAN CORN ACREAGE, 1995

Country/ Province and State	Planted Acres (1,000)	Percent of Country's Planted Acres	Percent of North America's Planted Acres
Canada[a]			
Ontario	2,073	69.6	2.8
Other Provinces	906	30.4	1.2
Canadian Total	2,979	100.0	4.0
United States			
Lake States			
Minnesota	6,700	9.4	9.0
Wisconsin	3,650	5.1	4.9
Michigan	2,450	3.4	3.3
Subtotal	12,800	18.0	17.2
Corn Belt			
Iowa	11,700	16.4	15.8
Illinois	10,200	14.3	13.7
Indiana	5,400	7.6	7.3
Other states	4,950	6.9	6.7
Subtotal	32,250	45.3	43.4
Northern Plains			
Nebraska	8,000	11.2	10.8
Other States	5,650	7.9	7.6
Subtotal	13,650	19.2	18.4
Other Regions[b]	12,545	17.6	16.9
U.S. Total	71,245	100.0	96.0
Canadian and U.S., Total	74,224	NA	100.0

[a]Canadian corn acreage data include grain corn and corn for forage. U.S. acreage data include corn planted for all purposes.

[b]Northeast, Appalachia, Southeast, Delta States, Southern Plains, Mountain States, and Pacific.

Sources: Statistics Canada and U.S. Department of Agriculture.

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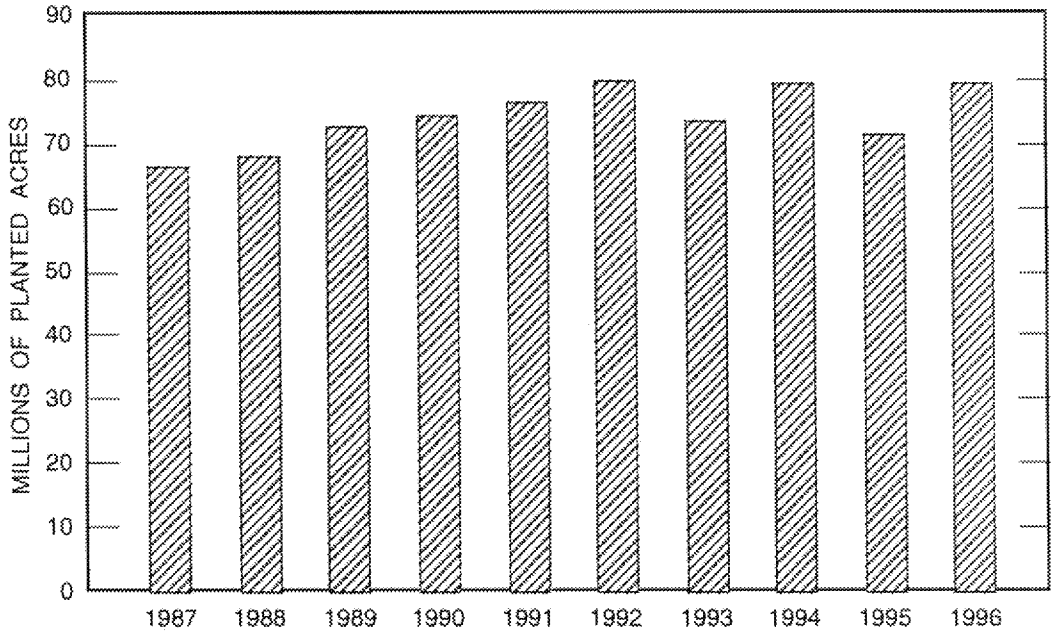
Figure 2 shows the trend in U.S. corn plantings (for grain, forage, and silage) since 1987. Planted corn acreage increased steadily between 1987 and 1992, at an average annual rate of 3.7%, but since then has fluctuated widely from year to year. The 71.2 million acres planted in 1995 represented a cutback of nearly 8 million acres from 1994. However, in 1996 U.S. corn plantings rebounded to an all-time high of about 79.5 million acres. Since 1987, U.S. corn plantings have increased at an average annual rate of about 2%.

Figure 2
U.S. PLANTED CORN ACREAGE, 1987-1996



Major Weed Problems

The most troublesome weeds in corn fields in the major North Central U.S. growing regions are grasses, of which the most difficult to control are woolly cupgrass, johnsongrass, shatter cane, and wire stem muhley.

The low-cost triazine herbicide, atrazine, is the most widely applied herbicide for preemergence control of both broadleaf weeds and grasses in corn fields. More expensive selective postemergent herbicides (those applied after the corn plant has emerged above the soil surface) are used to control broadleaf weeds. Conventional postemergence selective herbicide programs do not control grasses.

Field rotation to a broadleaf crop such as soybeans is the most typical cultural practice used to control weeds in corn production. Rotation to soybeans allows grasses that can not be controlled in corn to be controlled by the selective grass-targeted herbicide

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spray regimen that is typically used for soybeans. Mechanical cultivation is another cultural practice that may be used to control grasses before corn plants become too tall.

Herbicide Use and Market Value

Table 2 summarizes herbicide use for North American corn in 1995 by region in terms of treated acres, the average number of chemical applications per treated acre, and herbicide treatment acres. For North America as a whole, 96% of the corn crop acreage received at least 1 herbicide treatment and, on average, 2.5 applications were made per treated acre.

Table 2

HERBICIDE USE FOR NORTH AMERICAN CORN BY COUNTRY AND REGION, 1995

Country/Region	Planted Acres[a] (1,000)	Treated Acres: Percent of Planted Acres	Treated Acres: 1,000 Acres	Average Number of Applications[b]	Herbicide Treatment Acres (1,000)
Canada	2,979	97	2,889.6	2.4	6,935.1
United States					
Corn Belt	32,250	98	31,602.0	2.6	82,165.2
Lake States	12,800	98	12,544.0	2.4	30,105.6
Northern Plains	13,650	94	12,831.0	2.5	32,077.5
Other Regions[b]	12,545	91	11,418.0	2.6	30,119.9
Subtotal	71,245		68,395.0		174,468.2
Average		96		2.6	
North America, Total	74,224		71,284.6		181,403.3
Average		96		2.5	

[a]Acreage figure for Canada includes 2,485,000 acres of grain corn and 494,000 acres of corn grown for forage. U.S. acreage data include corn planted for all purposes.

[b]Components of tank mixes and premixes are counted as separate applications.

[c]Northeast, Appalachia, Southeast, Delta States, Southern Plains, Mountain States, and Pacific.

Sources: SRIC estimates.

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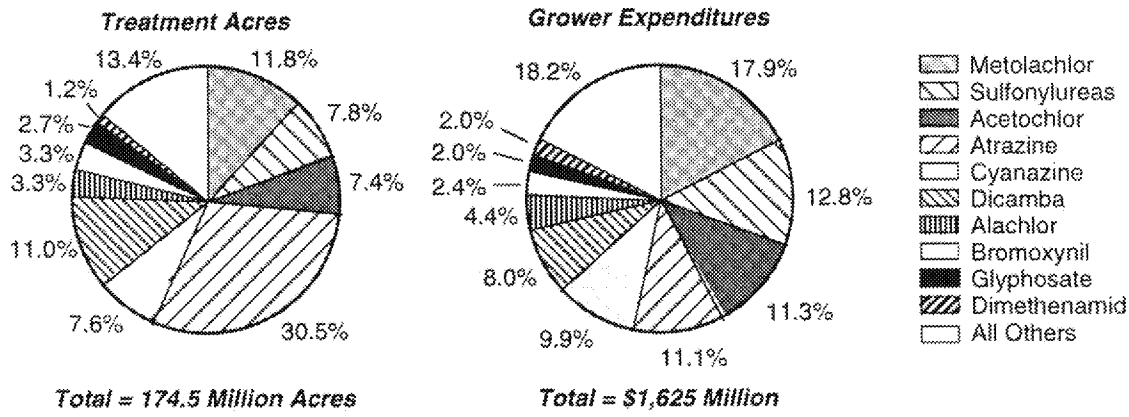
Canadian corn growers spent an estimated $65 million for herbicides in 1995 and U.S. growers spent $1,625 million. Figure 3 shows the breakdown of the U.S. corn herbicides market by leading product in terms of both treatment acres and grower expenditures.

Figure 3
U.S. CORN MARKET FOR HERBICIDES, 1995



Leading Herbicides

Table 3 ranks the leading herbicides in the U.S. corn market according to sales in 1995. Most of these products are marketed in several formulations, including premixed combinations of two or three active ingredients. The leading product, with a market share of about 18%, was Novartis' metolachlor (Dual®). Sulfonylurea herbicides as a group accounted for nearly 13% of the U.S. corn herbicides market, based on grower expenditures, followed by acetochlor (Harness® from Monsanto and Surpass® from Zeneca) at 11.3%, atrazine (Aatrex®, other trade names) from Novartis at 11.1%, cyanazine (Bladex® from DuPont and generic products) at 9.9%, and dicamba (Banvel®) at 8%. Banvel®, formerly a Sandoz product, was recently acquired by BASF.

Three of the leading corn herbicides—cyanazine, alachlor, and atrazine—all of which are older products, are being displaced primarily by two recently introduced products, nicosulfuron and acetochlor, as well as by another older product, dicamba. Acetochlor, which was launched in 1994, had estimated sales of $68 million in its initial year on the market and almost $183 million in 1995.

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Table 3

U.S. CORN HERBICIDE MARKET BY LEADING PRODUCT OR PRODUCT CLASS, 1995

Name	Treatment Acres		Volume Applied (1,000 Pounds, A.I.)	Grower Expenditures	
	1,000 Acres	Product/ Class Share (%)		1,000 Dollars)	Product/ Class Share (%)
metolachlor	20,661.1	11.8	37,189.9	291,000.0	17.9
Sulfonylureas[a]					
nicolulfuron	9,261.9	5.3	277.9	158,266.5	9.7
primisulfuron	2,137.4	1.2	42.7	27,000.0	1.7
rimsulfuron	712.5	0.4	7.1	8,000.0	0.5
halosulfuron	712.5	0.4	28.5	7,915.6	0.5
thifensulfuron	712.5	0.4	3.6	6,609.3	0.4
Subtotal	13,536.6	7.8	359.8	207,791.4	12.8
acetochlor	12,824.0	7.4	20,518.4	182,818.9	11.3
atrazine	53,209.3	30.5	52,145.1	179,900.6	11.1
cyanazine	13,322.8	7.6	26,912.1	160,934.3	9.9
dicamba	19,236.2	11.0	6,347.9	130,000.0	8.0
alachlor	5,699.6	3.3	11,399.2	71,929.0	4.4
bromoxynil	5,699.6	3.3	1,481.9	38,870.1	2.4
glyphosate	4,702.2	2.7	2,868.3	33,129.1	2.0
dimethanamid	2,137.4	1.2	2,287.0	32,932.3	2.0
EPTC	2,137.4	1.2	8,357.0	29,416.8	1.8
pendimethalin	2,849.8	1.6	3,334.3	23,539.9	1.4
2,4-D	10,188.0	5.8	4,380.9	13,274.0	0.8
simazine	2,137.4	1.2	2,500.7	10,502.9	0.6
imazethapyr	712.5	0.4	35.6	10,336.6	0.6
bentazon	1,424.9	0.8	598.5	9,647.1	0.6
butylate	783.7	0.4	2,578.4	7,967.1	0.5
Others [b]	3,206.0	1.8	1,015.2	191,009.8	11.8
Total	174,468.2	100.0	184,310.1	1,625,000.0	100.0

a. Does not include prosulfuron, which is included in Others.

b. Includes paraquat, flumetsulam, metribuzin, ametryn, trifluralin, clopyralid, pyridate, propachlor, prosulfuron, sethoxydim, and others

Source: SRIC estimates

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MARKET TRENDS AND ISSUES

New Technologies and Products

Herbicide-Tolerant Plants

Herbicide-resistant corn has already affected consumption of herbicides in U.S. corn production, primarily by increasing the use of the preemergent herbicide Pursuit® (imazethapyr) in IMI-Corn™, which is resistant to that herbicide. Beginning in 1997, use of new genetically engineered herbicide-tolerant corn hybrids is expected to increase, simultaneously adding to herbicide consumption as well. Substantial increases in no-till corn production are also anticipated.

The current IMI-Corn™ seed universe contains about 180 hybrids with varying characteristics. Those hybrids were planted on about 1.8 million acres in the United States in 1995, and on about 2.5 million acres in 1996. The leading producers of IMI Corn™ seed are ICI Seeds and Pioneer Hybrid, which together hold about two-thirds of the market. Novartis Seeds and Asgrow are the next largest producers; however, they share the remainder of the IMI-Corn™ seed market with five other producers. Although IMI-Corn™ was developed to allow Pursuit®-based weed control programs, in practice an estimated 70% of the IMI-Corn™ planted does not receive Pursuit® applications. Rather, many farmers grow IMI-Corn™ because they know that if their weed problems become too great, they can use a Pursuit®-based weed control program.

Although more frequently used in conventional tillage programs, IMI-Corn™ also fits well in no-till corn programs. In addition, IMI-Corn™ has niche-oriented advantages: It allows conventional till and no-till growers who have had difficulty in controlling weeds to use Pursuit®, which is particularly good at controlling johnsongrass, shatter cane, and tall water hemp. Pursuit® also has some residual soil activity. Another IMI-Corn™ variety with resistance to the selective, pre- and post-emergent herbicide imazaquin (Scepter®) is in late stages of development.

In 1995, corn seed with resistance to the postemergent herbicide sethoxydim (Poast®) became commercially available. The product, marketed as SR-Corn, is expected to be niche-oriented because sethoxydim controls grasses only; sethoxydim-resistant corn is thus unlikely to achieve the same level of market penetration as IMI-Corn™.

In 1997, corn with resistance to the postemergent herbicide glufosinate (Liberty®) will be launched in North America. Liberty® is a broad-spectrum herbicide that controls both grasses and broadleaf weeds. Entire weed management programs using only Liberty® herbicide may be possible. As a result, many growers are expected to convert from conventional tillage programs to minimum-till or no-till. The commercial entry of glufosinate-resistant corn is expected to cause no-till production of corn to increase at an average annual rate of 2% or more per year.

Corn with resistance to the postemergent herbicide glyphosate (Roundup®) is expected to become commercially available in 1998 or 1999. Roundup®, like Liberty®, is a broad-spectrum herbicide that controls both grasses and broadleaf weeds. The entry

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of glyphosate-tolerant corn into the market, combined with the sales growth of glufosinate-resistant corn, is likely to increase the no-till production of corn by 5% per year.

Producers of other corn herbicides may react to the increasing sales growth of glufosinate and glyphosate with aggressive price cutting to reduce their loss of market share.

Table A-3 in the Appendix summarizes field trial release permits issued to companies developing herbicide-tolerant corn in the 1990-1995 period. Companies that have been the most active in field trials of herbicide-tolerant corn are Pioneer Hi-Bred International, with 11 permits during 1990-1995; Holden's Foundation Seeds, with 7 permits; DeKalb Genetics, with 6 permits; Hoechst-Roussel (now AgrEvo), with 6 permits; Monsanto, with 6 permits; Asgrow Seed Company, with 6 permits. Asgrow was formerly part of Upjohn, but was recently acquired by Monsanto. In January 1997, Monsanto announced that it will also acquire Holden's Foundation Seeds.

New Herbicides

The EPA registered three new herbicide active ingredients for use on corn in 1995 (see Table 4).

Table 4
HERBICIDES REGISTERED FOR U.S. CORN IN 1995

Common Name	Trade Name	Supplier
flumiclorac	Resource®	Valent
halosulfuron-methyl	Permit®, Battalion®	Monsanto
prosulfuron	Exceed®[a]	Novartis (Ciba)
rimsulfuron	Basis™	DuPont

[a]Exceed® 57 WG contains 28.5% prosulfuron and 28.5% primisulfuron
[b]Basis™ is a premix combination of 50% rimsulfuron and 25% thifensulfuron.

Source: EPA

Table 5 identifies 10 new herbicides currently under development for the U.S. corn market and the companies developing each product.

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Table 5

NEW HERBICIDES UNDER DEVELOPMENT FOR THE U.S. CORN MARKET

Common Name	Code Name	Trade Name	Chemical Class	Developing Company	Application Timing and Target Weeds
carfentrazone	F-8426	na	phenylpropionate	FMC Corp.	Postemergence: grasses and broadleaf weeds
fluthiacet-methyl	CGA 248-757	Action®	heterocyclic nitrogen	Kumiai; Licensed to Novartis	Postemergence; velvetleaf and other broadleaf weeds
imazamox	AC 299 263	Raptor®	imidazolinone	American Cyanamid	Postemergence and residual activity on a broad spectrum of grasses and broadleaf weeds
isoxaflutole	RP-201772	Balance®	isoxazole	Rhône-Poulenc	Preemergence: broadleaf weeds and grasses
metobenzuron	UMP-488	na	methoxy urea	Mitsui Petrochemical	Early postemergence; broadleaf weeds
metosulam	DE-511	Eclipse®	sulfonamide	DowElanco	Preemergence and postemergence; broadleaf weeds
sulfentrazone	F-6285	Authority®	sulfonanilide	FMC Corp.	Preemergence on broadleaf weeds and some grasses
thiafluamide	Bay Foe 5043	Axiom®	oxyacetamide	Bayer	Preemergence and early postemergence; grasses and some broadleaf weeds
na	ZA 1296	na	triketone	Zeneca	Preemergence and post-emergence; broadleaf weeds

Sources: Communication with university extension specialists and trade literature.

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MARKET PROJECTIONS, 2000 AND 2005

Herbicide-Tolerant Corn

Table 6 presents projections for U.S. plantings of traditionally bred and transgenic herbicide-resistant or herbicide-tolerant corn plantings in 2000 and 2005. By 2000, new hybrids with herbicide resistant traits are expected to account for 30%–41% of total U.S. corn plantings, and by 2005, for 63%–75%.

Table 6
PROJECTED PLANTINGS OF HERBICIDE- RESISTANT/TOLERANT CORN HYBRIDS IN NORTH AMERICA, 2000 AND 2005[a]
(Thousands of Acres)

Technology/Product	1995	2000	2005
Traditionally Bred Hybrids:			
Imidazolinone Resistant or Tolerant (IMI-Corn™)	1,800	5,000-8,000	7,000-10,000
Sethoxydim-Resistant (SR-Corn)	--	1,100	1,000
Subtotal	1,800	6,100-9,100	8,000-11,000
Transgenic Hybrids:			
Single Gene:			
Glufosinate-Tolerant(Liberty® Link)	--	12,000-14,000	23,000-25,000
Glyphosate-Tolerant (Roundup® Ready)[b]	--	4,000-6,000	Neg
Sulfonylurea-Tolerant	--	--	Neg
Subtotal	--	16,000-20,000	23,000-25,000
Stacked Gene:			
Glufosinate-Tolerant + Insect-Resistant (Liberty ® Link + Bt)	--	--[b]	----[b]
Glufosinate-Tolerant and Imidazolinone-Tolerant (Liberty® and IMI-Tolerant)	--	1,000-2,000	5,000-7,000
Glyphosate-Tolerant + Lepidopteran and/or Coleopteran-Resistant	--	--	12,000-14,000
Subtotal	--	1,000-2,000	17,000-21,000
Total	1,800	23,100-31,100	48,000-57,000

[a]Based on an assumed total planted acreage of 76 million acres in both 2000 and 2005.

[b] Included with projection for single-gene Liberty®-Link hybrids.

Source: SRI Consulting

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By 2000, we expect that Liberty® Link will be the dominant herbicide-tolerant corn technology. Single-gene Liberty® Link hybrids will be planted on 12–14 million acres, accounting for 16%–18% of U.S. and Canadian corn plantings, and stacked Liberty®- and IMI-tolerant hybrids will account for an additional 1%–3%. Roundup® Ready corn is expected to have the next largest market share—6%–8% of North American corn plantings. SR-Corn is expected to achieve about a 1% market share by 2000, and to be displaced by other technologies thereafter. Sulfonylurea-tolerant corn is not expected to gain significant market acceptance.

By 2005, Liberty® Link and IMI-tolerant hybrids will account for 37%–42% of U.S. and Canadian corn plantings and will account for more than half of all total market for herbicide-tolerant corn hybrids, based on planted acres. Hybrids containing the Roundup® Ready gene stacked with one or more *Bacillus thuringiensis* (Bt) genes and/or other insect-resistance genes will account for 16%–18% of total U.S. and Canadian corn plantings by 2005 and for about 25% of total herbicide-tolerant corn plantings.

The only herbicide-tolerant corn hybrids without built-in insect resistance that we expect to gain market share after 2000 are those with stacked herbicide tolerances (e.g., Liberty® + IMI resistant hybrids).

Herbicides

Table 7 presents projections for the world corn herbicide market in 2000 and 2005 by region. The total world and U.S. markets are expected to increase in value by only 1.4% per year in real terms. The U.S. market accounted for 68% of the world corn herbicides market in 1995. The much smaller Canadian market is also expected to grow very modestly, at an average annual rate of 1.5% through 2005.

Table 7
PROJECTED GROWTH TRENDS IN MAJOR WORLD REGIONAL MARKETS FOR CORN HERBICIDES, 1995-2005

	Millions of Dollars			Average Annual Growth Rate, 1995-2000
Region	1995	2000	2005	(Percent)
United States	1,625	1,750	1,860	1.4
Western Europe	405	440	455	1.2
Canada	65	70	76	1.5
Far East	60	66	70	1.6
Other Regions	220	249	279	2.4
Total	2,375	2,575	2,740	
Average				1.4

SRIC estimates.

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The triazine herbicides, including atrazine and cyanazine, will be substantially affected by concerns about the underground and surface drinking water contamination caused by their use. DuPont will voluntarily phase out the production of cyanazine by 2000; at the same time, the use of atrazine will come under increased regulatory pressures, with potential for an outright ban in the future. These triazine herbicides accounted for 38% of the corn herbicides market in 1995, and most of this market share is expected to be replaced by "greener" alternatives within the next 10 years. Among the existing conventional chemical herbicides, the leading candidate for an increasing market share in the corn market and replacement of the triazines is glyphosate (Roundup®).

Imidazolinones

The strongest increase in the use of imidazolinones resulting from the use of herbicide-tolerant corn is expected to take place around 2000. IMI-Corn™ has thus far had only a very limited impact on increasing the consumption of imidazolinones. Overall, as much as 70% of the IMI-Corn™ planted does not receive applications of an imidazolinone herbicide. IMI-Corn™ is expected to lose market share to Roundup® Ready corn by 2005, although the IMI-resistance trait will become available in stacked gene Liberty®- and IMI-tolerant hybrids. It is difficult to predict the impact on consumption of imidazolinone herbicides; however, they may lose market share as a consequence of the growth of other herbicide-tolerant technologies.

Glufosinate

The strongest growth for glufosinate consumption resulting from the availability of glufosinate-tolerant corn hybrids is expected to occur around 2000. By 2005, the Liberty® Link gene will also be available in stacked gene glufosinate and imidazolinone (Liberty® and IMI)-tolerant hybrids. As a result, the use of glufosinate for corn is expected to increase over the 2000 to 2005 period.

Glyphosate

Glyphosate clearly stands to make the largest gains in the corn herbicide market. The use of glyphosate should rise significantly by 2000, in part stimulated by the growing use of Roundup® Ready corn, and in part because Roundup® herbicide will be used as a partial replacement for cyanazine. By 2005, glyphosate could attain as much as a 40% share of the corn herbicide market. Increasing plantings of Roundup® Ready corn and partial replacement of atrazine with Roundup® will be the two major factors driving the projected growth in Roundup® use for corn.

Sethoxydim

Of the herbicides linked to herbicide-resistant corn, sethoxydim has the lowest growth prospects. We do not expect SR-Corn to remain a significant product much past 2000, when Roundup® Ready corn should begin to dominate the market. Therefore, no growth in the consumption of sethoxydim resulting from the use of SR-Corn is foreseen.

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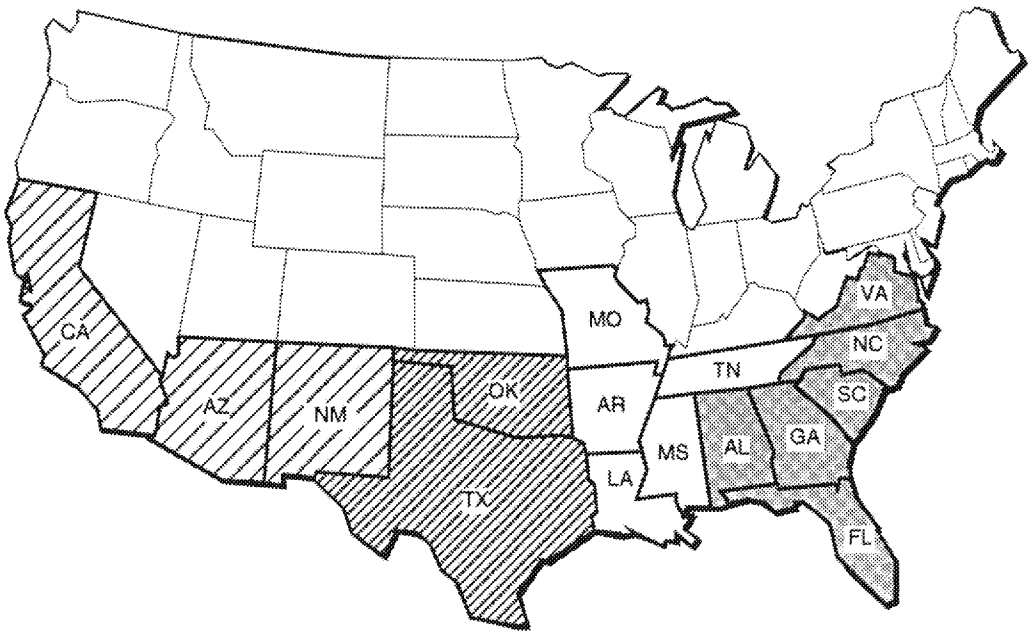
COTTON

WEED CONTROL MARKET 1995

Crop Area and Major Growing Regions

Figure 4 and Table 8 show the regional distribution of U.S. planted cotton acreage in 1995. Total U.S. plantings in 4 growing regions amounted to 16.9 million acres. The Southern Plains region—primarily Texas—accounted for 40% of the U.S. cotton crop acreage, the Mid-South accounted for nearly 29%, the Southeast for about 20%, and the West for 10.5%.

Figure 4
U.S. COTTON ACREAGE BY REGION, 1995



REGION	Planted Acres (1,000)
Southeast	3,460
Mid-South	4,877
Southern Plains	6,820
West	1,775
Total	**16,931**

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Table 8
U.S. COTTON ACREAGE BY REGION AND STATE, 1995

Region/State	Planted Acres (1,000)	Percent of Total
Southeast		
Georgia	1,500.0	8.9
North Carolina	805.0	4.8
Alabama	590.0	3.5
South Carolina	348.0	2.1
Florida	110.0	0.6
Virginia	107.0	0.6
Subtotal	3,460.0	20.4
Mid-South		
Mississippi	1,460.0	8.6
Arkansas	1,170.0	6.9
Louisiana	1,085.0	6.4
Tennessee	700.0	4.1
Missouri	462.0	2.7
Subtotal	4,877.0	28.8
Southern Plains		
Texas	6,436.0	38.0
Oklahoma	380.0	2.2
Kansas	3.8	0.0
Subtotal	6,819.8	40.3
West		
California	1,285.0	7.6
Arizona	413.6	2.4
New Mexico	76.0	0.4
Subtotal	1,774.6	10.5
U.S. Total	16,931.4	100.0

Source: *Crop Production, 1996 Summary*, January 1997, USDA, NASS.

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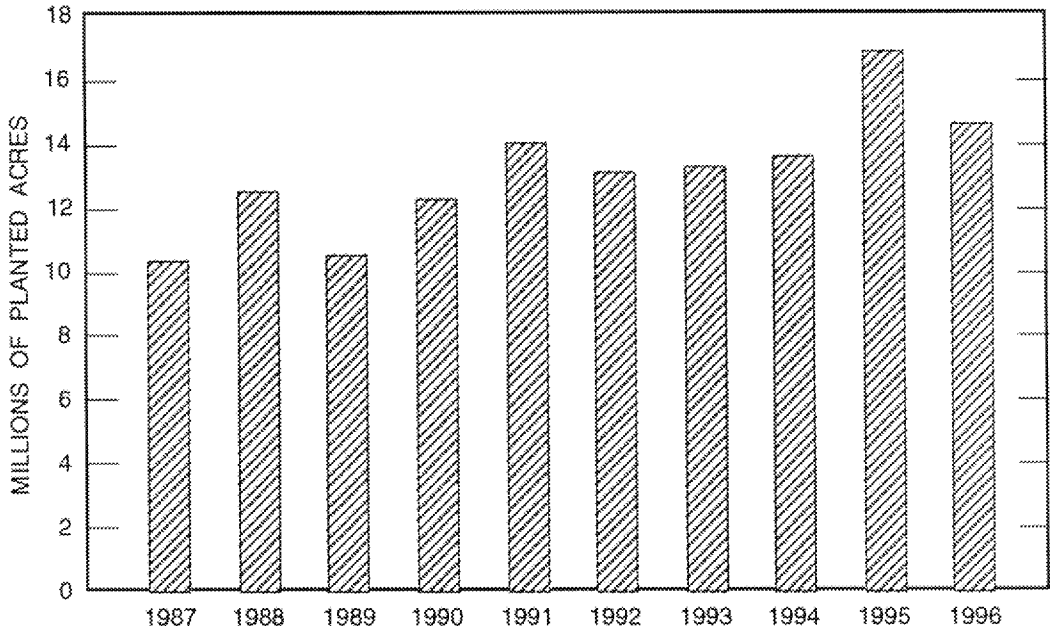
Figure 5 shows U.S. cotton plantings from 1987 through 1996. Planted cotton acreage rose in 1995 by more than 23% over 1994 levels but declined in 1996 to 14.7 million acres. In 1995, harvested acreage rose 20% over 1994, but in 1996 declined substantially from 1994 to 12.8 million acres.

Figure 5
U.S. PLANTED COTTON ACREAGE, 1987-1996



Major Weed Problems

The major problem weeds in cotton production are broadleaf species. Among the most difficult to control are cocklebur, hemp sesbania, morning glory, pigweed, and sicklepod. These weeds typically escape most herbicide programs.

Herbicides generally control most other weeds in cotton fields. In addition to herbicide-based control programs, many growers also use cultural controls. The most typical is mechanical cultivation before the cotton plants become too tall. Relatively few growers rotate their fields, given that many continuously crop cotton, particularly in the Southern United States. When rotation is used, a grain crop is typically grown and allows broadleaf weeds to be controlled through a selective herbicide spray regimen. Manual cultivation is also used to a limited extent.

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Herbicide Use and Market Value

Table 9 summarizes herbicide use for cotton by region in terms of treated acres and herbicide treatment acres in 1995.

Table 9
HERBICIDE USE FOR U.S. COTTON BY REGION, 1995

Region/State	Planted Acres (1,000)	Treated Acres: Percent of Planted Acres	Treated Acres: 1,000 Acres	Average Number of Applications[a]	Insecticide Treatment Acres (1,000)
Southeast	3,460.0	98	3,398.9	5.6	18,920.4
Mid-South	4,877.0	98	4,779.5	5.2	24,853.2
Southern Plains	6,819.8	98	6,683.4	2.0	13,366.8
West	1,774.6	88	1,561.6	5.0	7,808.2
U.S. Total	16,931.4		64,948.7		64,948.7
Average		97%		4.0	

[a]Components of tank mixes and premixes are counted as separate applications.

Source: SRIC estimates.

The U.S. cotton market for herbicides amounted to 171.3 million treatment acres in 1995, and growers spent an estimated $330 million for the herbicides they applied (see Figure 6)

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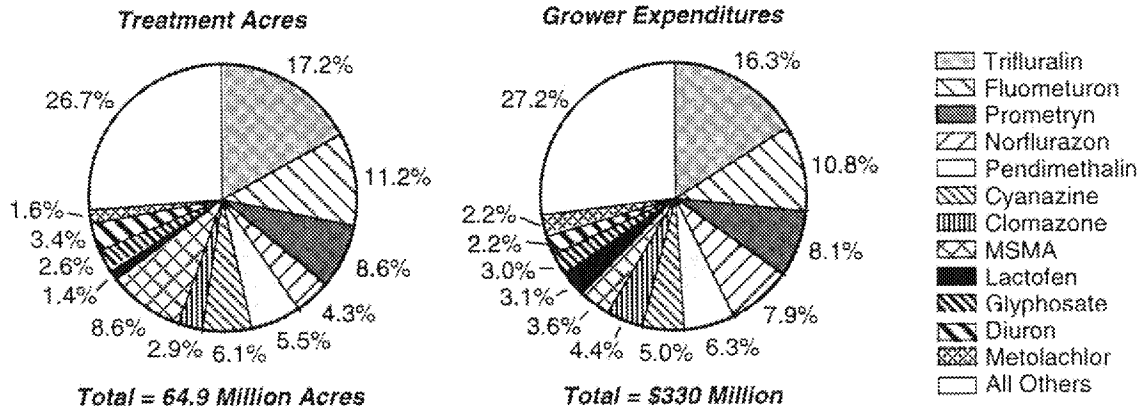
Figure 6
U.S. COTTON MARKET FOR HERBICIDES, 1995



Leading Herbicides

In 1995, in terms of treatment acres the top 4 herbicides used in cotton production, trifluralin (Treflan®), fluometuron (Cotoran®), prometryn (Caparol®), and MSMA together had a 45.6% share of the cotton herbicide market. The next market tier included 4 herbicides, cyanazine (Bladex®), pendimethalin (Prowl®), norflurazon (Zorial®), and diuron (Karmex®, Direx®) with a 19.3% share of the market. The remaining herbicides used—more than 20—accounted for the remaining 35.1% of the market (see Figure 6 above). Table 10 ranks the leading herbicides in the U.S. cotton market according to grower expenditures in 1995.

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Table 10

U.S. COTTON MARKET FOR HERBICIDES BY LEADING PRODUCT, 1995

Common Name	Treatment Acres [a] 1,000 Acres	Treatment Acres [a] Product/ Class Share (%)	Volume Applied {1,000 Pounds, A.I.)	Grower Expenditures[b] 1,000 Dollars)	Grower Expenditures[b] Product/ Class Share (%)
trifluralin	11,175.4	17.2	8,381.5	53,809.5	16.3
fluometuron	7,264.0	11.2	4,067.8	35,634.3	10.8
prometryn	5,587.7	8.6	3,129.1	26,597.4	8.1
norflurazon	2,793.8	4.3	1,480.7	25,912.9	7.9
pendimethalin	3,555.8	5.5	2,738.0	20,671.7	6.3
cyanazine	3,962.2	6.1	2,535.8	16,660.2	5.0
clomazone	1,862.6	2.9	856.8	14,668.1	4.4
MSMA	5,587.7	8.6	4,470.2	11,890.6	3.6
lactofen	880.5	1.4	96.9	10,121.2	3.1
glyphosate	1,676.3	2.6	972.3	10,043.4	3.0
diuron	2,235.1	3.4	1,318.7	7,173.7	2.2
metolachlor	1,015.9	1.6	1,005.8	7,100.8	2.2
fluazifop P-butyl	1,015.9	1.6	111.8	5,588.8	1.7
sethoxydim	372.5	0.6	74.5	4,733.1	1.4
oxyfluorfen	338.6	0.5	71.1	3,058.0	0.9
DSMA	1,100.6	1.7	1,221.7	2,541.1	0.8
other products	14,524.0	22.4	9,440.6	73,795.2	22.4
Total	64,948.7	100.0	41,973.2	330,000.0	100.0

Source: SRIC estimates

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MARKET TRENDS, 1996-2000

New Technologies and Products

Herbicide-Tolerant Plants

Table 11 shows the herbicide-tolerant cotton plants currently available or soon to be commercially available.

Table 11
HERBICIDE-TOLERANT COTTON PLANTS RECENTLY LAUNCHED OR UNDER DEVELOPMENT IN THE UNITED STATES

Product	Trade Name	Developing Company	Year on the Market
Single-Gene Varieties			
bromoxynil-tolerant	BXN®	Calgene	1995
glyphosate-tolerant	Roundup® Ready	Monsanto	1997
Stacked-Gene Varieties			
Lepidopteran resistant + bromoxynil tolerant	Bollgard® + BXN®	Stoneville/ Pedigreed	1998
Lepidopteran resistant + glyphosate tolerant	Bollgard® + Roundup® Ready	Monsanto	1999
bromoxynil tolerant and glyphosate tolerant	BXN® + Roundup® Ready	Monsanto and Calgene	

Source: Communications with industry and university pest management specialists.

BXN® cotton was used on about 300,000 acres of picker cotton and about 300,000 acres of stripper cotton in 1996. The strengths of the BXN® system are that Buctril® controls a number of broadleaf weeds and has no rotational (plant-back) restrictions. However, because Buctril® does not control grasses or nutsedges, growers who use the system need to use other herbicides for grass weed control.

Roundup® Ready cotton was planted on a limited acreage in 1996 and will be officially launched in 1997. The Roundup® Ready system will allow use of Roundup® herbicide for postemergence control of both grasses and broadleaf weeds. Growers can use Roundup® alone, but will need to use several applications. Although Roundup® is a broad-spectrum product, it may not control all weeds in cotton field, (e.g., Florida pusley).

Ongoing research may result in additional commercial herbicide-tolerant cotton products. Field trial release permits summarized in the Appendix indicate additional recent R&D work. The most active companies in field trials of transgenic herbicide-tolerant cotton since 1989 have been Calgene, with 20 release permits in the 1989–1993 period, and Monsanto with 7.

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New Herbicides

Only one new herbicide has been registered for use in U.S. cotton in recent years (see Table 12). DuPont's Staple® achieved registration in 1995 and was launched in 1996. It is unique among cotton herbicides in its control of postemergence broadleaf weeds. It is used for that purpose in nontransgenic cotton. Until Staple®'s registration, cotton was the only major economic crop for which no postemergence broadleaf herbicide existed. Growers could use fluometuron and arsenical herbicides, but these products have the potential for reducing yield. Thus, most growers relied on soil-applied directed sprays and hand labor for broadleaf weed control.

Weed control specialists interviewed for this study noted two disadvantages associated with Staple®. The first is that it does not control some important weeds (e.g., sickle pod, common ragweed, common lambs quarters). The second is that Staple® has the same mode of action as the imidazolinone and sulfonylurea herbicides; that is, it is an acetolactate synthase (ALS) inhibitor. There have been instances of weed resistance to ALS inhibitors, and some weeds have already developed resistance to Staple®. Although the area where resistance has occurred is small, growers are concerned that resistance may become more widespread.

Rohm and Haas is developing a new preemergence residual herbicide, thiazopyr (Visor®) to control grass and broadleaf weeds in cotton. The company acquired this compound from Monsanto.

Table 12
NEW HERBICIDES RECENTLY LAUNCHED OR UNDER DEVELOPMENT FOR U.S. COTTON

Herbicide (Common Name)	Trade Name	Application Timing and Target Weeds(s)	Developing Company	Year on the Market
New Chemistry				
pyrithiobac sodium	Staple®	Broadleaf, postemergent	DuPont	1995
thiazopyr	Visor®, RH 123 652	Grasses and broadleaf weeds; preemergent	Rohm and Haas	1997-1998

Source: Communications with industry and university pest management specialists.

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MARKET PROJECTIONS, 2000 AND 2005

Herbicide-Tolerant Plants

Table 13 presents market projections of the acres that will be planted with herbicide-tolerant cotton in 1995-2005.

Table 13
PROJECTED U.S. PLANTINGS OF TRANSGENIC HERBICIDE-TOLERANT COTTON VARIETIES, 2000 AND 2005
(Thousands of Acres)

Technology/Product	1995	2000	2005
Single Gene Varieties:			
Bromoxynil-Tolerant (BXN®)	--	600-700	Neg
Glyphosate-Tolerant (Roundup®) Ready	--	1,000-1,500	Neg
Subtotal	--	1,600-2,200	Neg
Stacked-gene Varieties:			
Bromoxynil and Glyphosate-Tolerant (BXN® + Roundup® Ready)	--	--	1,000-1,500
Bromoxynil-Tolerant + Lepidopteran Resistant (BXN® + Bollgard®)	--	200-300	600-700
Lepidopteran Resistant + Glyphosate -Tolerant (Bollgard ® + Roundup® Ready)	-	--	500
Subtotal	--	200-300	2,100-2,700
Total	--	1,800-2,500	2,100-2,700

Source: SRI Consulting

Herbicide-tolerant cotton plants were not grown commercially on any U.S. cotton acreage in 1995. DuPont abandoned precommercial development work on sulfonylurea herbicide-tolerant cotton in 1997. However, Roundup® Ready as well as BXN® varieties will have significant impacts on the market. By 2000, we expect that Roundup® Ready cotton will be the dominant herbicide-tolerant cotton, accounting for more than 55%–60%of the 13%–18% of the U.S. cotton crop with herbicide tolerance. BXN® and BXN® + Bollgard® cotton together will account for 6%–7% of the total U.S. planted cotton acres.

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By 2005, stacked-gene varieties, including herbicide-tolerant (BXN® + Roundup® Ready) and herbicide-tolerant and insect-resistant (BXN® + Bollgard® and Bollgard® + Roundup® Ready) varieties and other herbicide-tolerant/insect resistant varieties (e.g., Roundup® Ready + Coleopteran resistant) will account for nearly all of the transgenic cotton seed market. Demand for cotton seed with single-gene herbicide tolerance traits is expected to decline with the increasing availability of seed with multiple transgenic traits. By 2005, we expect transgenic cotton plants with one or more herbicide tolerance traits to account for 15%–19% of total U.S. cotton plantings.

Conventional Chemical Herbicides

The triazine herbicide, cyanazine (Bladex®) will be voluntarily phased out by 2000. In 1995, this product accounted for 6.1% of the cotton herbicide market based on treatment acres, and for 5% based on grower expenditures. In the Southeast, Bladex® is widely relied on for layby applications, typically in combination with MSMA. Bladex® is also used as a component of weed control programs for BXN® cotton. Other "greener" herbicides are expected to fill the gap this phase-out creates, with glyphosate one of the top candidates to partially replace cyanazine.

Bromoxynil

In 1995, the herbicide bromoxynil had an insignificant share of the U.S. cotton herbicide market. The increased use of BXN® cotton by 2000 is likely to result in only a minor increase in bromoxynil consumption. In subsequent years, bromoxynil may encounter severe competition from glyphosate in herbicide-tolerant cotton plants, particularly when stacked resistance allows a choice of application of herbicides.

Glyphosate

Glyphosate is expected to benefit the most of all cotton herbicides from the use of herbicide-tolerant cotton. In 1995, glyphosate accounted for 2.6% of the cotton herbicide market. By 2000, glyphosate consumption will be stimulated by the growing use of Roundup® Ready cotton, helping it to become one of the top 6 cotton herbicides with a market share in excess of 5%. This trend should continue through 2005, with glyphosate remaining the dominant herbicide applied in conjunction with stacked herbicide resistance.

Sulfonylurea Herbicides

Sulfonylurea herbicides are not expected to be affected by the use of herbicide-tolerant cotton, given DuPont's decision to abandon the development of sulfonylurea-resistant cotton in 1997.

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SOYBEANS

WEED CONTROL MARKET, 1995

Crop Area and Major Growing Regions

Figure 7 shows major soybean growing areas in North America, and Table 14 summarizes the planted crop acreage by country and region. Canada, with about 2 million acres, accounted for 3% of the North American soybean plantings in 1995 and the United States, with 62.6 million acres, accounted for 97%. The province of Ontario accounted for 87% of Canada's total soybean crop area and for 88% of total Canadian production. Soybean plantings in Canada more than doubled between 1986 and 1995, and increased a further 6.6% in 1996.

The Corn Belt is by far the largest U.S. growing region for soybeans, with 52.3% of the nation's total planted acres in 1995. The South accounted for 18.3% of U.S. soybean plantings, followed by the Northern Plains (13.4%) and the Lake States (13.2%).

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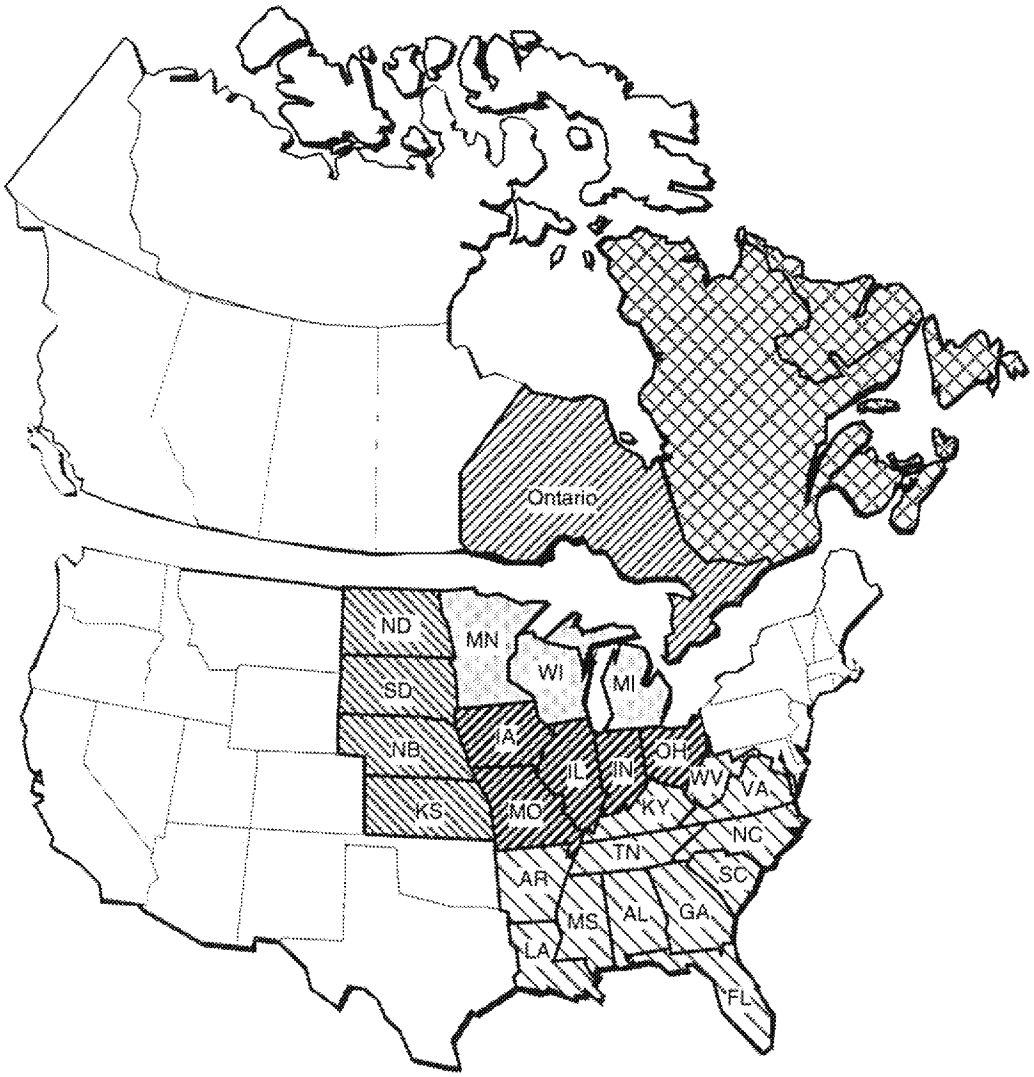
Figure 7

NORTH AMERICAN SOYBEAN ACREAGE BY COUNTRY AND REGION, 1995



	Planted Acres (1,000)	Percent of Country's Planted Acres	Percent of North America's Planted Acres
Canada			
Ontario	1,764	87.0	2.7
Other E. Provinces	264	13.0	0.4
United States			
Lake States	8,230	13.2	12.7
Corn Belt	32,700	52.3	50.6
Northern Plains	8,410	13.4	13.0
South	11,450	18.3	17.7
Other U.S. Regions	1,785	2.8	2.9

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Table 14
NORTH AMERICAN SOYBEAN ACREAGE BY COUNTRY AND REGION, 1995

Country/Region	Planted Acres (1,000)	Share of Total U.S. Planted Acres (%)	Share of North America's Planted Acres (%)
Canada, Total	2,028	N/A	3.1
United States			
South	11,450	18.3	17.7
Lake States	8,230	13.2	12.7
Corn Belt	32,700	52.3	50.6
Northern Plains	8,410	13.4	13.0
Other Regions [a]	1,785	2.9	2.8
Total	62,575	100.0	96.9
North America, Total	64,603	N/A	100.0

[a] Northeast and Southern Plains.

Sources: Statistics Canada and USDA

Figure 8 shows U.S. soybean plantings from 1987 through 1996. In 1995, planted soybean acreage increased by slightly more than 1% over 1994 levels, increasing more strongly in 1996 to 64.2 million acres. Harvested soybean acreage showed increases similar to planted acreage in 1995 and 1996.

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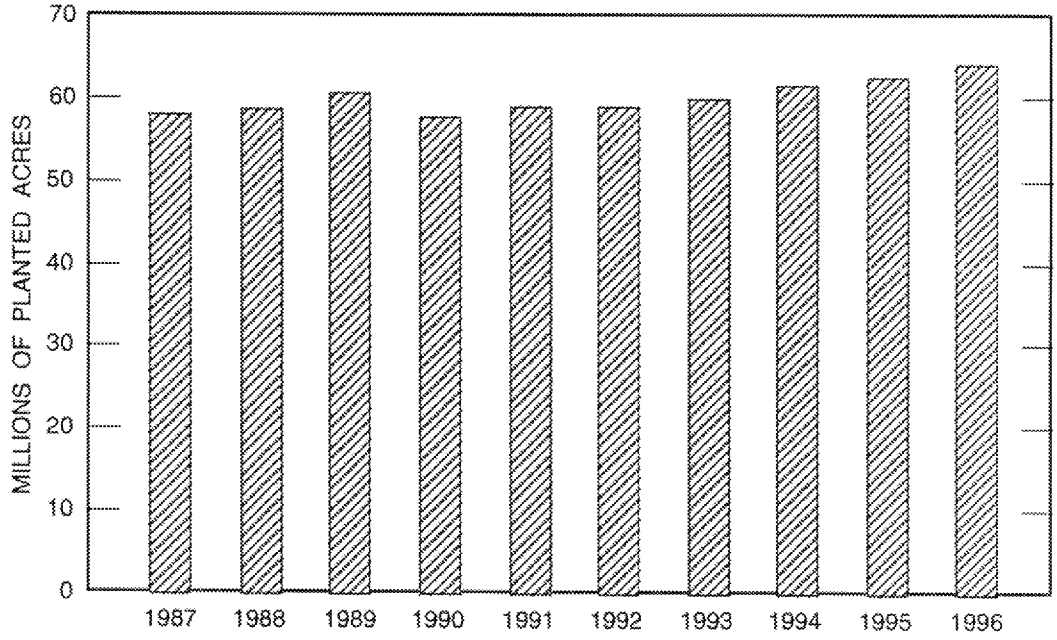
Figure 8
U.S. PLANTED SOYBEAN ACREAGE, 1987-1996



Major Weed Problems

The major problem weeds in soybean production are broadleaf species. The most difficult to control broadleaves include giant ragweed, lambs quarters, morning glory, tall water hemp, and velvet leaf; these weeds typically escape most herbicide programs. Most other weeds are controlled with available herbicides.

In addition to herbicide-based control programs, many growers also use cultural controls. The most typical is field rotation to a grain crop (in the grass family) such as corn. The rotation allows broadleaf weeds to be controlled through the herbicide spray regimen used for corn, which targets broadleaf weeds. Mechanical cultivation can be used to control grasses before the soybean plants become too tall.

Herbicide Use and Market Value

In 1995, U.S. growers spent $1,590 million to control weeds in soybeans, and Canadian growers spent about $40 million. Figure 9 shows the breakdown of the U.S. soybean herbicide market by leading product in terms of treatment acres and grower expenditures.

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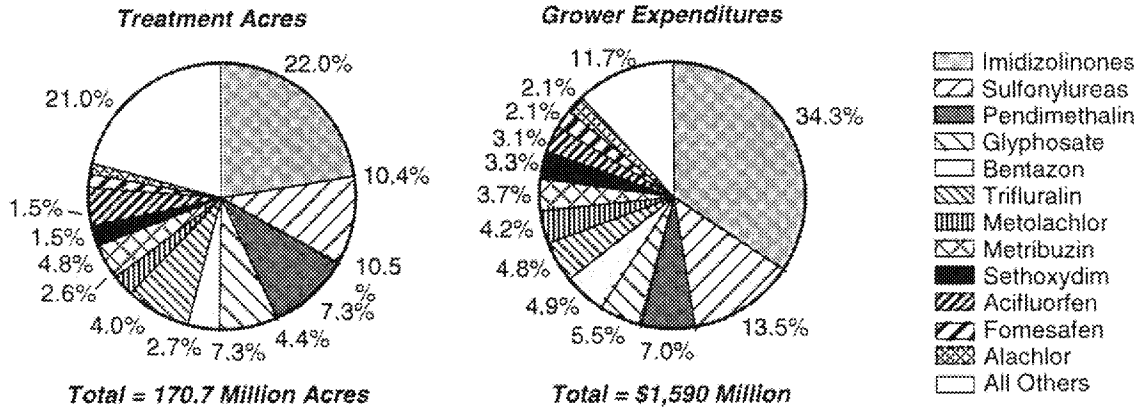
Figure 9
U.S. SOYBEAN MARKET FOR HERBICIDES, 1995



In 1995, 97% of the U.S. soybean acreage received at least 1 herbicide treatment, and on average, 2.8 chemical applications were made per treated acres. (see Table 15). The Corn Belt accounted for 52% of the herbicide treatments applied for U.S. soybeans in 1995, the South accounted for 18%, the Northern Plains for 13%, and the Lake States for 13%.

Table 15
HERBICIDE USE FOR U.S. SOYBEANS BY REGION, 1995

Region	Planted Acres (1,000)	Treated Acres: Percent of Planted	Treated Acres: Acres	Treated Acres: 1,000 Acres	Average Number of Applications	Treatment Acres
South	11,450	94		10,763	3.0	32,289
Lake States	8,230	99		8,124	2.5	20,154
Corn Belt	32,700	98		32,098	2.7	86,400
Northern Plains	8,410	96		8,074	2.5	20,462
Other Regions [a]	1,785	98		1639	6.9	11,337
Total	62,575			60,698		170,642
Average		97			2.8	

[a] Components of premixed formulations and tank mixes are counted as separate applications.

Source: SRIC estimates

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Leading Herbicides

In 1995, the imidizolinone class of herbicides accounted for 22% of the U.S. soybean herbicides market based on treatment acres, and for 34.3% based on grower expenditures (see Table 16). Imazethapyr (Pursuit®) was the leading product in this class. Sulfonylurea herbicides, led by chlorimuron-ethyl (Classic®), accounted for 10.4% of the total treatment acres and 13.5% of soybean growers' total expenditures for herbicides. Pendimethalin (Prowl®) and glyphosate (Roundup®) accounted for 10.5% and 7.3% of the total treatment acres, respectively.

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Table 16

U.S. SOYBEAN HERBICIDE MARKET BY LEADING PRODUCT OR PRODUCT CLASS, 1995

Class/Product	Treatment Acres: 1,000 Acres	Treatment Acres: Product/ Class Share (%)	Volume Applied (1,000 Pounds, A.I.)	Grower Expenditures: 1,000 Dollars)	Grower Expenditures: Product/ Class Share (%)
Imidizolinone					
imazethapyr	27,220.1	16.0	1,524.3	442,314.0	27.8
imazaquin	10,324.9	6.1	863.2	103,052.6	6.5
Subtotal	37,545.0	22.0	2,387.5	545,366.6	34.3
Sulfonylurea					
chlorimuron-ethyl	10,184.1	6.0	162.9	168,733.1	10.6
thifensulfuron	7,509.0	4.4	22.5	45,688.4	2.9
Subtotal	17,693.1	10.4	185.5	214,421.5	13.5
pendimethalin	17,896.5	10.5	15,748.9	111,187.1	7.0
glyphosate	12,515.0	7.3	7,509.0	86,729.0	5.5
bentazon	7,509.0	4.4	4,880.9	78,093.6	4.9
trifluralin	12,515.0	7.3	10,137.2	75,623.1	4.8
metolachlor	4,555.5	2.7	8,746.5	66,473.3	4.2
metribuzin	6,883.3	4.0	1,720.8	58,387.2	3.7
sethoxydim	4,380.3	2.6	832.2	52,398.3	3.3
acifluorfen	8,259.9	4.8	1,817.2	49,518.1	3.1
fomesafen	2,503.0	1.5	675.8	33,067.4	2.1
alachlor	2,503.0	1.5	4,955.9	32,659.6	2.1
clomazone	2,503.0	1.5	1,526.8	26,139.3	1.6
quizalofop-ethyl	3,754.5	2.2	187.7	24,535.7	1.5
clethodim	3,128.8	1.8	281.6	22,217.3	1.4
fluazifop-P-butyl	6,883.3	4.0	413.0	20,653.9	1.3
fenoxaprop-ethyl	4,130.0	2.4	454.3	20,443.3	1.3
lactofen	3,128.8	1.8	250.3	13,120.7	0.8
others [a]	12,355.4	7.2	5,413.7	58,965.2	3.7
Total	170,642.0	100.0	68,124.7	1,590,000.0	100.0

a. Includes dimethanamid, linuron, paraquat, 2,4-D, ethalfluralin, flumetsulam, 2,4-DB, and others.

Sources: SRIC estimates

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MARKET TRENDS, 1996-2000

New Technologies and Products

Herbicide-Tolerant Plants

Table 17 indicates herbicide-tolerant soybean varieties recently launched or under development in North America. DuPont's sulfonylurea-tolerant (STS) technology for traditionally bred soybeans was the first major enhanced soybean seed technology. Launched in late 1993, STS varieties were planted on an estimated 3 million acres in 1995 and on some 4 million acres in 1996. More than 60 seed companies offered STS soybean varieties in 1996, but Asgrow Seeds was the leading supplier with about a 50% market share.

In 1996, Monsanto commercialized its transgenic Roundup® Ready technology for soybeans. The Roundup® Ready gene increases the amount of the enzyme EPSP synthase, which is essential to plant growth but is inhibited by glyphosate, Roundup®'s active ingredient. According to weed control specialists and seed companies interviewed for this study, growers who planted Roundup® Ready soybeans were generally highly satisfied with the system, although they were required to sign a license agreement to apply only Roundup® Ultra and to pay a $5 per bag technology fee.

Table 17
HERBICIDE-TOLERANT SOYBEAN VARIETIES RECENTLY LAUNCHED OR UNDER DEVELOPMENT IN NORTH AMERICA

Product	Trade Name	Supplier or Developer	Year on the Market
Traditionally Bred Varieties			
sulfonylurea-tolerant	STS Soybeans	DuPont	1993
Single-Gene Varieties			
glufosinate-tolerant	Liberty® Link	AgrEvo	1998
glyphosate-tolerant	Roundup® Ready Soybeans	Monsanto	1996
Stacked-gene Varieties			
glyphosate and sulfonylurea-tolerant	STS and Roundup® Ready	Asgrow	1997

Source: Communications with industry and university pest management specialists.

About 1.5 million acres of Roundup® Ready soybeans were planted in 1996, of which about 200,000 acres were for seed propagation. Asgrow sold about 80% of all the

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Roundup® Ready soybean seed planted in 1996. The Roundup® Ready system allows growers to achieve season-long control of a broad spectrum of annual and perennial weeds, from crop emergence to full flowering. It also simplifies weed control programs—fewer herbicides need to be used. Other potential advantages are reduced crop injury and cost savings.

Other companies are also conducting R&D work for herbicide-tolerant soybeans. On the basis of field trial release permits issued by the USDA during 1989-1993, companies with the most active field trial programs for herbicide-tolerant soybeans are Monsanto, with 42 release permits during 1989-1993, and Asgrow (formerly Upjohn; now owned by Monsanto), with 14 permits. Table A-3 in the Appendix identifies other companies that have conducted herbicide-tolerant soybean field trials and the herbicide tolerances they are working with.

New Herbicides

Table 18 lists new herbicides that have been launched in the U.S. soybean market since 1995 or that are under development and expected to be registered within the next few years.

Table 18
NEW HERBICIDES RECENTLY LAUNCHED OR UNDER DEVELOPMENT FOR NORTH AMERICAN SOYBEANS

Product	Weeds Controlled	Application Timing[a]	Year on Market	Developing Company
flumiclorac (Resource®)	Broadleaf weeds	Post	1995	Sumitomo
oxasulfuron (Expert®)	Broadleaf weeds	Post	1998	Novartis (Ciba)
sulfentrazone (Authority®)	Broadleaf weeds: some grasses and sedges	Pre	1997	FMC

[a]Post = postemergence; Pre = preemergence

Source: Communications with industry and university pest management specialists.

Weed control specialists in the Corn Belt who have conducted trials of FMC's sulfentrazone (Authority®) in soybeans consider it to be an excellent product that will compete with DuPont's preemergence soybean herbicide, Canopy® (a premix of chlorimuron-methyl and metribuzin). Both soil-applied herbicides are considered alternatives to the new transgenic plant systems.

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MARKET PROJECTIONS, 2000 AND 2005

Herbicide-Tolerant Plants

Table 19 shows market projections for plantings of herbicide-resistant/tolerant soybean varieties in North America in 2000 and 2005.

Table 19
PROJECTED PLANTINGS OF HERBICIDE RESISTANT/TOLERANT SOYBEAN VARIETIES IN NORTH AMERICA, 2000 AND 2005[a]
(Thousands of Acres)

Technology/Product	1995	2000	2005
Traditionally Bred			
Sulfonylurea-Tolerant (STS Soybean)s	3,000	6,000-8,000	--[b]
Subtotal	3,000	6,000-8,000	--[b]
Transgenic Varieties			
Single-Gene:			
Glufosinate-Tolerant (Liberty® Link)	--	5,000-6,000	5,000-7,500
Glyphosate-Tolerant (Roundup® Ready)	--	25,000-29,000	33,000-36,500
Subtotal		30,000-35,000	38,000-44,000
Stacked-gene Varieties:			
STS and Roundup®	--	1,000	7,000-9,000
Subtotal	--	1,000	7,000-9,000
Total	3,000	37,000-44,000	45,000-53,000

[a]Based on an assumed total planted acreage of 64 million acres in both 2000 and 2005.
[b]Projections for STS soybeans are included with STS and Roundup® Ready varieties.

Source: SRI Consulting

Market penetration of herbicide-tolerant soybeans is expected to be rapid. By 2000, traditionally bred STS soybeans are expected to be planted on 6–8 million acres in the United States and Canada, and to account for 9%–12% of the total crop acreage. Single-gene transgenic herbicide-tolerant plants will be planted on 30–35 million acres by 2000 and will account for 47%–44% of total North American soybean plantings. In contrast

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with the corn market, the dominant herbicide technology in the soybean market is expected to be Monsanto's Roundup® Ready technology.

Conventional Chemistry

In 1995, sulfonylurea herbicides (chlorimuron-ethyl and thifensulfuron) had a 10.8% share of the soybean herbicide market, and glyphosate accounted for 5.5%. By 2005, it is likely that glyphosate's market share will exceed 30%, in part because of the use of Roundup® Ready soybeans, whereas sulfonylurea herbicides will increase only slightly because of STS soybeans in single- and stacked-trait varieties.

Glufosinate

The use of Liberty® Link soybeans will not help to increase the consumption of glufosinate herbicides until after 1998. By 2000, the impact will begin to be significant, and by 2005, the use of Liberty® Link soybeans could add 3% or more to glufosinate's soybean herbicide market share.

Glyphosate

Glyphosate is positioned to become the dominant herbicide used in conjunction with herbicide-tolerant soybeans by 2000. By 2005, glyphosate is expected to achieve a 30% market share, following the dominant position of Roundup® Ready soybeans.

Sulfonylurea Herbicides

Sulfonylurea herbicides are expected to slightly increase their market share as a result of their use in conjunction with herbicide-tolerant soybeans. By 2000, sulfonylurea herbicide consumption will increase its market share by 1%–2% due to STS soybeans. By 2005, growth in the use of sulfonylurea herbicides is likely to stabilize or decline because of the increasing competition of STS soybeans with Roundup® Ready soybeans, as well as the ability to use glyphosate instead of sulfonylurea herbicides in STS and Roundup® Ready stacked soybeans.

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Appendix

HERBICIDE-TOLERANT PLANT FIELD TRIALS

Appendix

HERBICIDE-TOLERANT PLANT FIELD TRIALS

Tables A-1, A-2, and A-3 summarize field trial release permits issued for herbicide-tolerant corn, cotton, and soybeans, respectively, since 1989 by company and date of issue.

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Table A-1
HERBICIDE TOLERANT CORN FIELD TRIAL RELEASE PERMITS BY COMPANY, 1990-1995

Company or Institution	Number of Sites	Site Locations(s)	Issue Date	Phenocat Category[a]	Phenotype	Gene Category[b]
Cargill	1	IL	12/23/91	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Cargill	1	IL	4/8/93	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Cargill	1	HI	4/30/93[c]	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Ciba-Geigy[d]	1	IL	5/27/92	HT/IR	Lepidopteran resistant/Lepidopteran resistant	SM-B-glucuronidase-E. coli/ SM-Phosphinothricin acetyl transferase-/ not SM-Cryl
Ciba-Geigy[d]	9	NC	4/13/93	HT/IR	Herbicide tolerance/Lepidopteran resistant	SM-B-glucuronidase-E. coli/ SM-Phosphinothricin acetyl transferase-/ not SM-Cryl
DeKalb	1	IL	3/6/91	HT	Phosphinothricin tolerant	SM-B-glucuronidase-E. coli/ not SM-Phosphinothricin acetyl transferase-Strep. hy
DeKalb	1	HI	3/12/91	HT	Phosphinothricin tolerant	SM-B-glucuronidase-E. coli/ not SM-Phosphinothricin acetyl transferase-Strep. hy
DeKalb	1	IL	4/27/92	HT	Phosphinothricin tolerant	SM-B-glucuronidase-E. coli/ not SM-Phosphinothricin acetyl transferase-Strep. hy
DeKalb	1	HI	8/10/92	HT	Glyphosate tolerant	Not SM-EPSPS-/ Not SM-Phosphinothricin acetyl transferase-
DeKalb	1	HI	4/1/93	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-
DeKalb	15	IA, IL, IN, KS, NE, OH, PA	4/30/93[c]	HT	Phosphinothricin tolerant	SM-B-glucuronidase-E. coli/ not SM-Phosphinothricin acetyl transferase-Strep. hy

Table A-1 (Continued)

Company or Institution	Number of Sites	Site Locations(s)	Issue Date	Phenocat Category[a]	Phenotype	Gene Category[b]
Du Pont	3	IA, MD	4/30/93[c]	HT/MG/PQ	Sulfonylurea tolerant/Visual marker/methionine pro	SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus/ not SM-Acetolactate
Hoechst-Roussel[e]	5	IA, IL, IN, NE	5/15/92	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Hoechst-Roussel[e]	2	MN	6/5/92	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Hoechst-Roussel[e]	13	IA, IL, IN, NE	4/15/93	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Hoechst-Roussel[e]	2	MN	4/22/93	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Hoechst-Roussel[e]	4	MO, MS, ND	4/30/93[c]	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Hoechst-Roussel[e]	11	CA, IA, IL, IN, MN, MO, NE	4/30/93[c]	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Holdens[f]	1	IA	7/1/91	HT	Phosphinothricin tolerant	Barnase-/ not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Holdens[f]	1	HI	2/4/92	HT	Phosphinothricin tolerant	Barnase-/ not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Holdens[f]	2	HI, IA	6/4/92	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus

Table A-1 (Continued)

Company or Institution	Number of Sites	Site Locations(s)	Issue Date	Phenocat Category[a]	Phenotype	Gene Category[b]
Holdens[f]	2	HI	10/8/92	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-
Holdens[f]	2	IA	5/5/93	AP/HT/MG	Male sterile/Phosphinothricin tolerant/Kanamycin r	SM-NptII-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus/ n
Holdens[f]	1	HI	5/14/93	AP/HT/MG	Male sterile/Phosphinothricin tolerant/Kanamycin r	SM-NptII-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus/ n
Holdens[f]	3	HI, IA	5/18/93	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
ICI	1	IA	5/29/92	HT	Phosphinothricin tolerant	Not SM--/ Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
ICI	1	IA	5/29/92	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
ICI	1	HI	11/23/92	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
ICI	1	IA	4/30/93[c]	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Interstate Payco Seed	1	WI	4/30/93[c]	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Iowa State U	1	IA	4/11/95[c]	HT	Phosphinothricin tolerant	SM-B-glucuronidase-E. coli
Michigan State U	1	MI	6/13/94[c]	HT/IR	Phosphinothricin tolerant/Insect predator resistant	Not SM-Phosphinothricin acetyl transferase-

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Table A-1 (Continued)

Company or Institution	Number of Sites	Site Locations(s)	Issue Date	Phenocat Category[a]	Phenotype	Gene Category[b]
Monsanto	1	IL	5/19/92	HT/IR	herbicide tolerance/Lepidopteran resistant	SM-NptII-E. coli/ not SM-CBI-CBI
Monsanto	1	FL	9/29/92[c]	HT/IR	Glyphosate tolerant/Insecticidal protein	Not SM-Cry-/ Not SM-EPSPS-
Monsanto	1	HI	11/2/92	HT/IR	Coleopteran resistant/Lepidopteran resistant	SM-CBI-/ SM-NptII-E. coli/ not SM-CryIA(b)-Bt
Monsanto	1	HI	12/4/92	HT/IR	Herbicide tolerance/Lepidopteran resistant	SM-CBI-/ not SM-CBI-CBI
Monsanto	1	MI, PR	12/17/92	HT/IR	Phosphinothricin tolerant/Lepidopteran resistant	SM-B-glucuronidase-E. coli/ SM-EPSPS-/ SM-NptII-E. coli/ not SM-CryIA(c)-Btk/ no
Monsanto	3	IL, OH	4/30/93[c]	HT/IR/IR/ PQ	Glyphosate tolerant/Insecticidal protein/Lepidopte	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-Cry-CBI/ not SM-EPSPS-CBI
Northrup King[d]	4	IL, MN	5/14/92	HT/IR	Phosphinothricin tolerant/European corn borer resistant	Not SM-CryIA(b)-Btk/ Not SM-Phosphinothricin acetyl transferase-Strep. viridochr
Northrup King[d]	22	IA, IL, KY, MN, NE, OH, PA	4/26/93	HT/IR/VR	Phosphinothricin tolerant/Lepidopteran resistant/M	SM-NptII-E. coli/ SM-Phosphinothricin acetyl transferase-/ not SM-Coat protein-M
Northrup King[d]	41	CA, CO, CT, DE, GA, HI, IA	1/31/95[c]	HT/IR	Phosphinothricin tolerant/Lepidopteran resistant	Not SM--
Pioneer	1	IA	5/15/91	HT	Sulfonylurea tolerant	Not SM-Acetolactate synthase-Corn

Table A-1 (Continued)

Company or Institution	Number of Sites	Site Locations(s)	Issue Date	Phenocat Category[a]	Phenotype	Gene Category[b]
Pioneer	1	IA	6/27/91	HT	Sulfonylurea tolerant	Barnase-/ not SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Pioneer	1	IA	4/1/92	HT	Pigment metabolism altered	SM-Phosphinothricin acetyl transferase-/ not SM-Transcriptional activator-Corn
Pioneer	1	IA	5/4/92	HT/IR	Phosphinothricin tolerant/European corn borer resistant	Not SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus/ Not SM-Wheat ge
Pioneer	1	IA	5/5/92	HT/VR	Phosphinothricin tolerant/MDMV resistant	SM-Phosphinothricin acetyl transferase-/ not SM-Coat protein-MDMV/ not SM-Phosph
Pioneer	1	HI	6/1/92	HT/IR	Phosphinothricin tolerant/European corn borer resistant	Not SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus/ Not SM-Wheat ge
Pioneer	1	HI	4/5/93	AP/HT/MG	Male sterile/Phosphinothricin tolerant/Kanamycin r	SM-B-glucuronidase-E. coli/ SM-Phosphinothricin acetyl transferase-Strep. hydros
Pioneer	2	IA	4/14/93	HT/VR	Phosphinothricin tolerant/MDMV-B resistant	Not SM-Coat protein-MDMV/ Not SM-Phosphinothricin acetyl transferase-Strep. hygr
Pioneer	1	IA	4/22/93	HT/IR	Phosphinothricin tolerant/Lepidopteran resistant	Not SM-Phosphinothricin acetyl transferase-Strep. hygroscopicus/ Not SM-Wheat ge
Pioneer	2	HI	4/30/93[c]	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-CBI
Pioneer	1	HI	11/17/93	HT/VR/VR/ VR	Phosphinothricin tolerant/MCDV resistantstant/MCMV resistant	Not SM-Coat protein-MCDV/ Not SM-Coat protein-MCMV/ Not SM-Coat protein-MDMV/ no

Table A-1 (Concluded)

Texas A&M	1	TX	8/30/95	HT	Phosphinothricin tolerant	SM-Phosphinothricin acetyl transferase-Corn
Upjohn[g]	2	MI, PR	6/5/91	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Upjohn[g]	1	PR	10/4/91	HT	Phosphinothricin tolerant	Barnase-/ not SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Upjohn[g]	2	MI, PR	4/29/92	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Upjohn[g]	2	MI	6/3/92	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. hygroscopicus
Upjohn[g]	1	PR	8/28/92	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes
Upjohn[g]	3	MI, PR	5/14/93	HT	Phosphinothricin tolerant	Not SM-Phosphinothricin acetyl transferase-Strep. viridochromogenes

[a] AP = agronomic properties; HT = herbicide tolerance; IR = insect resistance; MG = marker gene; PQ = product quality; VR = virus resistance.

[b] CBI = confidential business information; SM = selectable marker.

[c] Withdrawn.

[d] Ciba Seeds and Northrup King were merged January 1, 1997 and are now Novartis Seeds.

[e] Now AgrEvo.

[f] Holden's Foundation Seed is being acquired by Monsanto.

[g] Now Asgrow Seed Company, recently acquired by Monsanto.

Source: Biotechnology Permits Data Base, USDA.

Table A-2

U.S. TRANSGENIC HERBICIDE TOLERANT COTTON FIELD RELEASE PERMITS BY COMPANY, 1989-1993

Company or Institution	Number of sites	Site Location(s)	Issuec Date[a]	Phenocat Category[b]	Phenotype	Gene Category[c]
American Cyanamid	2	AZ, LA	4/30/93a	HT/IR	Bromoxynil tolerant/Lepidopteran resistant	not SM-CryIA(c)-Btk/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	1	MS	5/24/89	HT	Bromoxynil tolerant	SM-NptII-E. coli/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	1	HI	10/10/89	HT	Bromoxynil tolerant	SM-NptII-E. coli/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	2	AZ, MS	4/11/90	HT	Bromoxynil tolerant	SM-NptII-E. coli/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	1	HI	9/12/90	HT/IR	Bromoxynil tolerant/Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(c)-Btk/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	12	AL, AR,AZ, CA, GA, LA, MO	3/6/91	HT	Bromoxynil tolerant	SM-NptII-E. coli/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	1	MS	3/6/91	HT/IR	Bromoxynil tolerant/Lepidopteran resistant	SM-NptII-E. coli/ not SM-Cry-Btk/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	2	GA ,SC	4/19/91	HT	Bromoxynil tolerant	SM-NptII-E. coli/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	2	MS,SC	6/18/91	HT	Bromoxynil tolerant	SM-NptII-E. coli/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	1	MS	1/14/92	HT	Bromoxynil tolerant	not SM-Nitrilase-Klebsiella ozaenae
Calgene	1	TX	3/6/92	HT	Bromoxynil tolerant	not SM-Nitrilase-Klebsiella ozaenae
Calgene	5	AR ,LA, MO TX	3/6/92	HT	Bromoxynil tolerant	not SM-Nitrilase-Klebsiella ozaenae
Calgene	1	NC	3/6/92	HT	Bromoxynil tolerant	not SM-Nitrilase-Klebsiella ozaenae

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Table A-2 (Continued)

Company or Institution	Number of sites	Site Location(s)	Issuec Date[a]	Phenocat Category[b]	Phenotype	Gene Category[c]
Calgene	6	AL, GA ,MS ,SC, TN	3/20/92	HT	Bromoxynil tolerant	not SM-Nitrilase-Klebsiella ozaenae
Calgene	4	AZ,MS, SC	4/17/92	HT/IR	Bromoxynil tolerant/Lepidopteran resistant	not SM-CryIA(c)-Btk/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	1	MS	4/20/92	HT/IR	Bromoxynil tolerant/Lepidopteran resistant	not SM-CryIA(c)-Btk/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	2	MS	6/9/92	HT	Bromoxynil tolerant	SM-NptII-E. coli/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	3	AZ, SC	6/25/92	HT	Bromoxynil tolerant	not SM-Nitrilase-Klebsiella ozaenae
Calgene	3	AZ, MS,SC,	3/18/93	HT/IR	Bromoxynil tolerant/Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(c)-Btk/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	1	MS	4/8/93	HT/IR	Bromoxynil tolerant/Lepidopteran resistant	not SM-CryIA(c)-Btk/ not SM-Nitrilase-Klebsiella ozaenae
Calgene	89	AL, AR, AZ, GA, LA,MO, MS	4/13/93	HT	Bromoxynil tolerant	SM-NptII-E. coli/ not SM-Nitrilase-Klebsiella ozaenae
Du Pont	1	MS	5/11/90	HT	Sulfonylurea tolerant	not SM-Acetolactate synthase-Arab. thaliana/ not SM-Acetolactate synthase-Tobacc
Du Pont	3	DE, MD, MS	5/1/91	HT	Sulfonylurea tolerant	Acetolactate synthase-Arab. thaliana/ not SM-Acetolactate synthase-Tobacco
Du Pont	6	AR, MS,TX	4/21/92	HT	Sulfonylurea tolerant	not SM-Acetolactate synthase-Tobacco

Table A-2 (Continued)

Company or Institution	Number of sites	Site Location(s)	Issuec Date[a]	Phenocat Category[b]	Phenotype	Gene Category[c]
Du Pont	6	AR, MS, TX	4/8/93	HT	Sulfonylurea tolerant	not SM-Acetolactate synthase-Tobacco
Miles[d]	2	GA ,MS	4/30/93a	HT/IR	Bromoxynil tolerant/Lepidopteran resistant	not SM-CryIA(c)-Bt/ not SM-Nitrilase-Klebsiella ozaenae
Monsanto	1	AL	5/3/89	HT	Glyphosate tolerant	SM-NptII-E. coli/ not SM-EPSPS-Petunia
Monsanto	2	AZ, IL	5/10/90	HT	Glyphosate tolerant	SM-NptII-E. coli/ not SM-CBI-CBI/ not SM-EPSPS-Arab. thaliana/ not SM-EPSPS-Petu
Monsanto	1	AL	5/15/90	HT	Glyphosate tolerant	SM-NptII-E. coli/ not SM-CBI-CBI/ not SM-EPSPS-Arab. thaliana/ not SM-EPSPS-Petunia
Monsanto	1	HI	9/20/90	HT/IR	Glyphosate tolerant/Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk/ not SM-EPSPS-Arab. tthaliana
Monsanto	1	AL	4/14/92	HT	Glyphosate tolerant	SM-NptII-E. coli/ not SM-EPSPS-Petunia
Monsanto	17	AL, AR ,AZ, CA,GA,LA, MS	4/6/93	HT	Glyphosate tolerant	SM-NptII-E. coli/ not SM-EPSPS-Arab. thaliana/ not SM-EPSPS-CBI/ not SM-EPSPS-Petunia
Monsanto	1	NC	5/3/93	HT	Glyphosate tolerant	SM-NptII-E. coli/ not SM-EPSPS-Arab. thaliana/ not SM-EPSPS-CBI/ not SM-EPSPS-Petunia

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Table A-2 (Concluded)

Company or Institution	Number of sites	Site Location(s)	Issuec Date[a]	Phenocat Category[b]	Phenotype	Gene Category[c]
Northrup King[e]	1	MS	4/5/90	HT/IR	Glyphosate tolerant/Lepidopteran resistant	SM-NptII-E. coli/ not SM-CryIA(b)-Btk/ not SM-CryIA(c)-Btk/ not SM-EPSPS-Petunia

[a] Withdrawn.

[b] HT = herbicide tolerance

[c] CBI = confidential business information; SM = selectable marker.

[d] Now Bayer Corp.

[e] Now Novartis Seeds.

Source: Biotechnology Permits Data Base, USDA.

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Table A-3

U.S. TRANSGENIC HERBICIDE TOLERANT SOYBEAN FIELD RELEASE PERMITS, 1989-1993

Company or Institution	Number of Sites	Site Location(s)	Issue Date[a]	Phenocat Category[b]	Phenotype	Gene Category[c]
AgriPro	1	PR	10/21/92	HT	Glyphosate tolerant	not SM-EPSPS-CBI
AgriPro	2	IA, IN	4/30/93[a]	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-EPSPS-CBI
Ciba-Geigy[d]	2	FL, IL	4/30/93[a]	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ not SM-EPSPS-CBI
Dairyland Seeds	3	IL, IN, WI	4/30/93[a]	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ not SM-EPSPS-CBI
Dairyland Seeds	1	FL	4/30/93[a]	HT	Glyphosate tolerant	not SM-EPSPS-CBI
Dairyland Seeds	1	PR	6/24/93[a]	HT	Glyphosate tolerant	not SM-EPSPS-
DeKalb	4	CT, HI,IL	4/30/93[a]	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ not SM-EPSPS-CBI
Delta & Pine Land	1	MS	4/30/93[a]	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ not SM-EPSPS-CBI
FFR Cooperative	2	IN ,TN	4/30/93[a]	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ not SM-EPSPS-CBI
Land O Lakes[e]	1	IA	4/30/93[a]	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-EPSPS-CBI
Monsanto	1	IL	5/4/89	HT	Glyphosate tolerant	SM-NptII-E. coli/ not SM-EPSPS-Petunia
Monsanto	1	AR	5/8/89	HT	Glyphosate tolerant	SM-NptII-E. coli/ not SM-EPSPS-Petunia
Monsanto	1	TN	5/8/89	HT	Glyphosate tolerant	SM-NptII-E. coli/ not SM-EPSPS-Petunia
Monsanto	1	PR	11/21/89	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-EPSPS-Petunia

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Table A-3 (Continued)

Company or Institution	Number of Sites	Site Location(s)	Issue Date[a]	Phenocat Category[b]	Phenotype	Gene Category[c]
Monsanto	3	AR, IL, MD	5/9/90	HT	Glyphosate tolerant	SM-NptII-E. coli/ not SM-B-glucuronidase-E. coli/ not SM-EPSPS-Petunia
Monsanto	1	IL	5/15/90	MG/HT	Visual marker/Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-EPSPS-Petunia
Monsanto	11	AR ,GA, IA, IL, IN,KY, MO	5/23/90	HT	Glyphosate tolerant	SM-NptII-E. coli/ not SM-EPSPS-Petunia
Monsanto	1	PR	9/14/90	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-CBI-CBI/ not SM-EPSPS-Petun
Monsanto	4	AR, IL, IN, MD	4/24/91	HT	Glyphosate tolerant	SM-NptII-E. coli/ not SM-B-glucuronidase-E. coli/ not SM-CBI-CBI/ not SM-EPSPS-P
Monsanto	8	GA, IA, IL, IN, KY, NE, OH	5/22/91	HT	Glyphosate tolerant	SM-NptII-E. coli/ not SM-EPSPS-Petunia
Monsanto	1	PR	9/24/91	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ not SM-EPSPS-Petunia
Monsanto	1	MS	4/24/92	HT	Glyphosate tolerant	not SM-EPSPS-CBI
Monsanto	1	IL	4/29/92	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ not SM-EPSPS-Petunia
Monsanto	2	AR, IA	4/30/92	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ not SM-EPSPS-CBI
Monsanto	40	AL, AR,DE, GA, IA, IL, IN	5/1/92	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM--CBI/ not SM-EPSPS-Petunia
Monsanto	1	IL	5/5/92	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM--CBI/ not SM-EPSPS-Petunia

Table A-3 (Continued)

Company or Institution	Number of Sites	Site Location(s)	Issue Date[a]	Phenocat Category[b]	Phenotype	Gene Category[c]
Monsanto	18	AL, AR, GA, IA, IL, IN,KY	5/5/92	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM--CBI/ not SM-EPSPS-Petunia
Monsanto	5	AR, IA, IL, I N, MD	5/6/92	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM--CBI/ not SM-EPSPS-Petunia
Monsanto	2	IA ,TN	5/6/92	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM--CBI/ not SM-EPSPS-Petunia
Monsanto	1	AR	5/11/92	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-EPSPS-CBI/ not SM-EPSPS-Pet
Monsanto	2	IA IN	5/14/92	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM--CBI/ not SM-EPSPS-Petunia
Monsanto	1	KY	5/14/92	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-CBI-CBI/ not SM-EPSPS-Petun
Monsanto	3	MN	5/14/92	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-CBI-CBI/ not SM-EPSPS-Petun
Monsanto	1	WI	5/19/92	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-CBI-CBI/ not SM-EPSPS-Petun
Monsanto	1	VA	5/20/92	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ not SM-CBI-CBI/ not SM-EPSPS-Petunia
Monsanto	21	AR, GA, IA, IL, IN, KS , KY	5/21/92	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ not SM-CBI-CBI/ not SM-EPSPS-Petunia

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Table A-3 (Continued)

Company or Institution	Number of Sites	Site Location(s)	Issue Date[a]	Phenocat Category[b]	Phenotype	Gene Category[c]
Monsanto	2	NC	6/3/92	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-CBI-CBI/ not SM-EPSPS-Petun
Monsanto	1	MI	6/9/92	HT/MG	Glyphosate tolerant/Visual marker	SM-B-glucuronidase-E. coli/ not SM-EPSPS-
Monsanto	1	PR	11/19/92	HT	Glyphosate tolerant	not SM-EPSPS-CBI
Monsanto	2	FL, IL	11/20/92	HT	Glyphosate tolerant	not SM-EPSPS-CBI
Monsanto	2	VA	3/2/93	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ not SM-EPSPS-Arab. thaliana/ not SM-EPSPS-CBI/ not S
Monsanto	18	AL, AR, GA, IA, IL, IN, KY	3/16/93	HT	Glyphosate tolerant	not SM-EPSPS-CBI
Monsanto	15	AL, IA,IL, IN, MD, MI, MO	3/26/93	HT	Glyphosate tolerant	not SM-EPSPS-CBI
Monsanto	3	WI	3/26/93	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ not SM-CBI-CBI/ not SM-EPSPS-CBI/ not SM-EPSPS-Petun
Monsanto	4	NC	4/5/93	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-EPSPS-CBI
Monsanto	4	NC	4/5/93	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-EPSPS-CBI
Monsanto	3	MN	4/20/93	HT	Glyphosate tolerant	not SM-EPSPS-CBI
Monsanto	19	AL, AR, GA, IA ,IL, IN, KY	4/22/93	HT	Glyphosate tolerant	not SM-EPSPS-CBI
Monsanto	1	AR	4/22/93	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ SM-NptII-E. coli/ not SM-EPSPS-CBI
Monsanto	2	IL	4/29/93	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ not SM-EPSPS-CBI

Table A-3 (Continued)

Company or Institution	Number of Sites	Site Location(s)	Issue Date[a]	Phenocat Category[b]	Phenotype	Gene Category[c]
Monsanto	1	DE	4/29/93	HT/MG	Glyphosate tolerant/Visual marker	SM-B-glucuronidase-E. coli/ not SM-CBI-CBI
Monsanto	1	MD	4/30/93[a]	HT	Glyphosate tolerant	not SM-EPSPS-CBI
Northrup King[d]	1	HI	12/4/92	HT	Glyphosate tolerant	not SM-EPSPS-CBI
Northrup King[d]	3	AR, IA, IL	4/30/93[a]	HT	Glyphosate tolerant	not SM-EPSPS-CBI
Pioneer	1	PR	10/16/92	HT/PQ	Glyphosate tolerant/Seed methionine storage increase	not SM-EPSPS-CBI/ not SM-Seed storage protein-Brazil nut
Pioneer	7	IA, IL, MO, MS OH, TN	4/30/93[a]	HT/PQ	Glyphosate tolerant/Storage protein	not SM-EPSPS-CBI/ not SM-Seed storage protein-Brazil nut
Upjohn[f]	1	PR	11/15/90	HT	Phosphinothricin tolerant	SM-B-glucuronidase-E. coli/ not SM-Phosphinothricin acetyl transferase-Strep. hy
Upjohn[f]	3	AR, IL, MD	5/30/91	HT	Phosphinothricin tolerant	SM-B-glucuronidase-E. coli/ not SM-Phosphinothricin acetyl transferase-Strep. hy
Upjohn[f]	1	PR	10/4/91	HT	Phosphinothricin tolerant	SM-B-glucuronidase-E. coli/ not SM-Phosphinothricin acetyl transferase-Strep. hy
Upjohn[f]	3	AR, IL, MD	5/21/92	HT	Phosphinothricin tolerant	SM-B-glucuronidase-E. coli/ not SM-Phosphinothricin acetyl transferase-Strep. hy
Upjohn[f]	4	IA, IL, MS, NE	5/22/92	HT	Phosphinothricin tolerant	SM-B-glucuronidase-E. coli/ not SM-Phosphinothricin acetyl transferase-Strep. hy
Upjohn[f]	1	MI	6/1/92	HT	Phosphinothricin tolerant	SM-B-glucuronidase-E. coli/ not SM-Phosphinothricin acetyl transferase-Strep. hy

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Table A-3 (Concluded)

Company or Institution	Number of Sites	Site Location(s)	Issue Date[a]	Phenocat Category[b]	Phenotype	Gene Category[c]
Upjohn[f]	2	PR	10/2/92	HT	Glyphosate tolerant	SM-B-glucuronidase-/ not SM-EPSPS-CBI
Upjohn[f]	1	PR	12/7/92	HT/SM	Phosphinothricin tolerant/Visual marker	not SM-B-glucuronidase-E. coli/ not SM-Phosphinothricin acetyl transferase-
Upjohn[f]	4	AR, IL, MD	4/13/93	HT	Phosphinothricin tolerant	SM-B-glucuronidase-E. coli/ not SM-Phosphinothricin acetyl transferase-Strep. hy
Upjohn[f]	2	MN	4/19/93[a]	HT	Phosphinothricin tolerant	not SM-Phosphinothricin acetyl transferase-Strep. hydroscopicus
Upjohn[f]	8	IA, IL, MS, NE	4/29/93	HT	Phosphinothricin tolerant	SM-B-glucuronidase-E. coli/ not SM-Phosphinothricin acetyl transferase-Strep. hy
Upjohn[f]	17	AR, IA, IL, IN, MD, MI, WI	4/30/93[a]	HT	Glyphosate tolerant	SM-B-glucuronidase-E. coli/ not SM-EPSPS-CBI
Upjohn[f]	5	IN, MO, ND, SC, VA	4/30/93[a]	HT	Phosphinothricin tolerant	SM-B-glucuronidase-E. coli/ not SM-Phosphinothricin acetyl transferase-Strep. hy
Upjohn[f]	8	AR, CA, IA, IL, IN, MO, MS	4/30/93[a]	HT	Phosphinothricin tolerant	not SM-Phosphinothricin acetyl transferase-

[a] Withdrawn.

[b] HT = herbicide tolerance; MG = marker gene; PQ = product quality.

[c] CBI = confidential business information; SM = selectable marker.

[d] Ciba Seeds and Northrup King merged to form Novartis Seeds on January 1, 1997.

[e] Now Croplan Genetics

[f] Now Asgrow Seed Company, a subsidiary of Monsanto Company.

Source: Biotechnology Permits Data Base, USDA.

REPORT III:
DISEASE AND NEMATODE CONTROL

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INTRODUCTION

Biotechnology and new chemistry will play increasingly important roles in crop disease and nematode control over the next several years, particularly after 2000. The new technologies—transgenic disease- and nematode-resistant plants, biological fungicides and nematicides, and new chemical fungicides—will be employed in integrated control programs in conjunction with conventional chemical fungicides, soil fumigants, and/or nonfumigant nematicides, as well as cultural and mechanical control methods.

SRI Consulting (SRIC) is monitoring new crop disease and nematode control technologies under development worldwide. In this report, we have identified those that are likely to affect U.S. crop markets before 2005. As a base line for monitoring market penetration of the new technologies and reporting estimates of future sales, we have assessed the size of markets for agricultural fungicides and soil fumigants and nematicides for the world, North America, and the United States in 1995.

The report focuses on U.S. agricultural crop markets for two pesticide product groups—fungicides, and soil fumigants and nematicides. In 1995, the United States accounted for 11% of worldwide sales of fungicides in agricultural crop markets and for 54% of worldwide sales of soil fumigants and nematicides for agricultural crops. Base line SRIC estimates of the size of individual U.S. crop markets for each product class are presented in terms of both treatment or treated acres and end-user market value.

This report is the third of six reports issued in 1997 to first-year subscribers to SRIC's new multiclient program, *Biotechnology and New Chemistry: Their Impacts on Agricultural Pest Control.*

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DISEASE CONTROL

OVERVIEW

World Fungicides Market

In 1995, world agricultural crop markets for fungicides totaled $5.95 billion at the end-user level. Figure 1 and Table 1 present estimated breakdowns of the total world market by region and crop sector. Western Europe and the Far East are the two largest regional markets for fungicides, together accounting for 74% of the total world market. Globally, the two largest crop markets for fungicides are fruits and nuts (29% of the total market) and cereals (24%), followed by rice (15%), and vegetables (10%).

Figure 1
WORLD CROP MARKETS FOR FUNGICIDES, 1995

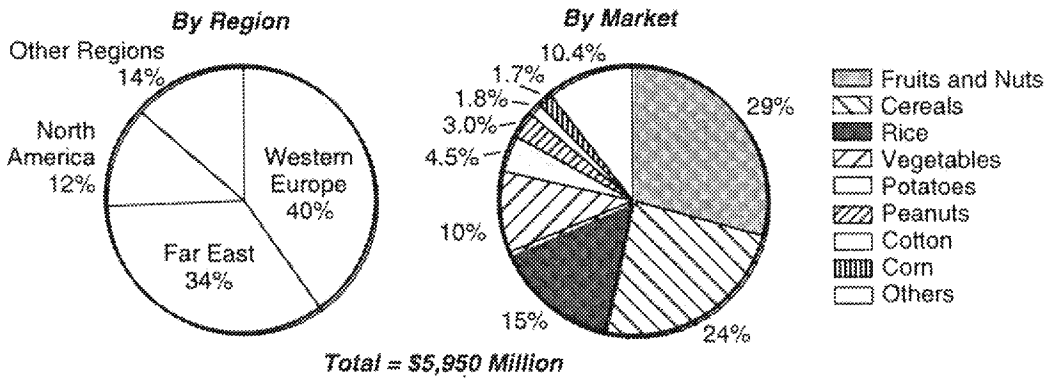

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Table 1
WORLD CROP MARKETS FOR FUNGICIDES BY REGION, 1995
(Millions of Dollars, End-User Sales)

Crop Market	North America	Western Europe	Far East[a]	Other Regions	Total
Fruits and Nuts	250	765	555	170	1,740
Cereals	45	1,200	40	155	1,440
Rice	21	15	800	64	900
Vegetables	150	70	313	62	595
Potatoes	75	61	104	30	270
Peanuts	78	--	90	12	180
Cotton	38	5	45	17	105
Corn	3	35	NA.	62	100
Sugar Beets	6	50	5	14	75
Soybeans	3	NA	9	43	55
Oilseed Rape/Canola	3	28	2	7	40
Others	34	161	77	178	450
Total	706	2,390	2,040	814	5,950

[a] East Asia and Australia
Source: SRIC estimates

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North American Fungicides Market

The North American agricultural fungicides market is relatively small in comparison with the Western European and Far East markets. Valued at an estimated $706 million in 1995, the North American market accounted for 12% of the world market. Fruits and nuts (36%) and vegetables (21%) are the two largest crop sectors of the North American market, given product sales at the end-user level. Peanuts (11%) and potatoes (11%) are the next largest sectors (see Figure 2 and Table 2). On the basis of grower expenditures, U.S. crop markets accounted for 92% of the North American agricultural fungicides market and Canadian crop markets for 8%.

Figure 2
NORTH AMERICAN CROP MARKETS FOR FUNGICIDES, 1995

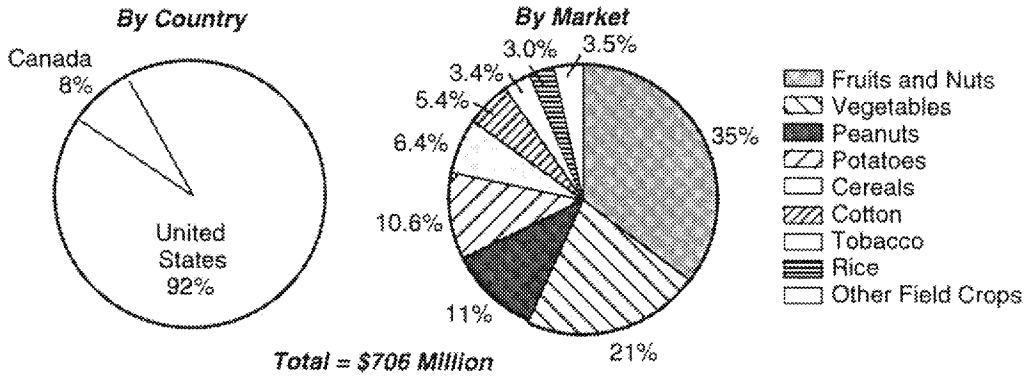

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Table 2
NORTH AMERICAN CROP MARKETS FOR FUNGICIDES, 1995
(Millions of Dollars, End-User Sales)

Crop Market	Canada	United States	Total
Fruits and Nuts	10	240	250
Vegetables	3	147	150
Peanuts	--	78	78
Potatoes	10	65	75
Cereals	20	25	45
Cotton	--	38	38
Tobacco	--a	24	24
Rice	--	21	21
Sugar Beets	--	6	6
Soybeans	Neg	3	3
Corn	Neg	3	3
Oilseed Rape/Canola	3	--	3
Others	8	2	10
Total	54	652	706

[a] Included in Others.
Source: SRIC estimates

Fungicide Use for U.S. Agricultural Crops

Fungicide use for U.S. agricultural crops amounted to 57.1 million treatment acres in 1995 (see Figure 3 and Table 3). Fruits and nuts—grapes, apples, tree nuts, stone fruits, citrus, strawberries, pears, and other fruits—collectively accounted for 31.5% of the total fungicide treatments, vegetable crops for about 22%, and potatoes for 15.5%. Peanuts and cotton are the two most important U.S. field crop markets for fungicides; respectively, they were about 11% and about 9% of fungicide treatments for U.S. agricultural crops in 1995. Small grains (4%) and rice (2%) are relatively small markets, and sugar beets, tobacco, soybeans, corn, and other field crops are minor markets — collectively, only about 5% of fungicide treatment acres in 1995.

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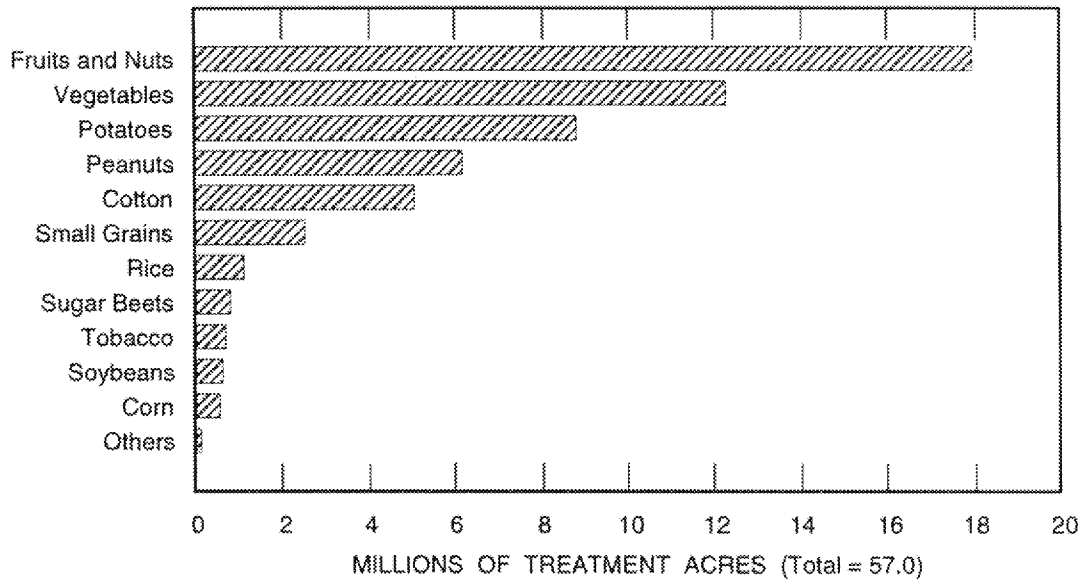
Figure 3

FUNGICIDE USE FOR U.S. AGRICULTURAL CROPS, 1995



Only 7% of the nearly 253 million acres of U.S. crop land received fungicide treatment in 1995. The treated acres received an average of 3.4 fungicide applications. Fruits and nuts, potatoes, vegetables grown for the fresh market, and peanuts typically receive the most intensive fungicide treatment.

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Table 3
FUNGICIDE USE FOR U.S. AGRICULTURAL CROPS, 1995

Crop Market	Planted Acres[a] (1,000)	Fungicide Treated Acres: Percent of Planted Acres	Fungicide Treated Acres: Acres (1,000)	Average Number of Applications	Fungicide Treatment Acres (1,000)
Fruits and Nuts					
Grapes					
Northeast/North Central	59.0	99	58	5.4	315
Washington and Oregon	39.6	39	15	4.7	73
California	646.8	96	621	8.2	5,092
Other Regions	8.8	86	8	5.7	43
Subtotal	754.2		702		5,523
Average		93		7.9	
Apples					
Northeast/North Central	194.8	99	193	13.4	2,584
Pacific States	196.6	80	157	3.1	488
Other Regions	69.1	91	63	11.6	729
Subtotal	460.5		413		3,801
Average		90		9.2	
Tree Nuts					
Pecans	422.0	64	270	4.8	1,296
Almonds	400.0	96	384	2.9	1,114
Walnuts	169.0	75	127	2.5	317
Pistachios	60.3	88	53	1.1	58
Hazelnuts	27.8	88	24	1.3	32
Subtotal	1,079.1		858		2,817
Average		80		3.3	
Stone Fruit					
Peaches	172.7	96	165	8.4	1,384
Cherries	93.0	94	87	8.2	715
Plums and Prunes	127.2	82	104	1.7	181
Nectarines	32.4	97	31	4.5	141
Apricots	21.3	98	21	3.5	73
Subtotal	446.6		408		2,494
Average		91		6.1	

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Table 3 (Continued)
FUNGICIDE USE FOR U.S. AGRICULTURAL CROPS, 1995

Crop Market	Planted Acres[a] (1,000)	Fungicide Treated Acres: Percent of Planted Acres	Fungicide Treated Acres: Acres (1,000)	Average Number of Applications	Fungicide Treatment Acres (1,000)
Fruits and Nuts (Continued)					
Citrus					
Florida	731.7	99	724	2.1	1,521
Texas	21.9	82	18	6.0	108
California and Arizona	301.5	83	250	1.1	275
Subtotal	1,055.1		993		1,904
Average		94		1.9	
Strawberries					
Florida	6.0	100	6	30.6	184
California	24.0	100	24	14.0	337
Other States	19.9	73	15	10.1	147
Subtotal	49.9		45		668
Average		90		14.8	
Pears	70.6	90	64	8.2	525
Other Fruits[b]	201.7	48	98	2.8	276
Fruits and Nuts, Total	4,117.7		3,581		18,009
Average		87		5.0	
Vegetables					
Tomatoes					
Florida	48.7	100	49	35.0	1,705
California	369.0	84	310	3.7	1,093
Other States	78.7	93	73	15.5	1,134
Subtotal	496.4		432		3,932
Average		87		9.1	
Cucurbits					
Watermelons	228.4	82	187	6.9	1,292
Cucumbers	185.1	46	85	7.4	630
Muskmelons[c]	131.0	80	105	3.3	346
Subtotal	544.5		377		2,268
Average		69		6.0	
Onions	168.9	96	162	7.1	1,151
Peppers, Bell	70.3	84	59	17.0	1,004
Lettuce	268.4	86	231	3.8	877
Carrots	113.9	77	88	8.5	745

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Table 3 (Continued)
FUNGICIDE USE FOR U.S. AGRICULTURAL CROPS, 1995

Crop Market	Planted Acres[a] (1,000)	Fungicide Treated Acres: Percent of Planted Acres	Fungicide Treated Acres: Acres (1,000)	Average Number of Applications	Fungicide Treatment Acres (1,000)
Vegetables (Continued)					
Corn, Sweet					
Fresh Market	235.3	40	94	6.0	565
Processing	531.4	10	53	1.0	53
Subtotal	766.7		147		618
Average		19		4.2	
Snap beans					
Fresh Market	95.2	70	67	7.0	466
Processing	227.1	40	91	1.2	109
Subtotal	322.3		157		575
Average		49		3.7	
Cole Crops					
Cabbage	85.9	72	62	5.3	328
Broccoli	121.6	55	67	1.8	120
Cauliflower	51.3	60	31	3.2	98
Brussels Sprouts	3.4	100	3	3.9	13
Subtotal	262.2		163		560
Average		62		3.4	
Celery	33.4	100	33	10.5	351
Others[d]	631.3	22	154	1.6	254
Vegetables, Total	3,678.7		1,989		12,336
Average		54		6.2	
Potatoes					
Northeast/Upper North Central	484.4	99	480	9.2	4,412
Northwest[e]	601.0	73	439	6.0	2,632
Other Regions	312.8	86	269	6.7	1,802
	1,398.2		1,187		8,847
		85		7.5	

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Table 3 (Concluded)
FUNGICIDE USE FOR U.S. AGRICULTURAL CROPS, 1995

Crop Market	Planted Acres[a] (1,000)	Fungicide Treated Acres: Percent of Planted Acres	Fungicide Treated Acres: Acres (1,000)	Average Number of Applications	Fungicide Treatment Acres (1,000)
Field Crops					
Peanuts	1,537.5	87	1,345	4.6	6,205
Cotton	16,931.4	15	2,540	2.0	5,079
Small grains[f]	83,759.0	3	2,513	1.0	2,513
Rice	3,121.0	36	1,124	1.0	1,124
Sugar Beets	1,475.8	52	767	1.1	844
Tobacco	663.1	91	603	1.1	664
Soybeans	62,575.0	1	626	1.0	626
Corn	71,245.0	< 1	570	1.0	570
Others[g]	2,485.5	5	124	1.1	137
Field Crops, Total	243,793.3		10,212		17,761
Average		4		1.7	
All Crops, Total	252,987.9		16,969		56,952
Average		7		3.4	

[a] Harvested acres for tobacco and certain other field crops; bearing acres for tree fruits and nuts and other berries; planted acres for all other crops.

[b] Avocados, blueberries, bushberries (blackberries, boysenberries, loganberries, and raspberries), cranberries, dates, and olives.

[c] Cantaloupe and honeydew.

[d] Artichokes, asparagus, beets, eggplant, escarole, garlic, green peas, lima beans, spinach, and sweet potatoes.

[e] Idaho, Washington, and Oregon.

[f] Barley, oats, rye, wheat.

[g] Dry beans and peas, mint, and hops.

Source: SRIC estimates

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New Technologies and Products

Transgenic Disease-Resistant Plants

Since the late 1980s, numerous agricultural chemicals, seed, food processing, and biotechnology companies, as well as universities and the U.S. Department of Agriculture (USDA), have conducted field trials of transgenic disease-resistant crop plants. Table 4 provides an overview of U.S. transgenic disease-resistant plant research by crop. Companies with the most active field trial programs include Seminis Vegetable Seeds and its subsidiaries, Asgrow Vegetable Seeds, and Petoseed; Novartis Seeds and its subsidiaries, Northrup King and Rogers Seed Co.; Monsanto; and Pioneer Hi-Bred International.

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Table 4
TRANSGENIC DISEASE-RESISTANT CROP PLANTS ON THE MARKET OR UNDER DEVELOPMENT IN THE UNITED STATES

Crop	Company/Institution	Disease or Causal Organism: Bacterial and Fungal Diseases	Disease or Causal Organism: Viral Diseases[a]	Remarks
Fruits and Nuts				
Apple	Cornell University	Fire blight	Cecropin produced	Field trials in 1995 of apples with altered fruit ripening, as well as fire blight resist- ance.
Grape	Gen Apps, Inc.		AMV CaMV CMV	Company headquarters, Patterson, WA.
Papaya	Cornell University		PRSV	
	University of Hawaii		PRSV	
Plum	USDA/ARS		PPV PRV	
Strawberry	Calgene	Fungus, NSPF		Field trials of strawberry plants with both fungus-resistant and altered fruit ripening traits.
	DNA Plant Technology	*Botrytis/Sclerotinia/ Verticillium*		Field trials in 1997 of strawberries with multiple disease-resistance and delayed ripening traits.
	USDA/ARS/ Plant Sciences Research	*Botrytis/Colletotrichum/ Phytophthora/Pythium/ Sphaeropsis* fruit rot/ *Verticillium*		Field trials of varieties with multidisease resistance and 2,4-D tolerance.

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Table 4 (Continued)
TRANSGENIC DISEASE-RESISTANT CROP PLANTS ON THE MARKET OR UNDER DEVELOPMENT IN THE UNITED STATES

Crop	Company/Institution	Disease or Causal Organism: Bacterial and Fungal Diseases	Disease or Causal Organism: Viral Diseases[a]	Remarks
Fruits and Nuts (Continued)				
Walnut	University of California - Davis		NSPF	Field trial s in 1995 of walnuts with both Coleopteran insect resistance and virus resistance
Vegetables				
Carrot	Asgrow Vegetable Seeds[b]	*Alternaria*		
	Seminis Vegetable Seeds	*Alternaria*		Field trials in 1997.
Corn, Sweet	Rogers Seed Co.[c]	Northern corn leaf blight	MDMV	
Cucumber	Asgrow Vegetable Seeds[b]		CMV/PRSV/SqMV/ WMV2/ZYMV	
	Michigan State University		ZYMV	
	New York State Agricultural Experiment Station		CMV	
	Seminis Vegetable Seeds Inc.		CMV/Nucleocapsid protein produced virus/PRSV/WMV2/ ZYMV	Field trials in 1997 of varieties with resistance to multiple viruses.
			CMV/PRSV/WMV2/ ZYMV	
			CMV/PRSV/SqMV/ WMV2/ZYMV	
			CMV /WMV2/ZYMV	

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Table 4 (Continued)
TRANSGENIC DISEASE-RESISTANT CROP PLANTS ON THE MARKET OR UNDER DEVELOPMENT IN THE UNITED STATES

Crop	Company/Institution	Disease or Causal Organism: Bacterial and Fungal Diseases	Disease or Causal Organism: Viral Diseases[a]	Remarks
Vegetables (Continued)				
Lettuce	Asgrow Vegetable Seeds[b]	Downy mildew	TSWV	
	Harris Moran[d]	Bacterial disease NSPF Fungal disease NSPF		
	Seminis Vegetable Seeds Inc.		LMV	
	University of Hawaii-Manoa		TSWV	Field trials in 1993.
Muskmelon	Asgrow Vegetable Seeds[b]		CMV/PRSV/SqMV/ WMV2/ZYMV CMV/WMV2/ZYMV	
	Cornell University		CMV/WMV2/ZYMV	
	Harris Moran[d]		CMV CMV/WMV2/ZYMV	
	Michigan State University		ZYMV	
	New York State Agricultural Experiment Station		CMV CMV/WMV2/ZYMV	
	Petoseed[b]		CMV/WMV2	

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Table 4 (Continued)
TRANSGENIC DISEASE-RESISTANT CROP PLANTS ON THE MARKET OR UNDER DEVELOPMENT IN THE UNITED STATES

Crop	Company/Institution	Disease or Causal Organism: Bacterial and Fungal Diseases	Disease or Causal Organism: Viral Diseases[a]	Remarks
Vegetables (Continued)				
Muskmelon (Continued)	Rogers Seed Co.[c]		CMV WMV2 ZYMV	Field trial permits obtained by Sandoz in 1996.
	Seminis Vegetable Seeds Inc.		CMV/TEV CMV/PRSV/SqMV/WMV2 CMV/PRSV/SqMV/WMV2/ZYMV CMV/PRSV/WMV2/ZYMV	
Onions	Texas Tech University	*Fusarium / Phoma*		
Pepper	Petoseed[b]		CMV	
Squash	Asgrow Vegetable Seeds[b]	Mildew, unspecified	CMV/PRSV/SqMV/WMV2/ZYMV CMV/WMV2/ZYMV WMV2/ZYMV	Asgrow's first transgenic virus-resistant squash product, Freedom II™, which is resistant to WMV2 and ZYMV, but not to PRSV or CMV, approved for sale in 1995.
	Cornell University		CMV CMV/WMV2 CMV/WMV2/ZYMV SqMV	

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Table 4 (Continued)
TRANSGENIC DISEASE-RESISTANT CROP PLANTS ON THE MARKET OR UNDER DEVELOPMENT IN THE UNITED STATES

Crop	Company/Institution	Disease or Causal Organism: Bacterial and Fungal Diseases	Disease or Causal Organism: Viral Diseases[a]	Remarks
Vegetables (Continued)				
Squash (Continued)	New York State Agricultural Experiment Station		CMV CMV/WMV2/ZYMV SqMV/WMV2/ZYMV SqMV	
	Petoseed[b]		CMV/PRSV/WMV2/ ZYMV CMV/WMV2/ CMV/WMV2/ZYMV	
	Seminis Vegetable Seeds Inc.		CMV CMV/Nucleocapsid protein produced virus/PRSV/SqMV/ WMV2/ZYMV CMV/PRSV/SqMV/ WMV2/ZYMV	
Sweet potatoes	Tuskegee University	Fungal disease NSPF		Field trials in 1997.
Tomato	Agritope, Inc.		BCTV	Field trial permit for 1994-1995.
	Asgrow Vegetable Seeds[b]	*Alternaria solani* *Phytophthora*	CMV/TMV CMV/TSWV Gemini virus TMV TMV/ToMV TSWV	

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Table 4 (Continued)
TRANSGENIC DISEASE-RESISTANT CROP PLANTS ON THE MARKET OR UNDER DEVELOPMENT IN THE UNITED STATES

Crop	Company/Institution	Disease or Causal Organism: Bacterial and Fungal Diseases	Disease or Causal Organism: Viral Diseases[a]	Remarks
Vegetables (Continued)				
Tomato	Calgene		CMV TMV	
	DNA Plant Technology	*Phytophthora/ Rhizoctonia* *Alternaria / Botrytis* *Postharvest fungal disease* Other fungal disease		
	Harris Moran[d]		CMV	
	Monsanto	*Phytophthora*	CMV/TMV TMV ToMV TMV/ToMV TYLCV	
	New York State Agricultural Experiment Station		CMV Others	
	Petoseed[b]		CMV	
	Purdue University	Bacterial speck		
	Rogers Seed Co.[c]		ToMV TSWV	

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Table 4 (Continued)
TRANSGENIC DISEASE-RESISTANT CROP PLANTS ON THE MARKET OR UNDER DEVELOPMENT IN THE UNITED STATES

Crop	Company/Institution	Disease or Causal Organism: Bacterial and Fungal Diseases	Disease or Causal Organism: Viral Diseases[a]	Remarks
Vegetables (Continued)				
Tomato (Continued)	Seminis Vegetable Seeds Inc.	Powdery mildew	CMV CMV/TSWV Gemini virus	
	University of California	Soft rot fungus		
	University of Florida	Bacterial disease NSPF	ToMV TMV	
	University of Wisconsin	Bacterial speck		
	USDA/ARS		CMV Others	
Potatoes	Asgrow Seed Company[e]		PVY	Field trials in 1997 of varieties resistant to Colorado potato beetle and PVY.
	Boyce Thompson Institute	*Phytophthora*		Field trials in 1996-1997.
	Calgene		PLRV	Field testing in 1992 of potatoes with dual resistance to the Colorado potato beetle and PLRV.
	Cornell University		PVY	Field trials in 1997

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Table 4 (Continued)
TRANSGENIC DISEASE-RESISTANT CROP PLANTS ON THE MARKET OR UNDER DEVELOPMENT IN THE UNITED STATES

Crop	Company/Institution	Disease or Causal Organism: Bacterial and Fungal Diseases	Disease or Causal Organism: Viral Diseases[a]	Remarks
Potatoes (Continued)	Frito-Lay	Bacterial soft rot *Rhizoctonia* *Verticillium dahliae* *Phytophthora* Soft rot/*Rhizoctonia*/PVX	PLRV PVY PLRV/BYDV PVX/PVY	Since 1992, field testing of potato varieties with single, dual, or multiple resistance traits, including varieties with resistance to Colorado potato beetle and PLRV
	Michigan State University		PVY	Field trials in 1997
	Monsanto	*Phytophthora*	PVY PLRV PVY/PLRV PVX/PVY	Plans by Monsanto's NatureMark™ subsidiary to commercialize NewLeaf® Plus potato varieties with stacked resistance to PLRV and PVY as well as the Colorado potato beetle in 1998. Field trials of late blight resistant potatoes in 1997. Additional Monsanto trials of potatoes with stacked herbicide tolerance, insect resistance, virus resistance, and enhanced product quality.

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Table 4 (Continued)
TRANSGENIC DISEASE-RESISTANT CROP PLANTS ON THE MARKET OR UNDER DEVELOPMENT IN THE UNITED STATES

Crop	Company/Institution	Disease or Causal Organism: Bacterial and Fungal Diseases	Disease or Causal Organism: Viral Diseases[a]	Remarks
Potatoes (Continued)	Montana State University	*Corynebacterium sepedonicum/ Erwinia carotovora*		Field trials of potatoes resistant to bacterial pathogens in 1991-1992.
		Erwinia carotovora		
	Oregon State University		PVY	
	Purdue University	*Phytophthora*		
	University of Idaho		BYDV/BYMV/PVX/PVY PYDV/PLRV/PVX PLRV PLRV/PVY PLRV/PVY/TRV PLRV/PVY/TVMV PVY	Field trials since 1992 of potato varieties with resistance to multiple viruses.
	University of Illinois	*Phytophthora*		
	University of Wisconsin	Fungal disease NSPF		
	USDA/ARS	*Corynebacterium sepedonicum/ Erwinia carotovora* *Erwinia carotovora* *Phytophthora* Ring rot and bacterial soft rot	PLRV PVY	
	Washington State University	Bacterial diseases, general *Verticillium dahliae*		

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Table 4 (Continued)
TRANSGENIC DISEASE-RESISTANT CROP PLANTS ON THE MARKET OR UNDER DEVELOPMENT IN THE UNITED STATES

Crop	Company/Institution	Disease or Causal Organism: Bacterial and Fungal Diseases	Disease or Causal Organism: Viral Diseases[a]	Remarks
Field Crops				
Alfalfa	Noble Foundation	*Phytophthora/ Rhizoctonia solani*	*Vibrio cholera*	
	Pioneer Hi-Bred		AMV	
Corn	AgrEvo	Leaf blight		Field trials in 1997 of hybrids with both leaf blight resistance and herbicide tolerance (to glufosinate).
	Holden's Foundation Seeds Inc.[e]	Leaf blight *Anthracnose/ Cercospora/Helminthosporium* *Anthracnose/ Cercospora*/Eyespot/ *Helminthosporium*		Field trials in 1996-1997 of hybrids with resistance to leaf blight or multiple fungus diseases plus herbicide tolerance.
	Monsanto		BYDV	Field trials in 1997.
	Novartis Seeds Ciba-Geigy	Frogeye leaf spot *Helminthosporium* Fungus NSPF		Field trials in 1994-1996.
	Northrup King	Eyespot Northern corn leaf blight	MDMV	Field trials of corn varieties with MDMV resistance, herbicide tolerance, and/or Lepidopteran insect resistance.

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Table 4 (Continued)
TRANSGENIC DISEASE-RESISTANT CROP PLANTS ON THE MARKET OR UNDER DEVELOPMENT IN THE UNITED STATES

Crop	Company/Institution	Disease or Causal Organism: Bacterial and Fungal Diseases	Disease or Causal Organism: Viral Diseases[a]	Remarks
Field Crops (Continued)				
Corn (Continued)	Pioneer Hi-Bred	Ear mold Gray leafspot Earmold/Gray leafspot Fusarium/Gray leafspot Smut Postharvest fungal diseases	CMV/TMV MCDV MCDV/MCMV MCDV/MCMV/MDMV MCMV MDMV	Trials of corn hybrids with both herbicide tolerance and virus resistance.
Peanut	Agracetus[e]		TSWV	
	University of Florida		TSWV	Field trials in 1993 of peanuts with herbicide tolerance and TSWV resistance.
	University of Georgia		PStV TSWV	
Rapeseed	Cargill Hybrid Seeds	Postharvest fungal diseases		Field trials in 1997.
Rice	Louisiana Stare University	*Rhizoctonia solani*		
	University of California - Davis	Bacterial leaf blight		Field trials in 1997.
Soybean	Pioneer Hi-Bred		SbMV	
	University of Kentucky		BPMV Others	

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Table 4 (Continued)
TRANSGENIC DISEASE-RESISTANT CROP PLANTS ON THE MARKET OR UNDER DEVELOPMENT IN THE UNITED STATES

Crop	Company/Institution	Disease or Causal Organism: Bacterial and Fungal Diseases	Disease or Causal Organism: Viral Diseases[a]	Remarks
Field Crops (Continued)				
Sunflower	Pioneer Hi-Bred	*Sclerotinia*	NSPF	Field trials in 1997.
	VanderHave[f]	Fungal disease NSPF		Field trials of varieties with fungus resistance and altered seed quality.
Sugar Beet	Betaseed		BNYVV	BNYVV is the causal agent of Rhizomania.
Sugar Cane	Texas A&M University		SrMV	
Tobacco	Bayer	*Botrytis cinerea*		Field trials in 1993.
	Novartis	*Phytophthora*		Field trials by Ciba-Geigy in 1993.
	DNA Plant Technology	*Phytophthora/ Rhizoctonia* *Rhizoctonia /Thelaviopsis*		Field trials in 1991-1992.
	DuPont	Fungal diseases, general		

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Table 4 (Continued)
TRANSGENIC DISEASE-RESISTANT CROP PLANTS ON THE MARKET OR UNDER DEVELOPMENT IN THE UNITED STATES

Crop	Company/Institution	Disease or Causal Organism: Bacterial and Fungal Diseases	Disease or Causal Organism: Viral Diseases[a]	Remarks
Field Crops (Continued)				
Tobacco (Continued)	Monsanto		TGMV TMV	
	Mycogen Seeds		AMV	Field trials in 1988 by Agrigenetics, now Mycogen Seeds.
	Noble Foundation	Frogeye leaf spot		
	North Carolina State University		PVY TEV TSWV	
	University of Arizona		BCTV	
	University of Florida		PVY TEV	
	University of Georgia		TSWV	
	University of Kentucky	Black shank Black shank/Tobacco etch virus	TEV TVMV AMV/PVY TEV/ TVMV TSWV PVY/TEV/TVMV	

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Table 4 (Continued)
TRANSGENIC DISEASE-RESISTANT CROP PLANTS ON THE MARKET OR UNDER DEVELOPMENT IN THE UNITED STATES

Crop	Company/Institution	Disease or Causal Organism: Bacterial and Fungal Diseases	Disease or Causal Organism: Viral Diseases[a]	Remarks
Field Crops (Continued)				
Tobacco (Continued)	USDA/ARS		BCTV PLRV/TSWV	Field trials of tobacco resistant BCTV in 1991. PLRV resistant and TSWV resistant tobacco field trials in 1997.
	U.S. EPA	Frogeye leaf spot		
Wheat	Monsanto	Fungal disease(s), general	WSMV	Development by Monsanto of wheat with both fungus resistance and glyphosate tolerance.
	University of Idaho		BYDV WSMV BYDV/WSMV	Field trials in 1996 and 1997.

[a] Plant virus acronyms:

AMV	Alfalfa mosaic virus	PVY	Potato virus Y
BCTV	Beet curly top virus	PVX	Potato virus X
BNYVV	Beet necrotic yellow vein virus	SqMV	Squash mosaic virus
BPMV	Bean pod mottle virus	SbMV	Soybean mosaic virus
BYDV	Barley yellow dwarf virus	SrMV	Sorghum mosaic virus
CaMV	Cauliflower mosaic virus	TEV	Tobacco etch virus
CMV	Cucumber mosaic virus	TGMV	Tomato golden mosaic virus
LMV	Lettuce mosaic virus	ToMV	Tomato mosaic virus

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MCDV	Maize chlorotic dwarf virus	TMV	Tobacco mosaic virus
MCMV	Maize chlorotic mottle virus	TRV	Tobacco rattle virus
MDMV	Maize dwarf mosaic virus	TSWV	Tomato spotted wilt virus
PLRV	Potato leafroll virus	TVMV	Tobacco vein mottling virus
PPV	Plum pox virus	TYLCV	Tomato yellow leaf curl virus
PRV	Prunus ringspot virus	WMV2	Watermelon mosaic virus 2
PRSV	Papaya ringspot virus	WSMV	Wheat streak mosaic virus
PSIV	Peanut stunt virus	ZYMV	Zucchini yellow mosaic virus

[b]Subsidiary of Seminis Vegetable Seeds Inc.

[c]Now part of Novartis Seeds.

[d]Acquired by Groupe Limagrain (France) in 1996 and merged with Ferry Morse Seed Company July 1, 1997.

[e]Now owned by Monsanto.

[f]Subsidiary of Advanta, a joint venture of Zeneca U.K. and Cosun in the Netherlands.

Sources: Biotechnology Permits Data Base, USDA; communication with industry; trade literature

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Applied Disease Control Products

Biological Fungicides

Since 1995, several new biological fungicides have been launched in U.S. agricultural crop markets, and others are under development. Table 5 lists these products, provides information about their the target diseases and target crop markets, and identifies the developing companies.

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Table 5
NEW BIOLOGICAL FUNGICIDES RECENTLY LAUNCHED
OR UNDER DEVELOPMENTFOR U.S. AGRICULTURAL CROPS

Organism/Product	Target Pathogen(s)/ Disease(s)	Crop Market	Developing Company	Status/Remarks
Bacteria				
Bacillus cereus (UW 85)	*Pythium* *Phytophthora*	Cereals Others	Lipha Tech	A biological seed treatment fungicide; in registration trials. The University of Wisconsin is conducting field screening of "ZWI Hermicin A," based on this organism for control and suppression of damping off diseases caused by *Phytophthora medicaginis.*
Bacillus subtilis GBO3 System 3	Seedling pathogens	Barley Beans Cotton Peanuts Peas Rice Soybeans	Helena Chemical Company	A dust formulation of *B. subtilis* with chemical pesticides sold for seed treatment in planter boxes.
Bacillus subtilis MB 600 ATCC-SD + 414 (GUS-376)	*Rhizoctonia solani* *Fusarium* spp.	Vegetables	Gustafson Inc.	A biological seed treatment fungicide; in registration trials.
Bacillus subtilis (Kodiak®)	*Rhizoctonia solani* *Fusarium* spp. *Alternaria* spp. *Aspergillus* spp.	Cotton Legumes	Gustafson Inc.	Usually applied with chemical fungicides in seed treatments or as hopper box treatment. Marketed as Epic® for commercial seed treatment.

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Table 5 (Continued)
NEW BIOLOGICAL FUNGICIDES RECENTLY LAUNCHED
OR UNDER DEVELOPMENTFOR U.S. AGRICULTURAL CROPS

Organism/Product	Target Disease(s)	Crop Market	Developing Company	Status/Remarks
Bacteria (Continued)				
Burkholderia cepacia *(Pseudomonas cepacia)* type Wisconsin (Deny®)	*Rhizoctonia* *Pythium* *Fusarium* Diseases caused by nematodes	Alfalfa Barley Beans Clover Cotton Fruits Nuts Vine crops Peas Potatoes Sorghum Vegetables Wheat	CCT Corporation	A peat-based formulation is sold for seed or hopper box treatment. A liquid formulation is sold for transplant treatment and for soil application in irrigation water. Other target markets include herbs, spices, ornamental and greenhouse crops, and turfgrass..
Pantoea agglomerans (Blight Ban™ C9-1)	Fire blight	Apples Pears	Plant Health Technologies	Company is a division of J.R. Simplot Co., Boise, ID.
Pseudomonas cepacia (Intercept®)	Damping off Nematodes	Vine crops Other fruits Potatoes Vegetables Field Crops	Soil Technologies Corp.	Commercial product. Formulated as a liquid inoculant for application in the furrow and as a peat-based seed treatment. Other target markets are greenhouse crops, ornamentals, flowers, bulbs, herbs, and spices.

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Table 5 (Continued)
NEW BIOLOGICAL FUNGICIDES RECENTLY LAUNCHED OR UNDER DEVELOPMENTFOR U.S. AGRICULTURAL CROPS

Organism/Product	Target Disease(s)	Crop Market	Developing Company	Status/Remarks
Bacteria (Continued)				
Pseudomonas flourescens A 506 (Blight Ban™ A506)	*Erwinia amylovora* Frost	Almonds Apples Cherries Peaches Pears Potatoes Strawberries Tomatoes	Plant Health Technologies	Launched in the United States in 1996. The company is a division of J.R. Simplot Co., Boise, ID.
Pseudomonas syringae pv *syringae*	Bacterial brown spot	Green beans	University of Wisconsin	A genetically modified organism undergoing field screening.
Rhizobium and *Sinorhizobium*	Soil diseases caused by bacteria	Alfalfa Beans Clover	University of Wisconsin	Genetically engineered nitrogen-fixing bacteria.
Streptomyces griseoviridis Strain K61 (Mycostop®)	Fusarium spp. Alternaria brassicola Phomopsis spp. Botrytis spp. Pythium spp. Phytophthora spp.	Cucumbers Other vegetables	Kemira Agro Oy (Finland)	Target pathogens cause seed, root, and stem rot and wilt diseases. Also marketed for greenhouse crops and ornamentals.

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Table 5 (Continued)
NEW BIOLOGICAL FUNGICIDES RECENTLY LAUNCHED
OR UNDER DEVELOPMENTFOR U.S. AGRICULTURAL CROPS

Organism/Product	Target Disease(s)	Crop Market	Developing Company	Status/Remarks
Bacteria (Continued)				
Streptomyce lydicus		Tomatoes Peppers Peas Lentils	Plant Health Technologies	This bacterium is patented by the Idaho Research Foundation, Inc., which has issued licenses to J.R. Simplot Co. and Natural Industries, Inc., Houston, TX. Simplot's Plant Health Technologies division is conducting small firld tests and has applied to the EPA for a registration. A marketable product may result by 1999.
Xanthomonas campestris, var. *vesicatoria*	Bacterial spot	Tomatoes Peppers	Agri Phi Inc.	Public Testing. Company is located in Logan, UT.
Fungi				
Gliocladium catenulatum Strain J 1446 (Primastop®)	*Pythium* spp. *Rhizoctoni* spp.*a* *Damping off* *Seed rot* *Root and stem rot* *Wilt diseases*	Vegetables	Kemira Agro Oy (Finland)	An EPA registration has been applied for. Other target markets are herbs, spices, ornamentals, turf, and home gardens.
Trichoderma spp., T-39 strain (ABG-8007)	*Botrytis cinerea*	Grapes Vegetables	Abbott Laboratories	EUP approved by EPA for 1997; registration trials. Also under development for ornamentals.

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Table 5 (Concluded)
NEW BIOLOGICAL FUNGICIDES RECENTLY LAUNCHED OR UNDER DEVELOPMENTFOR U.S. AGRICULTURAL CROPS

Organism/Product	Target Disease(s)	Crop Market	Developing Company	Status/Remarks
Fungi (Continued)				
Trichoderma harzianum, Strain T22 (T-22)	*Pythium* spp. *Rhizoctonia solani* *Fusarium* spp. *Sclerotinia homeocarpa*	Beans Cabbage Corn Cotton Cucumbers Peanuts Potatoes Sorghum Soybeans Sugar beets Tomatoes	BioWorks Inc.	Patented strain of *T. harzianum*. Product was launched in 1996. Also registered for turf and greenhouse ornamentals. Formulations for agricultural crops are available for in-furrow application and for seed treatment in planter boxes (T-22 Planter Box).
Yeast				
Ampelomyces quisqualis Isolate M-IO (AQ 10)	Powdery mildew	Apples Cucurbits Grapes Tomatoes Strawberries	Ecogen	Launched in the United States in 1996. Also registered for use on ornamentals.
Other				
Carbohydrate Compounds, Naturally-Derived (Elexa®, AGI-02105 F)	*Downy mildew* *Powdery mildew* *Botrytis cinerea* *Colletotrichum* spp. *Phytophthora infestans* *Pythium* spp. Others	Grapes Potatoes Rice Vegetables Others	IGG International	Data for registration have been submitted to EPA.. A nontoxic compound that stimulates a plant's internal immune system to make it less susceptible to diseases.

Source: Communication with industry and trade literature.

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New Chemistry

Table 6 lists new chemical fungicides that have been launched since 1995 or that are being developed for U.S. agricultural crop markets. Target diseases, target crop markets, and companies developing and/or marketing each new product are indicated in the table.

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Table 6
NEW CHEMICAL FUNGICIDES RECENTLY LAUNCHED
OR UNDER DEVELOPMENT FOR U.S. AGRICULTURAL CROPS

Product	Target Diseases/ Organisms	Target Crop Markets	Developing Company	Status/Remarks
Actigard® CGA-245704	Bacterial diseases Downy mildew Powdery mildew Rice blast Sigatoka Viral diseases	Bananas Cereals Cucurbits Rice Tobacco Tomatoes Others	Novartis	A plant activator that increases a plant's resistance to diseases. A benzothiadiazole derivative. This product will be commercialized first in Europe—as Bion®.
azoxystrobin (Abound®, Quadris®)	Downy mildew Early blight Late blight Powdery mildew Various others	Apples Cereals Grapes Peanuts Pecans Potatoes Rice Stone fruits Vegetables	Zeneca	Abound® was registered by EPA June 4, 1997 for use on grapes, peanuts, pecans, peaches, and bananas. Zeneca will seek additional crop registrations for Abound® over the next few years. Quadris® is being used under Section 18 emergency exemptions for rice in five states, and is expected to achieve registrations for tomatoes and wheat in 1997. Azoxystrobin was registered for use on turf as Heritage® in February 1997.
BL-1280	Broad spectrum	Vegetables	Buckman Laboratories	Registration trials. A benzothiazole compound. A contact fungicide that is also under development for ornamentals.
cymoxanil (Curzate®)	Late blight	Potatoes Tomatoes	DuPont	Used under Section 18 emergency exemptions since 1995.

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Table 6 (Continued)
NEW CHEMICAL FUNGICIDES RECENTLY LAUNCHED
OR UNDER DEVELOPMENT FOR U.S. AGRICULTURAL CROPS

Product	Target Diseases/ Organisms	Target Crop Markets	Developing Company	Status/Remarks
cyprodinil (Vangard®)	Scab Brown rot *Botrytis*	Almonds Grapes Pome fruits Stone fruits	Novartis	Vangard® P2 (cyprodinil/ propiconazole) is under development for stone fruit.
dimethomorph (Acrobat®)	Late blight Downy mildew Blue mold *Phytophthora* root and crown rot	Cucurbits Grapes Lettuce Peppers Potatoes Tobacco Tomatoes	American Cyanamid	A morpholine compound. Registration for potatoes is expected in 1997. Tomato and tobacco registrations are expected by 1989. Acrobat® MZ, a premix of dimethomorph (9%) + mancozeb 60%), is used for potatoes, tomatoes, and vegetables in several states under Section 18 emergency exemptions.
famoxadone (DPX-JE874)	*Active on ascmycetes, basidiomycetes, and phycomycetes.*	Cereals Fruits Oilseed rape Potatoes Sugar beets Vegetables Others	DuPont	An oxazolidinedione compound. Public testing.

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Table 6 (Continued)
NEW CHEMICAL FUNGICIDES RECENTLY LAUNCHED OR UNDER DEVELOPMENT FOR U.S. AGRICULTURAL CROPS

Product	Target Diseases/ Organisms	Target Crop Markets	Developing Company	Status/Remarks
fluazinam (Frowncide®)	Bacterial spot *Botrytis* Downy mildew *Monilinia* *Sclerotinia*	Apples Peaches Peanuts Lettuce Others	ISK Biosciences	Marketed in 1996 under an EUP. Initial U.S. crop registration is expected in 1997. Imported from Japan Zeneca markets fluazinam as Shirlan® outside the United States.
fludioxonil (Maxim®)	Silver scurf Black scurf Dry rot *Fusarium* *Rhizoctonia* Stem canker	Potato seed pieces	Novartis	Section 18 emergency exemptions in MN and WA; fykk EPA registration is expected in 1997.
flumetover (RPA-403397)	*Phytophthora* spp. *Pythium* sp. Grape downy mildew	Grapes Other fruits Potatoes Tomatoes Other fruits	Rhone-Poulenc	Registration trials. A toluamide compound with curative and preventative activity.
kresoxim-methyl (Candit®, Suvran®, BAS-490F)	Powdery mildew Downy mildew Scab	Apples Cereals Grapes Lettuce Other vegetables Pears	BASF	Derived from strobilurine, a fungal secondary metabolite. Registration for pome fruits and grapes is expected in 1999.

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Table 6 (Concluded)
NEW CHEMICAL FUNGICIDES RECENTLY LAUNCHED OR UNDER DEVELOPMENT FOR U.S. AGRICULTURAL CROPS

Product	Target Diseases/ Organisms	Target Crop Markets	Developing Company	Status/Remarks
potassium bicarbonate (Armicarb®)	Powdery mildew	Citrus	Church & Dwight Co., Inc.	Product registered in December 1994. Initial target market is greenhouse flowers and ornamentals. Field tests in 1995 for Florida citrus.
potassium bicarbonate (Kaligreen®)	Powdery mildew	Grapes Strawberries Tobacco Vegetables	Taogosei Co.	Company has applied to EPA for registration. Also under development for roses.
propamocarb hydrochloride (Tattoo®)	Late blight *Pythium*	Potatoes Tomatoes Sugar beets	AgrEvo	Used in 1995, 1996, and 1997 for control of late blight in potatoes and tomatoes under Section 18 emergency exemptions. Tattoo® C (propamocarb hydrochloride+ chlorothalonil) is also being used under Section 18 exemptions.
RH-7281	*Pythium* *Plasmopara* *Phytophthora*	Grapes Vegetables Others	Rohm and Haas	Field screening.
TM-402	*Botrytis* *Monilinia*	Berries Grapes Stone fruits Vegetables	Tomen Agro	A nonsystemic fungicide discovered by Bayer. Tomen Agro will market it for agricultural crops and ornamentals in the United States and Canada.

Sources: Communications with industry and trade literature.

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Future Trends

U.S. crop markets for fungicides are mature, and little overall change in fungicide use, in terms of treatment acres, is expected through 2000. However, replacement of older contact fungicides will continue in major tree and vine crop markets by new systemic fungicides, which are applied at much lower rates than the older contact products.

After 2000, biotechnology will begin to have an impact, initially in the potatoes and small grains sectors. Transgenic late-blight-resistant potatoes and fungus-resistant wheat varieties are expected to be introduced in the 2000-2005 period.

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FRUITS AND NUTS

As indicated in Table 3 in the Overview section, an estimated 87% of U.S. fruit and nut crop acreage received an average of 5 fungicide applications in 1995, and fungicide use totaled 18.0 million treatment acres. Fruit and nut growers' collective expenditures for fungicides amounted to $240 million, or about 37% of the total U.S. agricultural fungicides market. Figure 4 shows the relative sizes of individual fruit and nut crop markets, based on both treatment acres and grower expenditures.

Figure 4
U.S. FRUIT AND NUT CROP MARKETS FOR FUNGICIDES, 1995

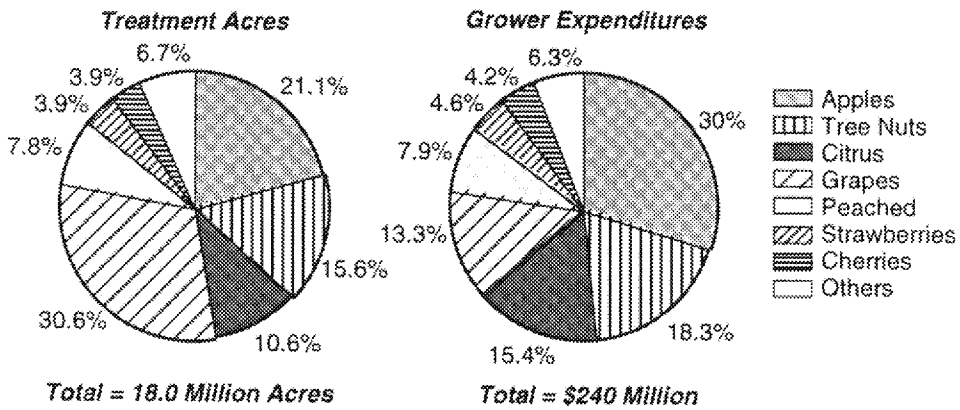

Table 7 provides a breakdown of U.S. fruit and nut growers' 1995 expenditures for fungicides by crop sector. The four largest sectors—apples, tree nuts, citrus, and grapes—together accounted for 77% of the total.

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Table 7
END-USER VALUE OF U.S. FRUIT AND NUT CROP MARKETS FOR FUNGICIDES, 1995

	Millions of Dollars
Apples	72
Tree Nuts[a]	44
Citrus	37
Grapes	32
Peaches	19
Strawberries	11
Cherries	10
Other Stone Fruits[b]	7
Pears	4
Other Fruits[c]	4
Total	240

[a] Almonds, hazelnuts, pecans, pistachios, and walnuts.

[b] Apricots, nectarines, plums, and prunes.

[c] Avocados, blueberries, bushberries, dates, and olives.

Source: SRIC estimates.

Apples and Pears

In 1995, U.S. apple growers' spent an estimated $72 million for fungicides. The products they purchased were applied on an estimated 90% of the country's 460,500 acres of apple orchards. On average, each treated acre received 9.2 fungicide applications.

Apples grown in the East and Midwest are affected by a wider range of diseases than apples grown in western states (see Table 8). In the East and Midwest, fungicide applications are required to control apple scab, various rust diseases, and "summer diseases" such as blotch, sooty blotch, flyspeck, bitter rot, Brook's fruit spot, black rot, and white rot. Fire blight is a major bacterial disease that also requires treatment.

Powdery mildew and apple scab are the targets of most fungicide treatments of apples grown in Washington, Oregon, and California. Fire blight requires treatment on an estimated 10-15% of the western apple acreage.

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Table 8
MAJOR APPLE DISEASES

Disease	Causal Organism
East and Midwest	
Apple scab	*Venturia inaequalis*
Bitter rot	*Glomerella cingulata*
Black rot	*Physalospora obtusa*
Blotch	*Phyllosticta solitaria*
Brook's fruit spot	*Mycosphaerella pomi*
Fire blight	*Erwinia amylovora*
Flyspeck	*Zygophiala jamaicansis*
Rust	*Gymnosporangium* spp.
Sooty blotch	*Gloeodes pomigena*
West	
Apple scab	*Venturia inaequalis*
Fire blight	*Erwinia amylovora,*
Powdery mildew	*Podosphaera leucotricha*

Source: University pest management guidelines

U.S. pear crop acreage totaled 70,600 acres in 1995, and pear growers spent an estimated $4 million for fungicides and bactericides in that year. An estimated 90% of the total pear acreage was treated, 8.2 times, on average.

Fire blight, pear scab, *Pseudomonas* blossom blast, and powdery mildew are the major disease problems of U.S. pears (see Table 9). Fire blight is the most widely treated pear disease; an estimated 90% or more of the country's commercial pear acreage receives multiple treatments annually with an antibiotic product (streptomycin and/or oxytetracycline) to control fire blight. Sulfur, copper compounds, mancozeb, ziram, and Benlate® are the principal fungicide products used to control fungal diseases on pears.

Table 9
MAJOR PEAR DISEASES

Disease	Causal Organism
Pear scab	*Venturia pirina*
Pseudomonas blossom blast	*Pseudomonas syringae*
Powdery mildew	*Podosphaera leuchotricha*
Fire blight	*Erwinia amylovora*

Source: University pest management guidelines

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During the 1993-1995 period, Cornell University conducted field trials of fire blight resistant apples in New York. Two new biological fungicides were registered for use on pome fruits in 1996. One is a bacterial product based on *Pseudomonas fluorescens* A 506 (BlightBan™ 506), from Plant Health Technology, and the other is based on a yeast, *Ampelomyces quisqualis*, marketed by Ecogen as AQ 10. BlightBan™ 506 is registered for both apples and pears; AQ 10 is labeled for apples only.

New chemical fungicides under development for pome fruits are cyprodinil (Vangard®) from Novartis and kresoxim-methyl from BASF. Zeneca's azoxystrobin (Abound®) and ISK Bioscience's fluazinam (Frowncide®) are also being developed for apples.

Tree Nuts

The tree nuts segment was valued at an estimated $44 million in 1995. An estimated 80% of the nearly 1.1 million acres of tree nuts planted in the United States (including pecans, almonds, walnuts, pistachios, and hazelnuts) received fungicide treatment, and each treated acre received an average of 3.3 fungicide applications. Pecans and almonds, the two most widely planted tree nut crops, are the two largest segments of the tree nut fungicide market; they accounted for 46% and 40%, respectively, of tree nut treatment acres in 1995. Walnuts accounted for about 11% of treatments.

Pecan diseases requiring fungicide treatment include scab (*Fusicladium* spp.), downy spot (*Mycosphaera* spp.), brown leaf spot (*Cercospora* spp.), and powdery mildew (*Microsphaera* spp.). Various copper compounds, benomyl (Benlate®), fenbuconazole (Enable®), thiophanate-methyl (Topsin®-M), triphenyltin hydroxide (Super Tin®), ziram, propiconazole (Orbit®), dodine (Syllit®), and sulfur are the principal fungicides used for pecans.

Brown rot blossom blight caused by *Monilinia laxa* and shot hole disease caused by *Stigmina carpophila* are the two major disease problems of almonds. The two most widely used fungicides for almonds are iprodione (Rovral®) and ziram. Copper hydroxide, basic copper sulfate, other copper fungicides, myclobutanil, thiophanate-methyl, benomyl, and captan are other important fungicides used for almonds.

Walnut blight, a bacterial disease caused by *Xanthomonas campestris*, is the only major walnut disease for which chemicals are an integral part of the management program. Copper fungicides are the only products available for use against walnut blight. Copper hydroxide is the most widely applied copper product.

In 1995, the University of California at Davis obtained a permit to conduct field trials of transgenic walnut varieties with both virus resistance and Coleopteran insect resistance traits. Novartis' propiconazole (Break®) is expected to be registered for control of Brown rot blossom blight and Anthracnose on California almonds in time for the 1998 growing season. Another Novartis fungicide, cyprodinil (Vangard®), is also under development for almonds. Zeneca's azoxystrobin (Abound®) was registered for use on pecans in June 1997.

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Citrus

The U.S. citrus market for fungicides was valued at an estimated $37 million in 1995. Of the country's nearly 1.1 million acres of citrus fruits, 94% received at least 1 fungicide treatment, and on average 1.9 applications were made per treated acre. Florida, with 69% of the country's total bearing citrus acreage, accounted for 80% of fungicide treatments.

Table 10 lists the major citrus disease problems. The two most widely treated diseases of Florida and Texas citrus are greasy spot and melanose. Brown rot is the target of most of the fungicide treatments applied for citrus in California and Arizona.

Table 10
MAJOR CITRUS DISEASES

Disease	Causal Organism
Alternaria Brown Spot	*Alternaria citri.*
Brown Rot	*Phytophthora* spp.
Citrus Scab	*Elsinöe fawcetti*
Greasy spot	*Mycosphaerella citri*
Melanose	*Diaporthe citri*
Phytophthora Root Rot/Gummosis	*Phytophthora* spp.
Septoria Spot	*Septoria* spp.

Source: University pest management guidelines

On the basis of grower expenditures, Metalaxyl (Ridomil®) and fosetyl-AL (Aliette®) are the leading fungicides in the U.S. citrus market. However, inorganic fungicides—both copper compounds and sulfur—accounted for more than 85% of the total volume of fungicide active ingredients that were applied in 1995. Copper compounds account for most of the fungicide treatments applied for California citrus.

In 1995, fenbuconazole (Indar®), fluazinam (Zeneca's Shirlan® 500), difenaconazole (Score®), and myclobutanil (Systhane®) were evaluated for disease control in Florida citrus. Of these products, Systhane® and Score® were the most effective against citrus scab and melanose. Church & Dwight Co.'s potassium carbonate based product, Armicarb®, has been evaluated in field trials for control of citrus scab and Alternaria brown spot in Florida citrus.

Grapes

U.S. grape acreage totaled 754,200 acres in 1995, with California accounting for 86% of that acreage. The Northeast and North Central regions together accounted for about 8% of the total grape acreage, and Washington and Oregon together accounted for 5%.

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U.S. grape growers spent an estimated $32 million for fungicides in 1995. An estimated 93% of the total grape acreage received at least one fungicide application, and on average, 7.9 applications were made per treated acre. California accounted for 92% of the total treatments

Powdery mildew (*Uncinula necator*), *Botrytis* bunch rot (*Botrytis cinerea*), black rot (*Guignardia bidwelli*), and downy mildew (*Plasmopara viticola*)are considered major grape diseases. Powdery mildew is by far the most widespread and costly problem. In California, more than 90% of the total acreage annually receives multiple fungicide applications for powdery mildew control.

Bunch rot affects about 25% of California's grape acreage and is a problem of wine grapes planted in Oregon, New York, Pennsylvania, and to a lesser extent, in Michigan and Washington as well. Eutypa dieback (*Eutypa lata*) and Spanish measles are considered major disease problems in some California's grape growing regions. Eutypa dieback has also been a problem of grapes in Pennsylvania, and Michigan. Black rot and downy mildew are problems of grapes in New York, Pennsylvania, and Michigan, but do not commonly affect grapes grown in the West.

California grape growers make multiple applications of sulfur to prevent losses due to powdery mildew. Typically, the initial application of the season is made after bud break. Thereafter, additional applications are made every 14 days until the fruit begins to ripen. In the mid-1980s, systemic fungicides began to be used as alternatives to sulfur for powdery mildew control. The first new systemic fungicide used in California was triadimefon (Bayleton®). Currently, myclobutanil (Rally®) and fenarimol (Rubigan®) are also used. Additional powdery mildew control products that have been used experimentally for grapes include propiconazole (Tilt®), diniconazole (Spotless®), triflumizole (Procure®), and flusilazole (Nustar®).

Benomyl (Benlate®), captan, iprodione (Rovral®), and DCNA (Botran®) are used to control *Botrytis* bunch rot. Dithiocarbamate fungicides—mancozeb, maneb, and ferbam—are used to control black rot in grapes, and mancozeb and maneb are also used to control bunch rot and downy mildew. Mancozeb is also used against Phomopsis cane and leafspot (*Phomopsis viticola*), which can be a problem in Northern California grape growing regions. Captan is also recommended for control of this disease problem.

A small biotechnology company, Gen Apps, Inc. (Patterson, WA), is conducting field trials of virus-resistant grape vines in 1997. Several new biological fungicides have recently been or are under development for use on grapes in the United States. They include a fungal product based on *Trichoderma spp.* from Abbott Laboratories (ABG-8007), Ecogen's yeast based fungicide, AQ10, and Soil Technologies' *Pseudomonas cepacia*-based product, Intercept®. IGG International is developing a new carbohydrate based biofungicide, Elexa® (AGI-02105 F) for powdery mildew control on grapes.

New chemical fungicides for grapes include Novartis' cyprodinil (Vangard®), dimethomorph (Acrobat®) from American Cyanamid, flumetover (RPA-403397) from Rhône Poulenc, kresoxim-methyl from BASF, potassium bicarbonate from Taogosei Co., RH 7281 from Rohm and Haas, and TM-402 from Tomen Agro.

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Stone Fruits

U.S. stone fruit acreage totaled 446,600 acres in 1995, including 172,700 aces of peaches, 127,200 acres of plums and prunes, 93,000 acres of cherries, 32,400 acres of nectarines, and 21,300 acres of apricots.

Peach growers spent an estimated $19 million for fungicides in 1995. Collectively, they treated 96% of their total acreage an average of 8.4 times. Cherry growers, who spent approximately $10 million for fungicides treated 95% of their total acreage an average of 8.2 times.

Plums and prunes, nectarines, and apricots, all of which are grown mainly in California, are treated less intensively with fungicides than peaches and cherries. Of the total U.S. plum and prune acreage, 82% received at least 1 fungicide treatment in 1995, and on average 1.7 applications were made per treated acre. For nectarines, 97% of the total acreage was treated an average of 4.5 times, and 98% of the total apricot acreage received an average of 3.5 applications. Growers of these four stone fruits collectively spent an estimated $7 million for fungicides in 1995.

Brown rot blossom and twig blight caused by *Monilinia* spp. is the most destructive fungal diseases of stone fruit. Other important stone fruit disease problems are powdery mildew (*Sphaerotheca pannosa*), shot hole (*Stigmina carpophila*), and peach leaf curl (*Taphrina deformans*).

Sulfur, fenbuconazole (Indar®), iprodione (Rovral®), triforine (Funginex®), captan, myclobutanil (Rally®, Nova®), copper compounds, benomyl (Benlate®), chlorothalonil (Bravo®), thiophanate-methyl (Topsin®-M),and ziram were the most widely used fungicides for stone fruits in 1995. Propiconazole (Orbit®) has been registered for control of brown rot on stone fruit in the Southeast for several years, and in late 1996, was approved by California's Department of Pesticide Registration. In California, propiconazole from Novartis is marketed under the trade name Break® for control of brown rot blossom blight control in peaches nectarines, apricots, plums, and prunes, and for control of fruit brown rot in all of these stone fruits, except prunes

The USDA's Agricultural Research Service field tested virus-resistant plum trees in 1992-1995. Zeneca's azoxystrobin (Abound®) was registered for use on peaches in June 1997 and is under development for use on other stone fruits. Other new chemical fungicides that are targeted for the U.S. stone fruits market include Novartis' cyprodinil (Vangard®), ISK Biosciences' fluazinam, and Tomen Agro's TM-402.

Strawberries

Strawberries were planted on nearly 50,000 acres in 1995. California accounted for 48% of the total plantings and Florida for 12%. An estimated 90% of the total U.S. crop acreage was treated with fungicides, and on average 15 applications were made per treated acre. All of the strawberry acreage in California and Florida received fungicide treatments. California growers made an average of 14 applications, whereas Florida growers applied an average of 30.6 treatments. Nationwide, strawberry growers' expenditures for fungicides totaled about $11 million.

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Botrytis fruit rot (*Botrytis cinerea*) and powdery mildew (*Sphaerotheca macularis*) are the two most widely treated strawberry disease problems.

Captan, sulfur, thiram, and iprodione (Rovral®) were the most widely used fungicides for strawberries nationwide, and for California strawberries, they collectively accounted for 70% of the total fungicide treatments. Myclobutanil (Rally®, Nova®) accounted for nearly 11% of the California strawberry fungicide treatments, and benomyl (Benlate®) accounted for about 8%.

New disease control technologies under development for strawberries include transgenic disease-resistant plants, biological fungicides, and new chemical fungicides. Calgene is developing strawberry plants with both fungus resistance and altered fruit ripening traits, and DNA Plant Technology is developing strawberry plants with multiple resistance to *Botrytis, Sclerotinia,* and *Verticillium.* The USDA has also conducted field trials of strawberries with multiple fungal disease resistance.

Blight Ban™ A506, based on *Pseudomonas flourescens,* and AQ 10 (*Ampelomyces quisqualis*) are two new biological fungicides registered for use on strawberries in 1996.

A potassium bicarbonate based fungicide, Kaligreen®, from Taogosei Co. (Japan) is under development for powdery mildew control in strawberries and other crops. An EPA registration for the product has been applied for.

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VEGETABLES

In 1995, an estimated 54% of the country's 3.68 million acres of commercial vegetable crops received at least 1 fungicide treatment, and overall an average of 6.2 applications were made per treated acre. Total fungicide use for U.S. vegetable crops amounted to more than 12.3 million treatment acres. Vegetable growers' expenditures for fungicides totaled an estimated $147 million. Tomatoes, lettuce, and cucurbits (cucumbers, muskmelons, and watermelons) collectively accounted for 57% of the total vegetable crop fungicide treatments and for 63% of vegetable growers' expenditures for fungicides (see Figure 5).

Figure 5
U.S. VEGETABLE CROP MARKETS FOR FUNGICIDES, 1995

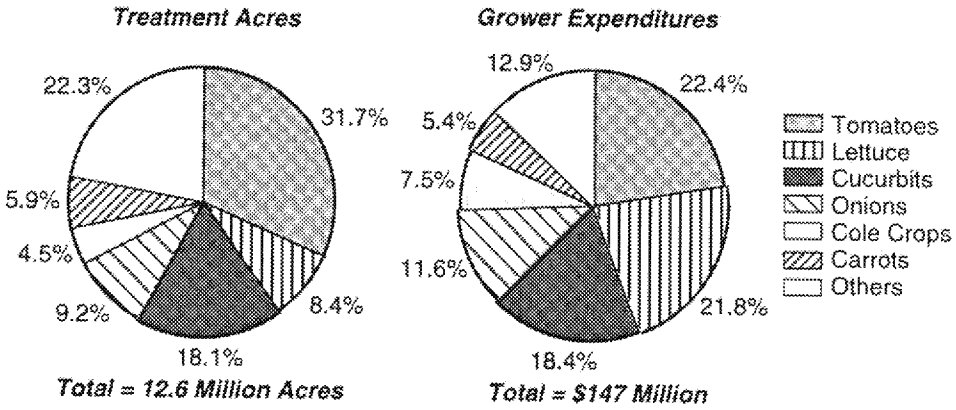

Table 11 ranks U.S. vegetable crop markets according to their estimated end-user value in 1995.

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Table 11
END-USER VALUE OF U.S. VEGETABLE CROP MARKETS FOR FUNGICIDES, 1995

	Millions of Dollars
Tomatoes	33
Lettuce	32
Cucurbits	27
Onions	17
Cole Crops	11
Carrots	8
Snap Beans	5
Bell Peppers	4
Sweet Corn	4
Celery	3
Others	3
Total	147

Source: SRIC estimates.

Disease control programs for vegetable crops employ a combination of chemical and nonchemical approaches. For some crops, varieties with resistance to certain fungal and viral pathogens are available. Seed bed fumigation to control various soil-borne pathogens is important in the production of transplants for certain vegetable crops. Fungicides are used for seed treatments as well as for soil treatments and foliar applications.

Table 12 lists major foliar and soil-borne diseases of U.S. vegetable crops and the organisms that cause them. For each crop, the diseases listed are those that are the principal targets of fungicide treatments.

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Table 12
MAJOR FOLIAR AND SOIL-BORNE DISEASES OF VEGETABLE CROPS

Crop	Disease	Causal Organism
Beans, Snap	Alternaria leaf spot	*Alternaria* spp.
	Anthracnose	*Colletotrichum lindemuthianum*
	Bacterial diseases	*Pseudomonas Syringae*
	Rust	*Uromyces phaseoli* var. *typica*
	White mold	*Sclerotinia* spp.
Carrots	Alternaria leaf blight	*Alternaria dauci*
	Cercospora leaf blight	*Cercospora carotae*
	Powdery mildew	*Erysiphe polygoni*
	Pythium diseases	*Pythium* spp.
	Sclerotinia diseases	*Sclerotinia* spp.
Celery	Bacterial leaf spot	*Pseudomonas* spp.
	Early blight	*Cercospora apii*
	Late blight	*Septoria apiicola*
	Rhizoctonia diseases	*Rhizoctonia* spp.
Cole Crops[a]	Alternaria brown spot/ Leaf spot	*Alternaria* spp.
	Cercospora leaf spot	*Cercospora* spp.
	Club root	*Plasmodiaphora brassicae*
	Downy mildew	*Peronospora parasitica*
Corn, Sweet	Northern leaf blight	*Helminthosporium turcicum*
	Rust	*Puccinia* spp.
	Southern leaf blight	*H. maydis*
Cucurbits[b]	Alternaria leaf spot	*Alternaria* spp.
	Anthracnose	*Colletotrichum lagenarium*
	Bacterial diseases	*Pseudomonas* spp.
	Downy mildew	*Pseudoperonospora cubensis*
	Gummy stem blight	*Mycosphaerella citrullina/ Phyllosticta citrullina*
	Powdery mildew	*Erysiphe cichoracearum, Sphaerotheca fuliginea*
Lettuce	Downy mildew	*Bremia lactucae*
	Sclerotinia drop	*Sclerotinia* spp.
Onions	Botrytis diseases	*Botrytis cinerea*
	Downy mildew	*Peronospora destructor*
	Purple blotch	*Alternaria porri*

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Table 12 (Concluded)
MAJOR FOLIAR AND SOIL-BORNE DISEASES OF VEGETABLE CROPS

Crop	Disease	Causal Organism
Peppers, Bell	Bacterial Diseases	*Pseudomonas* spp.
	Bacterial spot	*Xanthomonas* spp.
	Frogeye spot	*Cercospora capsici*
	Phytophthora root and crown rot	*Phytophthora* spp.
Tomatoes	Anthracnose	*Colletotrichum* spp.
	Bacterial speck	*Pseudomonas syringae* pv *tomato*
	Bacterial spot	*Xanthomonas vesicatoria*
	Black mold	*Alternaria alternata*
	Botrytis gray mold	*Botrytis cinerea*
	Damping-off	*Phytophthora, Pythium, and Rhizoctonia* spp.
	Early blight	*Alternaria solani*
	Late blight	*Phytophthora infestans*
	Phytophthora root rot	*Phytophthora* spp.
	Powdery mildew	*Leveillula taurica*
	Target Spot	*Corynespora cassiicola*

[a] Cabbage, cauliflower, broccoli, and brussels sprouts.

[b] Cucumbers, muskmelons, and watermelons.

Source:

The dithiocarbamate fungicides, mancozeb and maneb, accounted for more than 50% of the volume of organic fungicides applied to vegetable crops in 1995. However, on the basis of grower expenditures, metalaxyl (Ridomil®), chlorothalonil (Bravo®), fosetyl-Al (Aliette®), and iprodione (Rovral®) had the largest shares of the vegetable crop fungicides market.

Tomatoes

Tomatoes represent the largest vegetable crop market for fungicides, given both treatment acres and grower expenditures. In 1995, 87% of the U.S. tomato crop acreage received at least 1 fungicide treatment, and on average 9.1 applications were made per treated acre (see Table 3 in the Overview section). Tomato growers spent an estimated $33 million for fungicides in 1995.

California and Florida are the two leading states in tomato production. California accounted for 74% of the total U.S. planted acreage in 1995, and Florida accounted for 10%. About 90% of California's 369,000 planted tomato crop acres were for processing

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and about 10% were for the fresh market. Fungicides were used on 84% the total tomato acreage, and each treated acre received an average of 3.5 applications.

Florida tomatoes are grown entirely for the fresh market and are treated much more intensively with fungicides. On average, 35 applications were made to 100% of Florida's 48,700 planted acres in 1995.

Major target diseases of fungicide treatments applied for tomatoes are listed in Table 12. Late blight, caused by *Phytophthora infestans*, has been an increasing problem in East Coast and California tomato fields in the last few years. On the basis of treatment acres, copper hydroxide was the leading fungicide used for tomatoes nationwide in 1995, followed by mancozeb, chlorothalonil, sulfur, and metalaxyl.

Six fungicides—sulfur, chlorothalonil, copper hydroxide, metalaxyl, mancozeb, and myclobutanil—accounted for 95% of the fungicide treatments for California's fresh market in 1995, as well as for 97% of the treatments for the state's processing tomatoes (see Table 13). Sulfur applications to California processing tomatoes are for control of tomato russet mites, as well as powdery mildew.

Table 13
LEADING FUNGICIDES USED FOR CALIFORNIA TOMATOES, 1995

	Treatment Acres (1,000)		
Fungicide	Fresh Market	Processing	Total
Sulfur	62.9	291.8	354.7
Chlorothalonil	70.8	152.8	223.6
Copper hydroxide	50.0	156.5	206.5
Metalaxyl	44.4	107.5	151.9
Mancozeb	36.0	39.0	75.0
Myclobutanil	27.5	17.8	45.3
All others	14.1	21.8	35.9
Total	305.7	787.2	1,092.9

Source: Pesticide Use Report, California Department of Pesticide Regulations

Copper hydroxide accounted for about 40% of the Florida tomato fungicides market in 1995, with mancozeb at about 34% and chlorothalonil at about 18%. Copper hydroxide and mancozeb are generally applied in combination to control bacterial spot; mancozeb also controls early blight. Chlorothalonil is primarily used to control target spot. Benomyl and metalaxyl accounted for most of the remaining fungicide treatments for Florida tomatoes. Benomyl is used to control *Botrytis* spp. and metalaxyl to control *Phytophthora* and *Pythium*.

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Significant changes have taken place in recent years in disease control practices for Florida tomatoes, largely because of increased problems with fungicide-resistant late blight. In 1996, three "Section 18" products became available to Florida growers for late blight control in both tomatoes and potatoes—cymoxanil (Curzate®) from DuPont and Griffin, dimethomorph (Acrobat®) from American Cyanamid, and propamocarb-hydrochloride (Tattoo®) from AgrEvo. These products are usually applied in tank mixes with either chlorothalonil or mancozeb.

Metalaxyl (Ridomil®/Ridomil® Gold) is also used for late blight control. Fosetyl-Al (Aliette®) has been used since 1996 to control diseases caused by *Phytophthora* spp.

Many companies, universities, and the USDA are developing and conducting field trials of transgenic tomato varieties with built-in resistance to bacterial, fungal, and viral diseases (see Table 4 in the Overview section). Fungal organisms and diseases of tomatoes that are targets for control by genetic engineering include *Alternaria solani*, *Phytophthora*, *Rhizoctonia*, *Botrytis*, powdery mildew, and soft rot. Several Midwestern universities are developing tomatoes with genetically engineered resistance to bacterial speck. Virus-resistant tomatoes are being developed by Monsanto and Calgene; by Seminis Vegetable Seeds and its subsidiaries, Asgrow Vegetable Seeds and Petoseed; by Rogers Seed Co.(part of Novartis Seeds); and by the New York Agricultural Experiment Station, the University of Florida, and the USDA.

Several new biological fungicides have been launched recently or are under development for tomatoes. T22 Planter Box from BioWorks is a seed treatment product based on *Trichoderma harzianum* Strain T22. Blight Ban™ A506 from J.R. Simplot's Plant Health Technologies Division (Boise, ID), and *Xanthomonas campestris* var. *vesicatoria* from Agri Phi Inc. (Logan, UT) are three new biological fungicides targeted for the tomato fungicides market. Ecogen's AQ 10 (*Ampelomyces quisqualis*)was registered for powdery mildew control in tomatoes in 1996.

IPM consultants in Florida report that new fungicides are needed for tomatoes in that state and that they are looking forward to the availability of Zeneca's azoxystrobin, which is expected to achieve registered for tomatoes (as Quadris®) by the end of 1997. Novartis' new plant activator, Actigard®, is under evaluation in Florida for bacterial spot control in both tomatoes and peppers. Four new chemical fungicides are under development for late blight control in tomatoes—DuPont's cymoxanil (Curzate®), American Cyanamid's dimethomorph (Acrobat®), flumetover (RPA-403397) from Rhône-Poulenc, and propamocarb hydrochloride (Tattoo®) from AgrEvo.

Lettuce

On the basis of treatment acres, lettuce ranks as the fifth largest vegetable crop market for fungicides, following tomatoes, cucurbits, onions, and bell peppers. However, on the basis of grower expenditures, lettuce ranks second after tomatoes. Lettuce growers spent $32 million for fungicides in 1995. About 86% of the country's lettuce plantings (268,400 acres, including head lettuce, leaf lettuce, and romaine) received an average of 3.8 fungicide applications. California and Arizona, the two major lettuce growing states, respectively accounted for 75% and 20% of U.S. planted acres.

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Downy mildew and Sclerotinia drop are the two major disease problems of lettuce. The incidence of both problems in the largest California growing regions, the Salinas Valley, is being affected by a change in cultural practices. Growers in the region are gradually moving from furrow to drip irrigation for lettuce and as a result, problems with downy mildew are decreasing. However, problems with Sclerotinia are becoming more severe because of the reduced soil tillage with drip systems.

Maneb was by far the leading fungicide in the California lettuce market in 1995, with a market share of more than 50%, based on treatment acres. Fosetyl-Al (Aliette®) was the second most widely used product and accounted for about 22% of the total treatments. Metalaxyl and iprodione each accounted for about 7% of the fungicide applications made for California lettuce and vinclozolin (Ronilan®) accounted for 5.5%. Increasing downy mildew resistance to fungicides is occurring in California, and thus new fungicides against that disease are needed.

Aliette® and Rovral® are the two most widely used fungicides for Arizona lettuce, followed by maneb. Rovral® and Ronilan® are the leading fungicides in the much smaller Florida lettuce market, and both products are used to control bottom rot and Sclerotinia.

Researchers at the University of California at Davis and vegetable seed companies (e.g., Seminis and its subsidiary, Asgrow Vegetable Seeds) have been working to develop transgenic lettuce resistant to downy mildew; however, they do not expect to be able to launch commercial downy mildew resistant varieties before 2002. Harris Moran is working on lettuce that is resistant both to bacterial and fungal diseases. Seminis Vegetable Seeds and the University of Hawaii are or have been conducting field trials of virus-resistant lettuce.

New fungicides that are under evaluation and/or development for downy mildew control in lettuce include dimethomorph, fluazinam, kresoxim-methyl, and propamocarb hydrochloride.

Cucurbits

The market includes cucumbers, muskmelons, and watermelons. (Pumpkins and squash are not included because total U.S. crop acreage statistics are not reported for them.) In 1995, U.S. cucumber plantings totaled 185,100 acres, muskmelon (cantaloupe and honeydew) plantings 131,000 acres, and watermelon plantings 228,400 acres. The percentage of planted acres treated and the average number of applications varied by crop (see Table 3 in the Overview section); overall, however, 69% of the total cucurbit crop acreage received an average of 6 fungicide applications. Watermelons accounted for 57% of cucurbit crop fungicide treatments, cucumbers for 28%, and muskmelons for 15%. At the grower level, the cucurbits market amounted to an estimated $27 million.

Southeastern states account for most cucurbit fungicide treatments. Virtually all of the cucumber, muskmelon, and watermelon plantings in Georgia and Florida receive intensive fungicide treatment.

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Downy mildew and gummy stem blight are the two principal disease targets of fungicides applied for cucurbit crops in Florida and other southeastern sate; in California and Arizona powdery mildew is the principal problem.

Chlorothalonil and mancozeb were the two most widely applied fungicides for cucurbit crops nationwide in 1995, followed by metalaxyl, benomyl, copper hydroxide, and sulfur. For Florida watermelons, chlorothalonil, mancozeb, and benomyl are used primarily for control of gummy stem blight. Fosetyl-Al (Aliette®) recently became available for downy mildew control in Florida cucumbers. Azidarachtin (Trilogy®), a botanical (neem-based) insecticide/fungicide from Thermo Trilogy, also became available for Florida cucurbits recently and is used to control powdery mildew and downy mildew.

Triadimefon (Bayleton®)was the most widely used fungicide for California cucurbit crops in 1995, accounting for 37% of fungicide treatments. Chlorothalonil was the next most widely used product (18% of treatments), followed by benomyl (about 15%), sulfur (11%), and metalaxyl (11%). A biological fungicide from Kemira Agro (Finland), *Streptomyces griseoviridis* Strain K61 (Mycostop®), was launched for cucumbers in California in 1995; use of the product on a single acre was reported by the California Department of Pesticide Regulation. This product received an EPA registration in 1993.

Research and development efforts concerning transgenic disease-resistant cucurbit crop plants have thus far focused on virus resistance (see Table 4 in the Overview section). Seminis Vegetable Seeds' subsidiary, Asgrow Vegetable Seeds, commercialized a virus-resistant squash product, Freedom II™, in 1995. Seminis, Asgrow, and Petoseed, another Seminis subsidiary, are continuing field trials of cucumber, muskmelon, watermelon, and squash varieties with resistance to multiple viruses. Asgrow is also working on a mildew-resistant squash, but does not expect to have a commercial product on the market before 2002.

AgrEvo is developing a cross protection and antisense technique to combat cucumber mosaic virus, but this work is still in the laboratory stage, and setbacks have occurred because of cell-specific proteins disrupting the interaction between viral RNA and antisense RNA. However, new research combining antisense RNA and ribozymes looks promising. A commercial product is not expected to result from this work for at least 5 years.

Harris Moran Seed Company and Rogers Seed Co. Are working on virus-resistant muskmelons. A number of universities and the New York State Agricultural Experiment Station have or are conducting field trials of virus-resistant cucumbers, muskmelons, and/or squash.

Ecogen's biological fungicide, AQ 10 was registered for powdery mildew control on cucurbits in 1996. Bioworks' *Trichoderma harzianum*-based product, T-22, and the *Pseudomonas cepacia*-based biofungicide products of CCT Corp. (Deny®) and Soil Technologies Corp.(Intercept®) recently became available for control of soil-borne diseases that affect cucurbit crops.

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Novartis' cyprodinil (Vangard®), Rohm and Haas' myclobutanil (Rally®), and Uniroyal's triflumizole (Procure®) are under development for powdery mildew control on cucurbits, as are new chemical fungicides, including BASF's kresoxim-methyl. Zeneca's azoxystrobin is being developed to control a broad spectrum of cucurbit crop diseases. Field trials of two numbered experimental fungicide compounds from Rohm and Haas, RH 7281 and RH 0611, for downy mildew control on cantaloupe and powdery mildew control on squash, respectively, have produced promising results.

Novartis' new plant activator, Actigard®, is also expected to become available to aid in control of downy mildew, powdery mildew, and other cucurbit diseases within the next 5 years.

Onions

Onions were planted on 168,900 acres in 1995, and 96% of the planted acres received an average of 7.1 fungicide applications. Onions ranked as the third largest vegetable crop market for fungicides on the basis of treatment acres, and as the fourth largest on the basis of end-user market value. Onion growers spent an estimated $17 million for fungicides in 1995. Chlorothalonil, mancozeb, and maneb are the three leading fungicides in this crop market.

Cole Crops

This crop market includes broccoli, brussels sprouts, cabbage, and cauliflower. U.S. cole crop plantings totaled 262,200 acres in 1995, including 121,600 acres of broccoli, 85,900 acres of cabbage, 51,300 acres of cauliflower, and 3,400 acres of brussels sprouts. Overall, 62% of the planted acres received an average of 3.4 fungicide applications. Of the 4 cole crops, cabbage is treated most intensively with fungicides; in 1995, 72% of the country's cabbage acreage received 5.3 fungicide applications, on average.

For cabbage, the most widely used fungicides are chlorothalonil, maneb, and mancozeb, whereas maneb, metalaxyl, chlorothalonil, and copper hydroxide are the leading fungicides used for broccoli. Cole crop growers' expenditures for fungicides totaled about $11 million in 1995.

Carrots

Carrots were planted on 113,900 acres in the United States in 1995. Carrots grown for the fresh market accounted for 74% of the total plantings and carrots for processing accounted for 26%. California, with 55,000 acres for the fresh market and 5,600 acres for processing, is the leading carrot producer, with 53% of U.S. carrot crop acreage in 1995.

U.S. carrot growers spent an estimated $8 million for fungicides in 1995. The leading fungicides in the California carrot market, based on treatment acres, were metalaxyl and iprodione, with market shares of about 38% and 27%, respectively. Chlorothalonil and copper hydroxide each accounted for about 13% of the California carrot fungicide treatments, and sulfur accounted for 6%.

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Snap Beans

U.S. snap bean acreage amounted to 322,300 acres in 1995, of which acreage planted for processing accounted for 70.5% and acreage planted for the fresh market accounted for 29.5%. Fungicides were applied on 70% of the fresh market crop acreage, and an average of 7 applications was made per treated acre. Only 40% of the processing crop acreage received any fungicide treatment; The treated acres received 1.2 applications, on average. In terms of grower expenditures, the U.S. snap bean market for fungicides amounted to about $5 million in 1995. Chlorothalonil and sulfur were the two most widely used fungicide products.

Bell Peppers

Bell peppers were grown on 70,300 acres in 1995. California and Florida are the two leading producing states; California accounted for 34% of the total planted acres and Florida accounted for 31%. North Carolina (11% of U.S. planted acres), New Jersey (about 8%), and Texas (7%) are the next most important bell pepper producing states. An estimated 84% of the total U.S. crop acreage received fungicide treatment, with an average of 17 fungicide applications made per treated acre. Florida bell peppers received the most intensive treatment—100% of that state's crop acreage was treated, and on average, about 22 applications were made per treated acre. Bacterial diseases are the principal targets of fungicide applications for Florida bell peppers. Copper compounds and maneb are the most widely used fungicide products in Florida and nationwide. U.S. bell pepper growers spent about $4 million for fungicides in 1995.

Sweet Corn

In 1995, U.S. growers planted 235,300 acres of sweet corn for the fresh market and 531,500 acres for processing. Although sweet corn has the largest acreage of all U.S. vegetable crops, it is a relatively small market for fungicides. At the grower level, the sweet corn fungicides market was valued at about $4 million.

About 40% of U.S. fresh market sweet corn acreage received fungicide treatment and on average, 6 applications were made per treated acre. Only 10% of processing sweet corn acreage received fungicide treatment—just 1 application was made per treated acre, on average. Thus, sweet corn grown for the fresh market accounted for more than 90% of the fungicide treatment acres.

Mancozeb is the leading fungicide used for sweet corn, followed by propiconazole (Tilt®). In 1995, the two products accounted for about 70% and 25% of the total treatment acres, respectively. Both products were applied to control northern corn leaf blight, southern corn leaf blight, and/or rust.

Fungicides are also applied in seed treatments for sweet corn. Seed treatments used for Florida sweet corn contain metalaxyl, thiram, and imazalil, plus an insecticide. Florida growers and pest management consultants are concerned about the pending or recent loss of imazalil for seed treatment; it has been used to control *Penicillium* and other seedling blights.

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Celery

U.S. celery plantings totaled an estimated 33,400 acres in 1995, of which California accounted for 73% and Florida for 15%. Michigan (8%) and Texas (3%) accounted for most of the remaining planted acreage. Virtually 100% of the celery crop acreage received fungicide treatments, and an average of 10.5 applications were made per treated acre. The end-user value of the celery fungicides market was about $3 million in 1995.

Chlorothalonil and benomyl were the two most widely applied fungicides for California celery in 1995, accounting for 41% and 29% of treatment acres, respectively. Copper hydroxide accounted for about 17% of treatments and dichloran (Botran®) for about 8%.

Others

Artichokes, asparagus, beets, eggplant, escarole, garlic, green peas, lima beans, spinach, and sweet potatoes are additional, although very small, vegetable crop markets for fungicides. Planted acreage of these crops totaled 631,300 acres in 1995. An estimated 22% of the combined planted acreage received at least 1 fungicide treatment, and on average, 1.6 applications were made per treated acre. The grower-level value of this sector was about $3 million.

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POTATOES

Fungicide Market, 1995

In 1995, potatoes represented a $65 million market for fungicides at the grower level. U.S. potato plantings totaled 1.4 million acres, of which the Northwest (Idaho, Washington, and Oregon) accounted for 43%, with the combined Northeast and Upper North Central regions for 35%.

Fungicides were applied on an estimated 85% of the total U.S. potato crop acreage, and each treated acre received an average of 7.5 fungicide applications. As indicated in Table 3 in the Overview section, potatoes in the Northeast and Upper North Central regions received substantially more intensive fungicide treatment than plantings in the Northwest. The Northeast/Upper North Central accounted for nearly 50% of the total potato fungicides market, based on treatment acres, with the Northwest at about 30%. In addition to their use to control foliar diseases of potato plants, fungicides are also used to treat seed pieces before planting.

Table 14 lists the potato diseases that are the principal targets of foliar and seed piece fungicide treatments and their causal organisms. Most foliar fungicide treatments applied for potatoes in the Northeast and Upper North Central growing regions are targeted for control of late blight. In the Northwest, early blight has historically been the principal disease target of fungicide sprays applied for potatoes. However, late blight has also become a problem in some Northwest growing areas in the last few years. Powdery mildew occasionally requires treatment in the Northwest.

Table 14
MAJOR POTATO DISEASES

Disease	Causal Organism
Foliar	
Early blight	*Alternaria solani*
Late blight	*Phytophthora infestans,*
Powdery mildew	*Erysiphe cichorcearum*
Seed Piece	
Bacterial soft rot and blackleg	*Erwinia carotovora*
Fusarium	*Fusarium*
Rhizoctonia	*Rhizoctonia*
Scab	*Streptomyces scabies*

Source: University pest management guidelines

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The original strain of *P. infestans*, called US-1, has been present in the United States since the beginning of this century. It has been successfully controlled with fungicide sprays applied according to computer forecasting schedules. Recently however, a new more aggressive strain of *P. infestans*, called US-8, has appeared. Evidence suggests that the additive effect of US-1 and US-8 is more destructive than either pathogen alone. Metalaxyl (Ridomil®), now being replaced by mefenoxam (Ridomil® Gold), has been the primary fungicide used for successful control the US-1 strain; however, the US-8 strain is resistant to metalaxyl/mefenoxam. In cool, wet periods during the summer of 1994, US-8 spread rapidly across potato fields in the North Central and Northeast regions. In Wisconsin alone, potato growers' economic losses due to *P. infestans* amounted to $26 million.

Late blight was not a problem for potatoes in the Northwest until 1995; previously, only one isolated case had been reported in Idaho. In the summer and fall of 1995, the disease was found in numerous fields in southwest and south-central Idaho, and the causal agent was determined to be the US-8 genotype.

Figure 6 and Table 15 show the breakdown of the 1995 U.S. potato market for fungicides by leading product. Chlorothalonil (Bravo® and generic brands) is by far the leading fungicide used for potatoes, accounting for about 40% of treatment acres and for about 51% of potato growers' expenditures for fungicides in 1995. Chlorothalonil is used to control both late blight and early blight and is applied either alone or combined with metalaxyl (Ridomil®, Bravo®). Mancozeb, the second most widely used fungicide for potatoes, accounted for 23.5% of treatment acres. Mancozeb is also used against both early blight and late blight.

Figure 6
U.S. POTATOE MARKET FOR FUNGICIDES, 1995

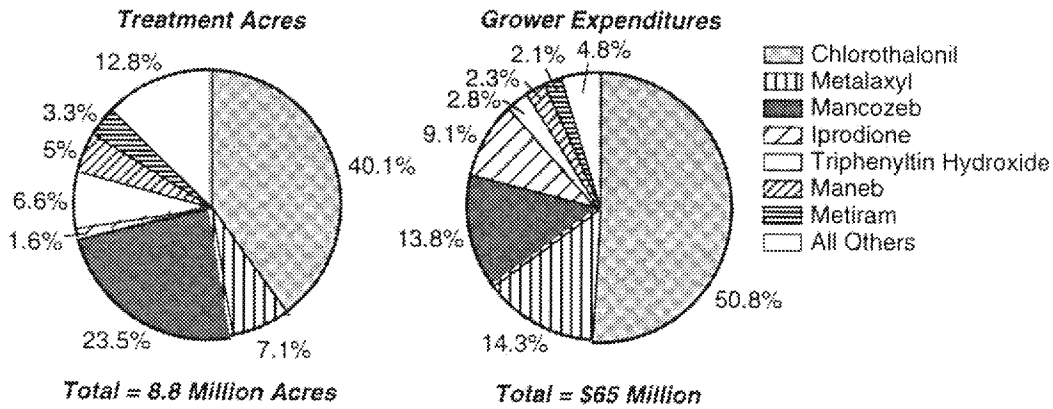

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Table 15
U.S. POTATO MARKET FOR FUNGICIDES, 1995

Product.	Treatment Acres		Volume Applied	Grower Expenditures	
	1,000 Acres	Product Share (%)	(1,000 Pounds, A.I.)	(1,000 (Dollars)	Product Share (%)
chlorothalonil	3,544.4	40.1	3,969.8	33,068.2	50.9
metalaxyl	626.4	7.1	119.0	9,283.2	14.3
mancozeb	2,076.3	23.5	2,699.2	8,988.4	13.8
iprodione	138.4	1.6	132.9	5,910.7	9.1
triphenyltin hydroxide	584.4	6.6	76.0	1,842.5	2.8
maneb	440.4	5.0	484.5	1,482.5	2.3
metiram	293.6	3.3	446.3	1,338.9	2.1
copper hydroxide	570.5	6.4	376.5	1,035.4	1.6
propamocarb	92.3	1.0	80.3	802.8	1.2
sulfur	167.8	1.9	454.7	368.3	0.6
others[a]	312.4	3.5	200.4	879.1	1.4
Total	8,847.0	100.0	9,039.5	65,000.0	100.0

[a] Includes dimethomorph, other copper compounds, cymoxanil, anilazine, captan, propiconazole, and thiophanate-methyl.

Source: SRIC estimates

In 1995, four experimental fungicides were granted Section 18 emergency exemptions for use against late blight in potatoes in the Northeast and North Central regions. They were American Cyanamid's Acrobat® MZ (dimethomorph + mancozeb), DuPont's Curzate® M (cymoxanil + mancozeb), Griffin's ® C-8 (mancozeb + cymoxanil), and AgrEvo's Tattoo® C (propamocarb hydrochloride + chlorothalonil). These four premix formulations and single active ingredient formulations of dimethomorph (Acrobat®) and propamocarb hydrochloride (Tatoo®) were also available under Section 18 emergency exemptions in the Northwest in 1996, and are available in many states again in 1997 under emergency exemptions.

Nearly all potato seed pieces are treated with fungicides for control of pathogens that cause seed piece decays such as bacterial soft rot and blackleg, scab, *Fusarium*, and *Rhizoctonia*. Various dust formulations of captan, mancozeb, thiabendazole (TBZ, Mertect®), and thiophanate-methyl are registered for this purpose.

New Disease Control Technologies

Transgenic Disease-Resistant Plants

In 1998, Monsanto expects to commercialize stacked gene potato varieties resistant to potato leaf roll virus (PLRV), potato virus Y (PVY), and the Colorado potato beetle

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(CPB) under the trade name, NewLeaf® Plus. The availability of these varieties is expected to substantially reduce the need for insecticide sprays to control aphids that transmit potato virus diseases.

The addition of virus-resistance traits is expected to expand the market for Monsanto's transgenic potatoes in the major Northwest growing region. The first-generation NewLeaf® potatoes, with single-gene CPB resistance, have not been widely adopted in the Northwest because growers in this region can still control CPB with relatively inexpensive synthetic pyrethroid insecticides. CPB resistance to pyrethroids is not yet a problem in the region.

Monsanto's transgenic potato research is also targeting other potato diseases. In 2001, the company plans to release a "NewLeaf® Ultra®" potato with stacked resistance to CPB, PLRV, PVY, bacterial soft rot, Verticillium wilt, and late blight.

Two Monsanto subsidiaries, Asgrow Seed Company (Asgrow Agronomics) and Calgene, have also conducted field trials of virus-resistant potatoes. Since the early 1990s, Frito-Lay, numerous universities, and the USDA have conducted field trials of transgenic disease-resistant potatoes (see Table 4 in the Overview section). The USDA is also working to develop a late blight resistant potato using conventional breeding techniques, but it has had limited success to date.

Biological Fungicides

Three bacterial fungicides were recently registered for use on potatoes. Deny® from CCT Corp. and Intercept® from Soil Technologies Corp. are both based on *Pseudomonas cepacia*, and BlightBan™ 506 from Plant Health Technologies (a division of J.R. Simplot Company) is based on *Pseudomonas fluorescens*.

New Chemistry

In addition to the Section 18 fungicides discussed above (cymoxanil, dimethomorph, and propamocarb hydrochloride), several other new chemical fungicides are also under development, or are being evaluated in field trials, for control of late blight, early blight, or both diseases. They include azoxystrobin from Zeneca, famoxadone from DuPont, azoxystrobin from Zeneca, flumetover from Rhône-Poulenc, and two numbered experimental compounds—RH 7281 and RH 131946—from Rohm and Haas. Novartis' cyprodinil is under development for potato seed piece treatment, as is kasugamycin hydrochloride (PCC 514), from United Agri Products.

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FIELD CROPS

Fungicide use for U.S. field crops amounted to approximately 17.8 million treatment acres in 1995. The end-user value of the fungicides applied for field crops totaled an estimated $200 million. Figure 7 shows relative sizes of the major field crop markets based on both treatment acres and market value, and Table 16 ranks the markets according to their end-user value.

Figure 7
U.S. FIELD CROP MARKETS FOR FUNGICIDES, 1995

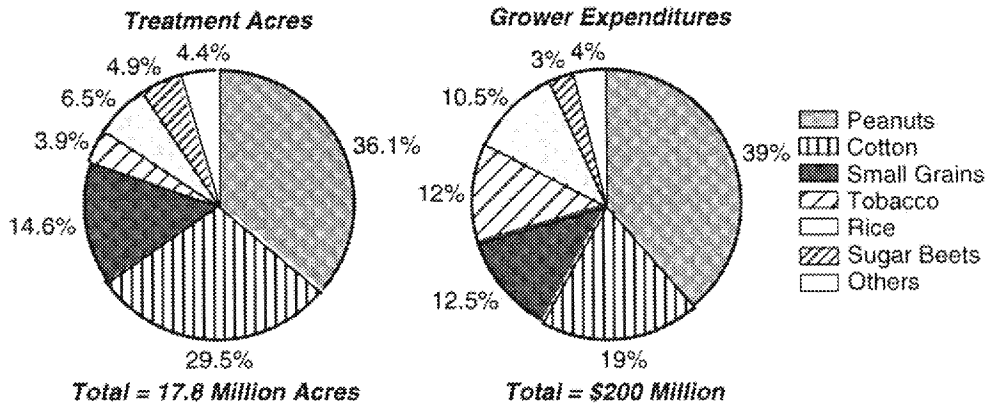

Table 16
END-USER VALUE OF THE U.S. FIELD CROP MARKETS FOR FUNGICIDES, 1995

	Millions of Dollars
Peanuts	78
Cotton	38
Small Grains	25
Tobacco	24
Rice	21
Sugar Beets	6
Others[a]	8
Total	200

[a] Corn, soybeans, and others.
Source: SRIC estimates

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Peanuts

On the basis of grower expenditures, peanuts rank as the largest U.S. field crop market for fungicides and the third largest agricultural fungicide market overall, following fruits and nuts and vegetables. Peanut growers' expenditures for fungicides totaled $78 million in 1995.

An estimated 87% of the more than 1.5 million acres of U.S. peanut plantings received fungicide treatment in 1995, and on average 4.6 applications were made per treated acre. Most of the fungicide treatments occurred in the major Mid-Atlantic and Southeastern growing regions, which together accounted for 74% of the total peanut crop acreage. In these regions, more than 95% of the crop acreage received an average of 5 fungicide applications. Fungicide applications for peanuts include both foliar and soil-applied treatments.

Table 17 lists the major foliar and soil-borne diseases of peanuts grown in the United States. Early leaf spot and late leaf spot are the two most destructive foliar diseases and both appear in all U.S. peanut growing regions. Because available fungicides will not eradicate either leaf spot disease, prevention is the most important aspect of their control. Peanut rust and web blotch are less widely distributed but can cause foliar damage, particularly in the Southwest peanut-growing states of Oklahoma, Texas, and New Mexico. The importance of web blotch as a pathogen has been decreasing, possibly as a result of replacement of highly susceptible Spanish-type cultivars with the moderately resistant Florunner cultivars. Occurrences of Sclerotinia blight have recently occurred on Florunner varieties, which do not respond well to fungicide treatment. Black hull affects mainly Spanish peanut varieties.

Table 17
MAJOR PEANUT DISEASES

Disease	Causal Organism
Foliar	
Black hull	*Thielaviopsis basicola*
Early leaf spot	*Cercospora arachidicola*
Late leaf spot	*Cercosporidium personatum*
Peanut rust	*Puccinia arachidis*
Web blotch	*Phoma arachidicola*
Sclerotinia blight	*Sclerotinia minor* on
Soil-borne	
Root and stem rot	*Rhizoctonia solani*
Southern blight	*Sclerotium rolfsii.*
Stem rot and white mold	*Sclerotinia rolfsii*

Source: University plant pathologiests and pest management consultants

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The primary soil-borne diseases of peanuts in the Southeast are southern stem rot and white mold, both caused by *Sclerotinia rolfsii*. Southern blight, also known as white mold or southern stem rot, is caused by a soil-borne fungus that is present in many peanut growing areas. It occurs in peanut fields in Georgia, North Carolina, Virginia, Oklahoma, and some counties in Texas.

Chlorothalonil (Bravo® and generic brands) is the leading fungicide in the U.S. peanut market and is used against early leaf spot, late leaf spot, rust, and web blotch. PCNB is used for soil applications to control Southern blight and root and stem rot. Sulfur is used, generally in combination with other fungicides, to provide additional suppression of foliar diseases. Other fungicides used for peanuts in 1995 included tebuconazole (Folicur®), propiconazole (Tilt®), flutolanil (Moncut®), iprodione (Rovral®), benomyl (Benlate®), thiophanate-methyl (Topsin®-M), and copper compounds.

Another new fungicide, fluazinam (Frowncide®) from ISK Biosciences was used experimentally for peanuts in 1995. Reportedly, this product is effective against the difficult-to-control Sclerotinia blight and there is considerable interest in its obtaining a registration for this use. Zeneca's new fungicide, azoxystrobin (Abound®), was registered for peanuts in June 1997.

Captan, carboxin (Vitavax®), PCNB, and various premixes of these fungicides are used as peanut seed treatments to control seedling diseases caused by *Pythium*, *Rhizoctonia*, and other soil-borne pathogens. Metalaxyl (now mefenoxam) and etridiazole are also used as components of some seed treatment premixes. Biological fungicides based on *Bacillus subtilis* are available for peanut seed treatment from Gustafson Inc. (Kodiak® HB and Quantum® 4000) and Helena Chemical (System 3). BioWorks' Trichoderma harzianum-based fungicide, T22 Planter box, is also registered for peanut seed treatment.

Field trials of peanut varieties with genetically engineered resistance to viral diseases have been conducted by Agracetus, the University of Florida, and the University of Georgia. The tomato spotted wilt virus is the principal target of the viral resistance research work for peanuts, but in 1996, the University of Georgia also tested varieties with peanut stunt virus resistance.

Cotton

U.S. cotton growers spent an estimated $38 million for fungicide in 1995. An estimated 15% of the country's 16.9 million cotton crop acres received fungicide treatment, and on average 2 chemical applications were made per treated acre.

For cotton, fungicides are used primarily to control seedling diseases that are caused by various soil-borne fungi, including *Fusarium*, *Pythium*, *Rhizoctonia*, *Thielaviopsis*, and *Phytophthora*. These pathogens must be controlled preventively before or at the time of planting. Recommended preventive measures include various cultural practices, maintaining soil pH at a level that both encourages vigorous plant growth and suppresses certain diseases, avoidance of planting too deeply or before the soil has warmed to at

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least 68°F, planting only high-quality seed, seed treatments, and at-planting soil treatments. At-planting fungicide treatments include both planter box and seed furrow applications.

Mancozeb, metalaxyl, chloroneb, PCNB, captan, imazalil, etridiazole, and carboxin were the fungicides used for at planting applications for cotton in 1995. Oxadixyl (Anchor®) is also recommended for at-planting seed treatment for control of *Pythium* damping-off and early season *Phytophthora.* The same biological fungicides mentioned above under peanuts are also available for cotton seed treatment in planter boxes. Two additional new biological fungicides, both based on *Pseudomonas cepacia* —Deny® from CCT Corporation and Intercept® from Soil Technologies Corp.— are also registered for planter box treatments for cotton.

Rust, caused by *Puccinia* spp., is a foliar disease of cotton that sometimes requires treatment; mancozeb and sulfur are the products that are used.

Small Grains

U.S. growers of barley, oats, rye, and wheat spent an estimated $25 million for fungicides in 1995. About 3% of the small U.S. grain crop acreage received fungicide treatment, and on average, just 1 was made per treated acre.

The limited use of fungicides on U.S. small grain crops is primarily due to crop economics (e.g., low profit margins) and the small number of effective fungicides that are available. Therefore, disease control programs require integration of cultural, biological, and chemical control measures. Traditionally bred resistant varieties effectively control some small grain diseases.

Fungicides are applied for small grains both as seed treatments and as foliar sprays. Seed treatment fungicides, generally viewed as "cheap insurance," are commonly applied routinely for general protection against a wide range of pathogens. The emphasis in recent years has been on the development of seed treatment compounds that provide residual disease control beyond the seedling stage. Seed treatment fungicides are often used in combination with one another or in combination with various insecticides.

Use of foliar fungicides for small grains varies widely across the United States and from one season to the next. Weather, economics, tillage and rotation systems, field history, and plant variety are some of the factors that influence the need for foliar disease control. However, fungicides are routinely applied in systems with high yield potential and/or heavy disease pressure, such as the intensive small grain cropping systems in the Pacific Northwest and wheat that is "double-cropped" with soybeans by some growers in southern U.S. states.

Although disease problems vary with small grain species and region of the country, foliar fungicides are used primarily to control fungal leaf spots, rusts, and powdery mildew. Regionally, black chaff (*Xanthomonas campestris*), black point (*Alternaria, Helminthosporium,* and *Fusarium*) and Cephalosporium stripe(*Cephalosporium gramineum*) are important diseases in the Pacific Northwest. Powdery mildew (*Erysiphe graminis*)and stripe rust (*Puccinia striiformis*) are significant problems in the Middle

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Atlantic states and parts of the Midwest. Common root rot (*Cochliobolus sativus*) and tan spot (*Pyrenophora tritici-repentis*) are other common pathogens in many areas of the United States.

Foliar and seed treatment fungicides that were used for small grains in 1995 included mancozeb, benomyl (Benlate®), thiabendazole (Mertect®), thiophanate-methyl (Topsin®-M), propiconazole (Tilt®), and triadimefon (Bayleton®).

Because growers need to maximize disease control with minimal fungicide application, development efforts for new small grain fungicides are mainly focused on systemic, long-residual compounds that have a broad spectrum of activity. Novartis' new triazole fungicide, difenoconazole (Dividend®) was launched for broad-spectrum disease control in wheat in 1996. Bayer's new triazole fungicide, tebuconazole (Folicur®) is being used experimentally. Other new chemical fungicides under development for small grain crops in the United States are Novartis' plant activator, Actigard®, Zeneca's azoxystrobin, famoxadone from DuPont, and kresoxim-methyl from BASF. A registration for azoxystrobin— as Quadris®— is pending and expected in 1997.

New biological fungicides available for use in small grain seed treatments include formulations based on *Bacillus subtilis* from Gustafson, Inc. and products based *on Pseudomonas cepacia* from CCT Corporation and Soil Technologies Corp.

Monsanto is working on transgenic fungus- and virus-resistant wheat varieties and has been conducting field trials since 1995. Trials of varieties with both fungus resistance and glyphosate tolerance were conducted in 1996. The University of Idaho is working on virus-resistant wheat, and the USDA's Agricultural Research Service has conducted field trials of barley varieties with both virus resistance and herbicide tolerance (to glufosinate).

Tobacco

Tobacco growers spent an estimated $24 million for fungicides in 1995. About 91% of the total crop acreage received fungicide treatment, and most of the treated acreage received only 1 application.

North Carolina and Kentucky are the country's two leading tobacco growing states, followed by Tennessee, South Carolina, Virginia, and Georgia. Flue-cured and burley are the two principal types of tobacco grown in the United States. Flue cured tobacco is grown mainly in Virginia, North Carolina, South Carolina, and Georgia, whereas burley tobacco is grown mainly in Kentucky and Tennessee.

Blue mold (*Peronospora tabacina*)and black shank (*Phytophthora parasitica*) are the two most widespread and serious fungus disease threats to U.S. tobacco. Almost all fungicides applied to both flue-cured and burley tobacco are preventive treatments with metalaxyl/mefenoxam (Ridomil®/Ridomil® Gold) for control of blue mold. Small percentages of growers of each type apply higher rates of Ridomil® to control black shank disease as well as blue mold. Ridomil® is typically soil-incorporated just before planting. In the last 10-15 years, problems with blue mold resistance to metalaxyl have

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become increasingly widespread; therefore, new disease control products or methods are needed.

No tobacco varieties are resistant to blue mold; however, resistant varieties and crop rotation are the preferred control methods for black shank. Multipurpose preplant soil fumigants are also used to control black shank in flue-cured tobacco

Brown spot (*Alternaria alternata*) is an air-borne tobacco disease that occurs occasionally and can cause severe damage to tobacco.

Since the late 1980s, a number of companies and universities and the USDA have conducted field trials of fungus- or virus-resistant tobacco varieties (see Table 4 in the Overview section). American Cyanamid's dimethomorph (Acrobat®) is under development for blue mold and black shank control in tobacco. A potassium bicarbonate product from Tagosei Co. (Japan) is under evaluation for powdery mildew control in tobacco. Tobacco is also a target market for Novartis' new plant activator, Actigard®.

Rice

U.S. rice growers spent $21 million for fungicides in 1995. An estimated 36% of the country's 3.1 million acres of rice plantings received fungicide treatment, and on average just 1 treatment was made per treated acre.

The important rice diseases are rice blast (*Pyricularia oryzae*), sheath blight (*Rhizoctonia solani*), sheath rot (*Acrocylindrium oryzae*), brown leaf spot (*Helminthosporium oryzae* and *Pythium* spp.). Disease occurrence is governed primarily by temperature and other weather factors; stems, leaf sheaths, inflorescences, and grains may be affected.

Benomyl (Benlate®), propiconazole (Tilt®), and iprodione (Rovral®) were the leading fungicides used for rice in 1995. Metalaxyl (Apron®), carboxin (Vitavax®), mancozeb, thiram, and PCNB are the principal fungicides used for rice seed treatment. New fungicides under development for U.S. rice include Zeneca's azoxystrobin (Quadris®), AgrEvo's (flutolanil (Moncut®), and Novartis' plant activator, Actigard®.

The University of California is working on rice varieties with genetically engineered resistance to bacterial leaf blight and is conducting field trials in 1997. Louisiana State University conducted trials of rice resistant to *Rhizoctonia solani* in 1995 and 1996.

Sugar Beets

The sugar beets market for fungicides amounted to an estimated $6 million in 1995. About 52% of the country's nearly 1.5 million acres of this crop received fungicide treatment, and an average of 1.1 applications were made per treated acre. Fungicides used for sugar beets include mancozeb, maneb, triphenyltin hydroxide (Super Tin®), a maneb-triphenyltin hydroxide premix (Pro-Tex®), thiophanate methyl (Topsin®-M), and sulfur.

DuPont's famoxadone and AgrEvo's propamocarb hydrochloride (Tattoo®) are new products that are currently under development for sugar beets. The seed company,

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Betaseed, is developing sugar beet varieties resistant to beet necrotic yellow vein virus, the causal agent of Rhizomania disease in sugar beets.

Other Crops

The combined total end-user value of other field crop markets for fungicides in 1995 was an estimated $8 million. Despite the extensive U.S. plantings of corn and soybeans, the two crops represent minor markets for fungicides. Only about 1% of the total U.S. soybean plantings and less than 1% of the total field corn acreage received a fungicide treatment in 1995. Dry beans, dry peas, mint, and hops are additional very small field crop markets for fungicides.

AgrEvo, Novartis Seeds, Holden's Foundation Seeds, and Pioneer Hi-Bred International are developing corn hybrids with resistance to fungal diseases. Monsanto is conducting field trials of virus-resistant corn in 1997. Novartis Seeds' subsidiary, Northrup King, and Pioneer Hi-Bred are also working on virus-resistant corn.

Pioneer Hi-Bred and the University of Kentucky have conducted field trials of virus-resistant soybeans. Information on disease-resistant plant research for corn, soybeans, and other field crops is summarized in Table 4 in the Overview section.

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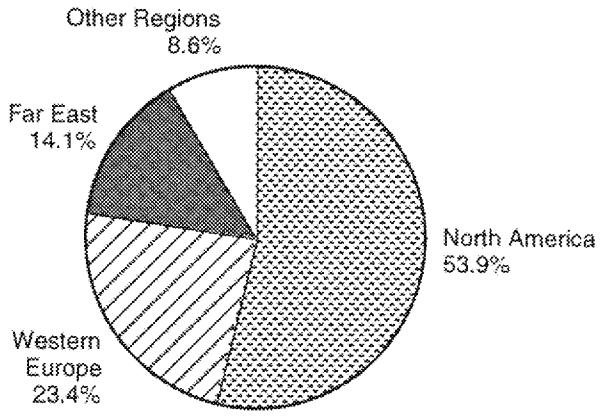
NEMATODE CONTROL

OVERVIEW

World Soil Fumigant and Nematicide Market

World sales of soil fumigants and nematicides amounted to an estimated $640 million at the end-user level in 1995. North American, the largest regional market, accounted for 54% of the world market. Western Europe accounted for 23% and the Far East for 14% (see Figure 8 and Table 18).

Figure 8
WORLD CROP MARKETS FOR SOIL FUMIGANTS AND NEMATICIDES, 1995



Total = $640 Million

Table 18
WORLD AGRICULTURAL CROP MARKET FOR SOIL FUMIGANTS AND NEMATICIDES BY MAJOR REGION, 1995

Region	Millions of Dollars	Percent of Total
North America	345	54
Western Europe	150	23
Far East	90	14
Other Regions	55	9
Total	640	100

Source: SRIC estimates

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North American Soil Fumigant and Nematicide Market

Figure 9 and Table 19 show the breakdown of the $345 million North American agricultural soil fumigant/nematicide market by country and crop sector. Potatoes and vegetable crops are the two largest crop sectors, accounting for 30% and 19% of the North American market, respectively. Cotton, tobacco, fruits and nuts, and sugar beets are the next most important crop sectors. Canada accounted for less than 1% of the total regional market; the principal Canadian crop market is tobacco.

Figure 9
NORTH AMERICAN CROP MARKETS FOR SOIL FUMIGANTS AND NEMATICIDES, 1995

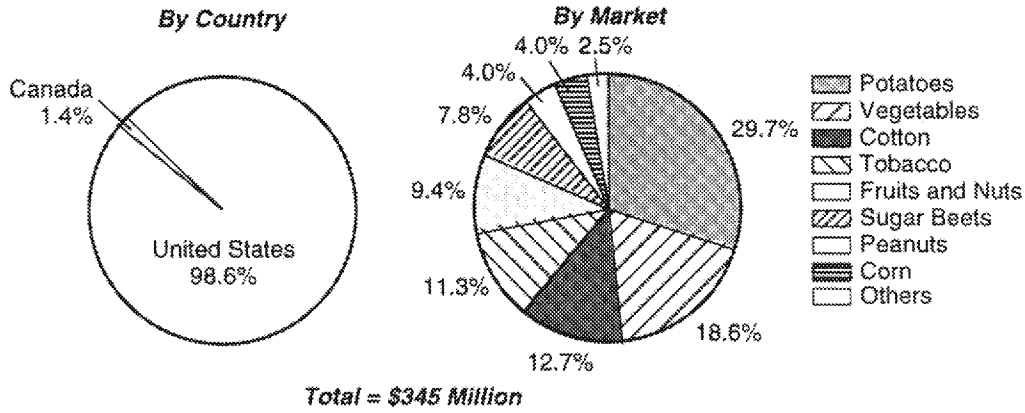

Table 19
NORTH AMERICAN CROP MARKETS FOR SOIL FUMIGANTS AND NEMATICIDES, 1995
(Millions of Dollars, End-User Sales

Crop Market	Canada	United States	Total
Potatoes	1	102	103
Vegetables	1	63	64
Cotton	--	44	44
Tobacco	3	36	39
Fruits and Nuts	--	33	33
Sugar Beets	--	27	27
Peanuts	--	13	13
Corn	--	13	13
Soybeans	--	7	7
Other Field Crops	--	2	2
Total	5	340	345

Source: SRIC estimates

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Soil Fumigant and Nematicide Use for U.S. Crops, 1995

Figure 10 ranks U.S. crop markets for soil fumigants and nematicides on the bases of treated acres in 1995. Although potatoes and vegetables are the two largest crop markets, given end-user sales value, cotton, corn, and soybeans account for the largest portions of the total fumigant/nematicide treated acres. Application rates and costs per acre for the nematode control products used for potatoes and vegetables (usually multipurpose soil fumigants) are generally substantially higher than rates and costs for the contact nematicides that are typically used for the three major field crops.

Figure 10

SOIL FUMIGANT AND NEMATICIDE USE FOR U.S. AGRICULTURAL CROPS, 1995

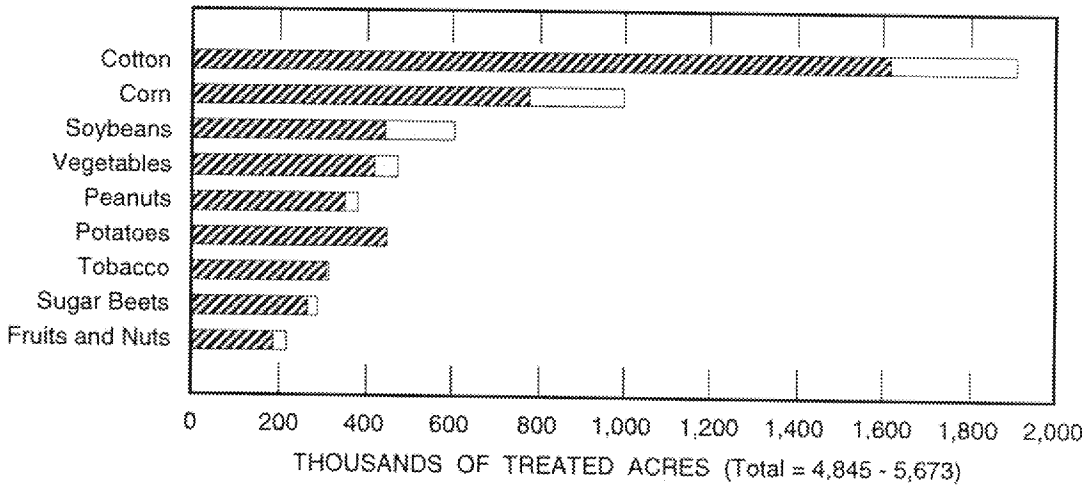

Table 20 provides a breakdown by crop of the U.S. agricultural crop land that was treated with soil fumigants and nematicides in 1995, and for some crops gives a further breakdown by major growing region.

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Table 20
SOIL FUMIGANT AND NEMATICIDE USE FOR U.S. AGRICULTURAL CROPS, 1995

Crop	Planted Acres[a] (1,000)	Fumigant/Nematicide Treated Acres: Percent of Planted Acres	Fumigant/Nematicide Treated Acres: Acres (1,000)
Field Crops			
Cotton			
Southeast	3,460.0	9-10	311-346
Mid-South	4,877.0	8-10	390-488
Southern Plains	6,819.8	12-14	818-955
West	1,774.6	6-7	106-124
Subtotal	16,931.4		1,626-1,913
Average		10-11	
Corn			
Mid-Atlantic/Southeast[b]	2,930.0	15-18	440-527
Other Regions	68,315.0	0.5-0.7	342-478
Subtotal	71,245.0		781-1,006
Average		1.1-1.4	
Soybeans			
South	11,450.0	3.0-4.0	344-458
Other Regions	51,125.0	0.2-0.3	102-153
Subtotal	62,575.0		446-611
Average		0.7-1.0	
Peanuts	1,537.5	23-25	354-384
Tobacco	663.1	47-48	312-318
Sugar Beets	1,475.8	18-20	266-295
Field Crops, Total	154,427.8		3,784-4,527
Average		2.5-2.9	
Potatoes			
Northeast/Upper North Central	484.4	10	48
Northwest[c]	601.0	53	319
Other Regions	312.8	27	84
Total	1,398.2		451
Average		32	

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Table 20 (Continued
SOIL FUMIGANT AND NEMATICIDE USE FOR
U.S. AGRICULTURAL CROPS, 1995

Crop	Planted Acres[a] (1,000)	Fumigant/Nematicide Treated Acres: Percent of Planted Acres	Fumigant/Nematicide Treated Acres: Acres (1,000)
Vegetables			
Tomatoes			
Florida	48.7	95-100	46-49
California	369.0	20-22	74-81
Other States	78.7	35-42	28-33
Subtotal	496.4		148-163
Average		30-33	
Cucurbits			
Cucumbers	185.1	22-23	41-43
Muskmelons[d]	131.0	10-13	13-17
Watermelons	228.4	12-16	27-37
Subtotal	544.5		81-96
Average		15-18	
Carrots	113.9	48-52	55-59
Sweet Potatoes	87.4	52-60	45-52
Cole Crops			
Cabbage	85.9	12	10
Broccoli	121.6	20	24
Cauliflower	51.3	10	5
Brussels Sprouts	3.4	50	2
Subtotal	262.2		41
Average		16	
Peppers, Bell	70.3	45-50	32-35
Onions	168.9	8-10	14-17
Lettuce	268.4	2.5-3.0	7-8
Sweet Corn	766.7	0.1-0.3	1-2
Vegetables, Total	2,786.1		423-475
Average		15-17	

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Table 20 (Continued)
SOIL FUMIGANT AND NEMATICIDE USE FOR U.S. AGRICULTURAL CROPS, 1995

Crop	Planted Acres[a] (1,000)	Fumigant/Nematicide Treated Acres: Percent of Planted Acres	Fumigant/Nematicide Treated Acres: Acres (1,000)
Fruits and Nuts			
Grapes			
Northeast/North Central	59.0	2-3	1-2
Washington and Oregon	39.6	0-1	NEG
California	646.8	12-14	78-91
Other Regions	8.8	0-2	NEG
Subtotal	754.2		79-93
Average		10-12	
Citrus			
Florida	731.7	4-5	29-37
Texas	21.9	50-55	11-12
California and Arizona	301.5	3-4	9-12
Subtotal	1,055.1		49-61
Average		5-6	
Strawberries			
Florida	6.0	100	6
California	24.0	100	24
Other States	19.9	20-30	4-6
Subtotal	49.9		34-36
Average		68-72	
Pineapple[e]	19.9	70-80	14-16
Apples	460.5	1-1.5	5-7
Stone Fruits			
Peaches	172.7	2-3	4-5
Nectarines	32.4	2.5	1
Plums and Prunes	127.2	0.3-0.4	0.4
Cherries	93.0	0.3-0.4	0.3-0.4
Apricots	21.3	NEG	NEG
Subtotal	446.6		5-7
Average		1-2	

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Table 20 (Concluded)
SOIL FUMIGANT AND NEMATICIDE USE FOR U.S. AGRICULTURAL CROPS, 1995

Crop	Planted Acres[a] (1,000)	Fumigant/Nematicide Treated Acres: Percent of Planted Acres	Fumigant/Nematicide Treated Acres: Acres (1,000)
Fruits and Nuts (Continued			
Tree Nuts			
Almonds	400.0	NEG	NEG
Walnuts	169.0	NEG	NEG
Subtotal	569.0		NEG
Average		NEG	
Fruits and Nuts, Total	3,355.2		186-219
Average		6-7	
All Crops, Total	161,967.3		4,845-5,673
Average		3.0-3.5	

[a] Harvested acres for tobacco; bearing acres for tree fruits and nuts and other berries; planted acres for all other crops.

[b] Includes Delaware, Maryland, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida, and Alabama.

[c] Idaho, Washington, and Oregon.

[d] Cantaloupe and honeydew.

[e] Hawaiian pineapple.

Source: SRIC estimates

New Nematode Control Technologies and Products

The tools of biotechnology are providing the means to determine the molecular basis of nematode and host plant interactions and to use that knowledge to (1) develop novel nematode-resistant crops, and (2) exploit natural enemies for biological control.

Transgenic Nematode-Resistant Plants

Since 1991, a number of companies and institutions worldwide have obtained patents relating to transgenic nematode resistant crop; they include:

- Advanced Technologies Bridge Ltd., UK
- Advanced Technologies (Cambridge) Ltd., UK
- Ciba-Geigy (now Novartis), Switzerland

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- Mogen International N.V., Netherlands
- Monsanto Company, USA
- Mycogen Corporation
- Nickerson Biochem Ltd., U.K.
- North Carolina State University, USA
- Pioneer Hi-Bred International, Inc., USA
- Plant Genetic Systems, N.V., Belgium
- Regents of the University of California, USA
- Rijkslandbouwuniversiteit Wageningen, Netherlands
- Sandoz-Erfinidungen Verwaltungs G m.b.H., (now Novartis), Austria
- Unilever PLC, UK
- University of Leeds, UK.

Table 21 provides a summary of transgenic nematode-resistant plant research that may affect the demand for soil fumigants and nematicides in U.S. (and/or world) crop markets within the next 5-10 years.

Table 21
TRANSGENIC NEMATODE-RESISTANT CROP PLANT RESEARCH

Crop	Company/ Institution	Target Nematode(s)	Remarks
Potatoes	Mogen International The Netherlands		Mogen is being acquired by Zeneca.
	Monsanto	Root-knot	
	Plant Genetic Systems, N.V. (Belgium)		The company was acquired by AgrEvo in 1996.
Tomatoes	Mogen International The Netherlands		Mogen has worked with Asgrow Vegetable Seeds to transfer genes for nematode resistance to vegetable crops.
	Plant Genetic Systems, N.V. (Belgium)		PGS is owned by AgrEvo.

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Table 21 (Concluded)
TRANSGENIC NEMATODE-RESISTANT CROP PLANT RESEARCH

Crop	Company/ Institution	Target Nematode(s)	Remarks
Corn	Novartis Seeds	NA	Novartis' Northrup King Division is working on Insect-resistant + nematode-resistant and nematode-resistant + herbicide-tolerant corn hybrids that are expected to be on the market after 2000.
Grapes	University of California-Kearney Horticultural Station	Lepidopteran Insects Ring nematodes Root-knot nematodes	Field trials in 1997.
Soybeans	Monsanto	Root-knot nematodes	
	Mycogen and Pioneer Hi-Bred	Soybean cyst nematode	In December 1995, the two companies entered a research collaboration to develop technology for transgenic pest-resistant plants. One of the targets of the collaboration is soybean cyst nematode-resistant soybeans. Commercial seed products are expected to be launched in 2001-2002.
Sugar Beets	Novartis Seeds	Sugar beet cyst nematode	A patent was obtained in 1993 by Sandoz Inventions, Austria.
	University of Kiel Institute of Crop Science and Plant Breeding (Germany)	Sugar beet cyst nematode	Scientists have identified and cloned a nematode-resistance gene that originated in a wild beet plant. Their goal now is to use the gene to create new lines of resistant sugar beets and other crops.
Tobacco	Mogen International The Netherlands		
	Monsanto	Root-knot nematodes	
	North Carolina State University	Root-knot nematodes	Field trials have demonstrated that the transgenic plants have season-long protection from root-knot damage.
Walnut	University of California-Davis	Lesion nematode	A permit for field trials has been applied for.

Source: Communication with industry and trade literature.

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Biological Nematicides

Table 22 lists biological nematicide products that have been recently registered for U.S. agricultural crops, are under development, or are being evaluated in field trials. Two recently commercialized products, Deny® and Intercept®, are based on strains of the bacterium *Pseudomonas cepacia*. Both are marketed as biological fungicide-nematicide products and control soil-borne fungi that cause seedling damping off as well as nematodes. DiTera®, from Abbott Laboratories, is based on the fungus *Myrothecium verrucaria*. It was registered at the end of 1996 and is available for use on grapes, citrus, and vegetables in 1997.

In addition to those listed in Table 22, other organisms are being evaluated by U.S. nematologists and plant pathologists for control of plant parasitic nematodes in peanuts, vegetables, and fruit crops. Those known to be nematode biocontrol agents include:

- *Pasteuria penetrans*
- *Paecilomyces lilacinus.*
- *Bacillus thuringiensis* (selected strains)
- *Streptomyces costaricanus*
- Several nematophagus fungi.

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Table 22
NEW BIOLOGICAL NEMATICIDES RECENTLY LAUNCHED OR UNDER DEVELOPMENT FOR AGRICULTURAL CROPS

Organism/Product	Target Nematodes and/ or Other Organism(s)	Target Crop Markets	Supplier/Developing Company	Status/Remarks
Burkholderia cepacia *(Pseudomonas cepacia)* type Wisconsin (Deny®)	Nematodes: Lance Sting Spiral Soil fungi: *Fusarium* spp. *Pythium* spp. *Rhizoctonia* spp.	Cotton Fruits and Nuts Vine crops Potatoes Vegetables Other field crops	CCT Corp.	Commercial. Liquid formulation is sold for transplant treatment and for soil application in irrigation water. A peat-based dry formulation is sold for seed or hopper box treatment. Herbs, spices, ornamental and greenhouse crops, and turfgrass are other target markets.
Hirsutella rhossiliensis	Root lesion nematode	Potatoes	USDA/ARS	Under evaluation in New York for suppression of root lesion nematode populations.
Myrothecium verrucaria Strain AARC-0255 (DiTera®)	Broad spectrum of nematodes, including: Citrus Cyst Dagger Reniform Root-knot Root lesion Stubby-root Others	Cotton Cucurbits Other Vegetables Fruits Potatoes	Abbott Laboratories	Approved for use in some states in 1997. A soil applied contact nematicide for application pre- or post- planting. Active ingredient is produced by an isolate of a soil fungus originally isolated from nematode cadavers.

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Table 22 (Concluded)
NEW BIOLOGICAL NEMATICIDES RECENTLY LAUNCHED OR UNDER DEVELOPMENT FOR AGRICULTURAL CROPS

Organism/Product	Target Nematodes and/ or Other Organism(s)	Target Crop Markets	Supplier/Developing Company	Status/Remarks
Pseudomonas cepacia (Intercept®)	Nematodes Damping off fungi	Field Crops Potatoes Vegetables Vine crops Other fruits	Soil Technologies Corp.	Commercial. Formulated as a liquid inoculant for application in the furrow and as a peat-. based seed treatment. Other target markets are greenhouse crops, ornamentals, flowers, bulbs, herbs, and spices.
Telluria mixta	Root-knot nematodes	Cotton Fruit Peanuts Potatoes Tomatoes	Ecogen	Under development by the company's subsidiary, Ecogen Israel Partnership (EIP). Early field trials.
Verticillium lecanii	Soybean cyst nematode	Soybeans	USDA/ARS	A mutant strain of V. Lecanii; under evaluation in field trials.

Source: Communication with industry and trade literature.

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New Chemistry

Table 23 lists six chemical products being evaluated or developed for use as soil fumigants or nonfumigant nematicides for agricultural crops. Two products—cadusafos (Rugby®) from FMC and fosthiazate from ISK Biosciences—have been commercialized outside the United States and both have been under evaluation for U.S. crop markets for a number of years. It is not known when or if they will eventually be registered for use in the United States.

A soil fumigant product, sodium tetrathiocarbonate (Enzone®), from Entek Corp. is the most recently registered new chemical nematode control product. Enzone® was originally developed by Unocal Corp. as GY-81. It achieved its first full EPA registrations—for grapes and citrus—in June 1993. In May 1997, EPA registered Enzone® for pre- and post-planting use on almonds, all other tree nuts, peaches, plums, and prunes to control nematodes, oak root fungus, and Phytophthora root rot.

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Table 23
NEW CHEMICAL SOIL FUMIGANTS AND NEMATICIDES UNDER DEVELOPMENT FOR AGRICULTURAL CROPS

Product	Target Pest	Target Crop Market(s)	Developing Company	Status/Remarks
AKD-3059	Root-knot nematodes Root-lesion nematodes Potato cyst nematode	Cucumbers Carrots Potatoes Radishes Strawberries Tomatoes	Agro Kanesho Company Ltd. (Japan)	Crops listed are those for which the product has been tested in Japan as of early 1997.
cadusafos (Rugby®)	Citrus nematode	Citrus	FMC Corporation	Field trial results in Arizona have indicated that this product is the most promising nematicide for control of citrus nematodes since DBCP was withdrawn from the market in 1977. It is registered for use on citrus in South Africa but has no U.S. crop registrations to date.
2*R*,5*R*-dihydroxymethyl-3*R*,4*R*-dihydroxypyrrolidine (DMDP)	Several nematode species	All crops	British Technology Group (UK)	A botanical nematicide; a pyrrolidine alkaloid derived from *Lonchocarpus costeriensis*. Originally developed by Scottish Crop Research Institute and the Royal Botanical Gardens.
fosthiazate (ASC-66824)	Broad spectrum of nematodes; aphids, thrips, mites	Bananas Coffee Cotton Tree fruits Peanuts Potatoes Vegetables Tobacco	ISK Biosciences	A contact nematicide that also has insecticidal activity against aphids, flea beetles, and the Colorado potato beetle.

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Table 23 (Concluded)
NEW CHEMICAL SOIL FUMIGANTS AND NEMATICIDES UNDER DEVELOPMENT FOR AGRICULTURAL CROPS

Product	Target Pest	Target Crop Market(s)	Developing Company	Status/Remarks
linear secondary alcohols/ ethylene oxide (SM-9)	Reniform nematode *Pythium* spp.	Cotton	SMI (Valdosta, GA)	Field tested in Louisiana cotton in 1995.
methyl iodide	Nematodes Soilborne disease organisms Weeds		n.a.	Under evaluation by University of California-Riverside scientists as a potential alternative to methyl bromide.
ozone (Soilzone®)	Root-knot nematod Citrus nematodees Other nematodes Soilborne disease organisms	Carrots Tomatoes Strawberries Tree and vine crops	Soilzone, Inc. (Sunnyvale, CA)	Use of ozone for soil fumigation is patented and under development in cooperation with University of California scientists. A potential product for use in integrated control programs.
phosphocarb (BAS-301)	Cyst nematodes Root-knot nematodes	Fruits Potatoes Sugarbeets Tobacco Vegetables	BASF	Product is being developed for use in combination with dazomet to increase that product's control spectrum.

Source: Communication with industry and trade literature.

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Future Trends

The ban on the use of methyl bromide for soil fumigation that will go into effect on January 1, 2001 has created opportunities for new, less toxic and more environmentally benign technologies and products for control of nematodes and other soil pathogens. No single chemical or nonchemical option to methyl bromide exists. The three remaining registered soil fumigants, chloropicrin, 1,3-dichloropropene (Telone® II), and metam-sodium, are only partial alternatives, given that their control spectrums are narrower and/or they are not as consistently effective as methyl bromide. Thus, work is under way in Florida, California, and other states where methyl bromide has been heavily relied on for production of high-value annual crops such as tomatoes, peppers, strawberries, and for preplant and replant treatments for orchard and vineyard crops, to develop integrated pest management strategies and integrated crop production systems. In the future, the remaining available soil fumigants are likely to be used in conjunction with cultural or mechanical methods for control of nematodes and soil diseases, in combination with herbicide treatments, and/or in mixtures of two fumigant materials (e.g., 1,3-D + chloropicrin).

Current government, university, and industry research focuses on accumulating basic information that is likely to be instrumental in:

- The development of new crop management alternatives
- More nematode-resistant crop varieties, both traditionally bred and transgenic
- Development of biological nematode control tactics
- An enhanced role for beneficial nematodes
- Design of effective cropping systems to minimize the potential for nematode damage and economic losses.

The overall goal of the current research is to develop sustainable management systems for preventing major economic losses due to nematodes, using strategies to limit crop production costs, enhance crop yields, and protect the environment.

In terms of treated acres, U.S. crop markets for soil fumigants and nematicides are not expected to change significantly during the 1995-2000 period. After 2000, however, the loss of methyl bromide for soil fumigation, coupled with the increasing availability of nematode-resistant crop plants—both transgenic and traditionally bred—is expected to result in a gradual decline in fumigant/nematicide treated acres.

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POTATOES

Fumigant and Nematicide Market, 1995

On the basis of end-user value, potatoes are the largest and most important U.S. crop market for soil fumigants and nematicides. With an estimated grower-level value of $102 million in 1995, potatoes accounted for 30% of the agricultural fumigant and nematicide market. An estimated 32% of the U.S. crop acreage received fumigant/nematicide treatments (see Table 20 in the Overview section). The Northwest (Idaho, Washington, and Oregon) accounted for about 71% of the total treated acres, and the combined Northeast and Upper North Central regions accounted for 15%. Table 24 lists the major nematode problems of U.S. potatoes.

TABLE 24

NEMATODE PROBLEMS OF U.S. POTATOES

Common Name	Scientific Name
Lesion	*Pratylenchus penetrans*
Potato cyst	*Globodera rostochiensis (golden)*
Root-knot	*Meloidogyne arenaria*
	M. chitwoodi
	M. hapla
	M. incognita
	M. javanica
Sting	*Belonolaimus* spp.
Stubby root	*Trichodorus* spp.

Source: University and USDA nematologists and plant pathologists

Overall, root-knot and lesion nematodes cause the most economic damage. Root-knot species are widespread in the primary growing states of the Northwest, the Southeast, and in California. Damage caused by root-knot nematodes on tubers (rough external appearance and internal brown spots) affects their marketability.

The Columbia root-knot nematode (*M. chitwoodi*) is widespread in the western United States and the most serious nematode pest of potatoes grown in the Northwest (Idaho, Washington, and Oregon). It occurs in Colorado, Utah, Idaho, Oregon, Nevada, and northern California. Biology and control studies in Washington show that this species is more important than the northern root-knot nematode (*M. hapla*), because it seems to be adapted to lower temperatures. The Columbia root-knot nematode also attacks corn and wheat, which are common rotation crops for potatoes. On the basis or their ability to

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reproduce on alfalfa, two races of *M. chitwoodi* have been identified in Washington. Race 1 reproduces poorly or not at all on alfalfa, whereas race 2 does reproduce on alfalfa.

Lesion nematodes are the most important pests of potatoes planted in the Northeast and North Central growing regions. They also are potential problems in the Northwest, but are controlled by fumigant treatments targeted for control of root-knot nematodes. Lesion nematodes also are implicated in certain potato disease complexes. Stubby root nematodes are considered serious problems in Florida, where they transmit the tobacco rattle virus that causes "corky ringspot" disease. Stubby root nematodes have also been detected in Oregon and in a few localized, very sandy soils in eastern Washington

In the past, instances of severe crop loss occurred because of the potato cyst (or golden) nematode (*Globodera rostochiensis*) on Long Island, New York; however, because of an effective cooperative containment program of state and federal government agencies, this pest no longer causes economic damage.

In the Northwest, preplant soil fumigation is the principal recommendation of extension advisors for control of root-knot nematodes. Crop rotation—commonly with corn or wheat, which are nonhosts to *M. hapla*, or with alfalfa, which is a poor host for *M. chitwoodi*, race 1 (but is a host for *M. chitwoodi*, race 2)—is also practiced to suppress root-knot populations.

Figure 11 and Table 25 show the breakdown of the U.S. potato market for soil fumigants and nematicides by leading product. Metam-sodium (Vapam®, Busan®, and other brands) is the most widely applied product in this crop market, accounting for 61% of the treated acres and nearly 77% of grower expenditures in 1995. DowElanco's 1,3-dichloropropene (Telone®II) was the next most widely applied product. Other products used were Rhône-Poulenc's ethoprop (Mocap®), minor amounts of chloropicrin (in DowElanco's 1,3-dichloropropene-chloropicrin mixture (Telone® C-17), methyl bromide, oxamyl (Vydate®), and carbofuran (Furadan®). In the Northwest, metam-sodium is applied through sprinkler irrigation systems and is effective against nematodes, diseases, and weeds. It is applied at an average rate of 55 gallons per acre. Mocap® is effective against *M. hapla*, but not against *M. chitwoodi*.

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Figure 11
U.S. POTATO MARKET FOR SOIL FUMIGANTS AND NEMATICIDES BY PRODUCT, 1995

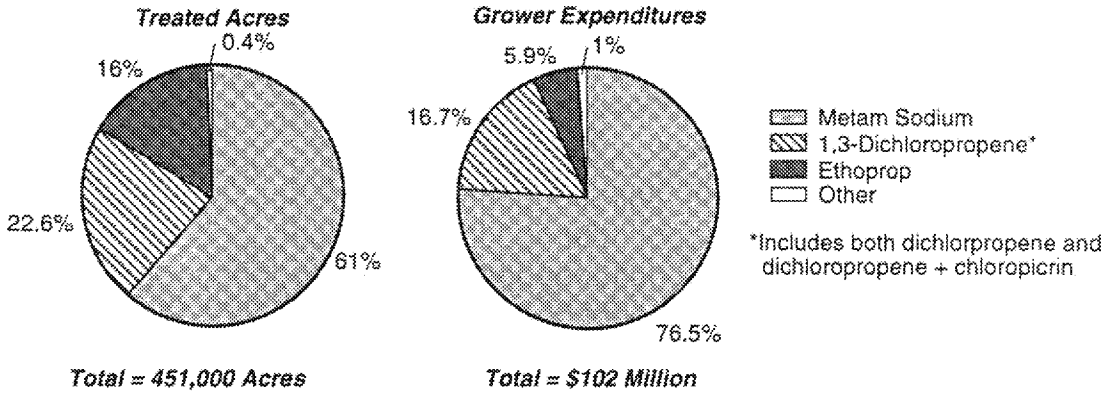

Table 25
U.S. POTATO MARKET FOR SOIL FUMIGANTS AND NEMATICIDES BY PRODUCT, 1995

	Treated Acres		Grower Expenditures	
Product	1,000 Acres	Product Share (%)	1,000 Dollars	Product Share (%)
Metam-Sodium	275.0	61.0	78,248.1	76.5
Dichloropropene	99.7	22.1	16,266.1	15.9
Dichloropropene + Chloropicrin	2.3	0.5	793.5	0.8
Ethoprop	72.0	16.0	6,000.0	5.9
Others[a]	2.0	0.4	917.3	0.9
Total	451.0	100.0	102,225. 0	100.0

[a] Includes methyl bromide, carbofuran, and oxamyl.

Source: SRIC estimates based on grower survey.

Since 1995, aldicarb (Temik®), which was voluntarily withdrawn from the market in 1990, has been reregistered for potatoes in many states and is expected to be popular for both insect and nematode control

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New Nematode Technologies

Transgenic Nematode-Resistant Plants

Transgenic nematode-resistant potatoes are expected to be commercialized in the United States after 2000. Companies working on this technology are Mogen International (acquired by Zeneca in 1997), Monsanto, and Plant Genetic Systems (acquired by AgrEvo in 1996).

Biological Nematicides

Commercially available biological nematicides for use on potatoes include Abbott Laboratories' DiTera® based on *Myrothecium verrucaria*, CCT's Deny® based on *Burkholderia cepacia* (also known as *Pseudomonas cepacia*), and Soil Technologies' Intercept®, also based on *Pseudomonas cepacia* (see Table 22 in the Overview section.) All three products are broad-spectrum nematicides, and the latter two also have activity against soil fungi that cause damping off disease.

Several additional biological nematicides are under development for potatoes. A USDA/ARS plant pathologist in New York is working with the fungus *Hirsutella rhossiliensis*, which shows promise as a potential product for suppression of lesion nematodes. Nematode-resistant potato varieties currently available are not 100% resistant. The USDA researcher hopes that this biological nematode control agent can be formulated for field application and used in conjunction with nematode-resistant potato varieties.

Ecogen's subsidiary in Israel, Ecogen Israel Partnership (EIP), is conducting field trials of a bacterium, *Telluria mixta*, for root-knot nematode control in potatoes and other crops.

New Chemistry

New chemical nematicides under development for potatoes in the United States include ISK Bioscience's organophosphate product, fosthiazate, and phosphocarb from BASF. Agro Kanesho Company, Japan, has a new nematicide compound AKD-3059 that it is testing for potatoes.

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VEGETABLES

Fumigant and Nematicide Market, 1995

U.S. vegetable crop markets for soil fumigants and nematicides amounted to $63 million at the grower level in 1995. An estimated 15-17% of the total vegetable crop acreage was treated with a soil fumigant or contact nematicide. Figure 12 shows the breakdown of the total vegetable crops sector by individual crop market in terms of both treated acres and end-user sales value. Tomatoes rank as the most important vegetable crop market on the basis of both treated acres and market value. Cucurbits and carrots rank as the second and third largest vegetable crop markets for soil fumigants and nematicides, followed by bell peppers and cole crops (see Table 26).

Figure 12
U.S. VEGETABLE CROP MARKETS FOR SOIL FUMIGANTS AND NEMATICIDES, 1995

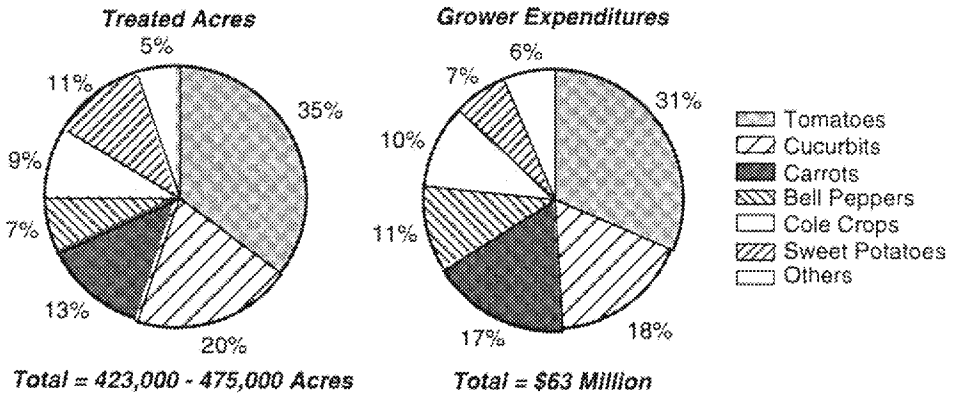

Table 26
END-USER VALUE OF U.S. VEGETABLE CROP MARKETS FOR SOIL FUMIGANTS AND NEMATICIDES, 1995

Market	Millions of Dollars
Tomatoes	20
Cucurbits	11
Carrots	11
Bell Peppers	7
Cole Crops	6
Sweet Potatoes	4
Onions	2
Lettuce	2
Sweet Corn	NEG
Total	63

Source: SRIC estimates

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Table 27 lists the principal nematode species that cause economic damage to major vegetable crops grown in the United States.

TABLE 27

PRINCIPAL NEMATODE PROBLEMS OF VEGETABLE CROPS

Crop	Common Name	Scientific Name
Carrots	Carrot cyst[a]	*Heterodera carrotae*
	Root-knot	*Meloidogyne* spp
Cole Crops	Awl[b]	*Dolichodorus* spp.
	Cabbage cyst	*Heterodera cruciferae*
	Reniform	*Rotylenchulus reniformis*
	Root-knot	*Meloidogyne* spp
	Sting	*Belonolaimus* spp.
	Stubby root	*Trichodorus* spp.
	Sugar beet cyst	*H. schactii*
Cucurbits	Reniform	*Rotylenchulus reniformis*
	Root-knot	*Meloidogyne* spp.
	Sting	*Belonolaimus longicaudatus*
Lettuce	Root-knot	*Meloidogyne* spp
	Root lesion[a]	*Pratylenchus penetrans*
	Needle	*Longidorus africanus*
Onions	Bulb and stem	*Ditylenchus dispaci*
	Root-knot	*Meloidogyne hapla*
	Stubby root	*Trichodorus allius*
Peppers, Bell	Root-knot	*Meloidogyne incognita*
		M javanica
	Stubby root	*Paratrichodorus minor*
		Trichodorus spp.
Sweet Potatoes	Reniform	*Rotylenchulus reniformis*
	Root-knot	*Meloidogyne incognita*
		M. hapla
	Root lesion	*Pratylenchus* spp.
	Spiral	*Helicotylenchus* spp.
	Stunt	*Tylenchorynchus* spp.
Tomatoes	Root-knot	*Meloidogyne hapla*
		M. incognita
	Sting	*Belonolaimus longicaudatus*
	Stubby root	*Trichodorus* spp.

[a] A serious nematode problem for this crop in Michigan.
[b] Awl nematode affects cabbage grown in Florida.

Source: University and USDA nematologists and plant pathologists

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Tomatoes

The tomato market for soil fumigants and nematicides amounted to approximately $20 million in 1995. Of the country's 496,400 acres of tomato plantings, an estimated 30-33% was treated. Most of the treatments were made before planting with broad-spectrum soil fumigant targeted for control of soil-borne disease organisms and weeds, as well as nematodes.

Tomatoes are damaged by a number of nematodes, but throughout the United States, root-knot species are of the most economic importance. In California, root-knot nematodes occur in all growing regions, but are most damaging in sandy soils and/or in older tomato producing areas. Tomatoes grown in Florida are subject to damage from a variety of nematode species, but root-knot, stubby-root (*Trichodorus* spp.) and sting (*Belonolaimus longicaudatus*) nematodes are the most economically important. Root-knot nematodes are problems in Florida's sandy and marl soils, and stubby-root and sting nematodes can damage tomatoes grown in sandy soils.

California, with 74% of U.S. tomato acreage, accounted for about 50% of the total fumigant/nematicide treated acres in 1995. Fumigant/nematicide treatments were made on 20-22% of the California tomato acreage. Metam-sodium, the most widely used fumigant/nematicide product for California tomatoes, is applied primarily for weed control. Most of the fresh market and processing tomato varieties now grown in California are resistant to root-knot nematodes. Methyl bromide-chloropicrin mixtures are applied preplanting to control soil-borne diseases and weeds on a small acreage of staked fresh market tomatoes. These high-value tomatoes are grown mainly in southern California. Oxamyl (Vydate®) is used for nematode control on a small portion of the treated staked fresh market tomato acreage.

Preplant soil fumigation with methyl bromide or methyl bromide + chloropicrin to control soil disease organisms, weeds, and nematodes is an integral component of the "plasticulture" production systems that are used for growing fresh market tomatoes (as well as bell peppers, eggplant, and strawberries) in Florida. An estimated 95-100% of Florida's 48,700 acres of fresh market tomatoes were treated with methyl bromide-chloropicrin mixtures in 1995. Similar production systems are used by tomato growers in Georgia and other Southeastern states.

Considerable research is under way to find alternatives to methyl bromide for nematode, soil disease, and weed control in Florida tomatoes. Use patterns are being developed for Abbott Laboratories' DiTera®, and some work in being conducted on predatory nematodes. Alternative soil fumigants under evaluation are metam-sodium and Telone® II. Mechanical methods under evaluation include solarization and hot water soil treatments. Trials of solarization in combination with low rates of Telone® II are being conducted.

Cucurbits

Cucumbers, muskmelons, and watermelons collectively constituted an $11 million market for soil fumigants and nematicides in 1995. Treatments were made on 15-18% of

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the total U.S. cucurbit crop acreage (see Table 20 in the Overview section).

Root-knot nematodes are the most economically important nematode problems of cucurbit crops grown in California and Arizona. The needle nematode has caused damage to cucurbit crops in California's Imperial Valley growing area. Other nematodes are sometimes found on cucurbits in California but are considered of minor importance.

Although root-knot nematodes are highly damaging to cucurbits, the acreage infested has been limited in most California growing regions. The infested area in the major San Joaquin Valley growing region is likely to increase, however, because cucurbits are typically grown in rotation with tomatoes, cotton, and/or beans—all of which are hosts to root-knot nematodes. Root-knot nematode-resistant cucurbit crop varieties are not available.

Texas and Georgia cucurbits are threatened both by root-knot and by reniform nematodes. Root-knot and sting are the major nematode problems for Florida cucurbits and other nematodes may occasionally cause some economic losses.

Rotation of fields to fallow for 3 to 7 years is the recommended cultural practice for avoiding nematode damage to cucumbers in Florida. In most Florida growing regions, watermelons are typically grown in old pastures or after long rotations to grasses to minimize loses to Fusarium wilt fungi. This cultural practice also prevents serious damage to watermelon crops by root-knot nematodes. In Florida's Southwest region, watermelons are commonly planted after tomatoes or peppers (in the same plant beds) to take advantage of the residual benefits of the preplant soil fumigant treatment that is routinely made for the tomato or pepper crop.

Methyl bromide, methyl bromide + chloropicrin, 1,3-dichloropropene (Telone®II), metam-sodium, oxamyl (Vydate®), and some Furadan® were used for nematode control in cucurbits in 1995.

Carrots

The U.S. carrot market for soil fumigants and nematicides amounted to an estimated $11 million in 1991. From 48–52% of the planted carrot acreage was treated with nematicides. Various root-knot species are the most serious nematode parasites of carrots. The carrot cyst nematode is a serious problem for carrots grown in Michigan.

California accounted for approximately 75% of the fumigant/nematicide treatments made for carrots in 1995, and metam-sodium and methyl bromide were the principal control products applied. Before its suspension in California in April 1990, dichloropropene (Telone® II) was the principal nematicide used for carrots in California. Telone® II and Vydate® were the nematicides used by carrot growers in other states.

Peppers

U.S. bell pepper growers spent an estimated $7 million for fumigants and nematicides in 1995. An estimated 45–50% of the crop acreage received fumigant/nematicide treatments. Bell peppers grown in Florida accounted for 60–65% of the fumigant/nematicide treatments. Florida bell pepper growers use plasticulture

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production systems similar to those used for tomatoes; more than 95% of the state's acreage is treated with methyl bromide. Methyl bromide or metam-sodium was used on 15–20% of California's bell pepper acreage in 1995. Telone®II was used for nematode control by pepper growers in Texas and other bell pepper growing states.

Cole Crops

U.S. growers of broccoli, brussels sprouts, cabbage, and cauliflower spent an estimated $6 million for soil fumigants and nematicides in 1995. Nationwide, an estimated 16% of the 262,200 acres of land used for growing cole crops received fumigant/nematicide treatment. California accounted for 61% of the total cole crop plantings and for 68% of the total treated acres.

Cyst nematodes and root-knot nematodes are considered to be important pests of California cole crops. Cyst nematodes occur in all California cole crop growing regions and can severely damage crops in any soil type. All cole crops are susceptible to cyst nematode damage. The sugar beet cyst nematode is much more widespread in California than the cabbage cyst nematode, which occurs mainly in the northern Central Coast region along the coast of San Mateo County. Sugar beet cyst nematode infestations affect at least 50% of the California's broccoli crop acreage and 75% or more of its cauliflower crop acreage. Heavy cyst nematode infestations can reduce yields and/or delay crop maturity. Brussels sprouts are the least tolerant of cyst nematode infection, followed by cabbage and broccoli. Cauliflower is slightly more tolerant then the other cole crops.

Root-knot nematodes occur in a wide range of soil types, but are most common and cause the most damage in coarse-textured soils (i.e., sandy, loamy sand, and sandy loam soils). Their infestations can cause significant yield reductions, particularly to cole crops raised in warm interior valley regions. Winter cole crops in California's coastal regions are less susceptible to damage from root-knot nematodes.

Nematodes are not perceived as problems for cole crops in Arizona. Reniform nematodes can damage cole crops grown in Texas, whereas root-knot nematodes may require control in cabbage plantings in Georgia. Root-knot, sting, awl, and stubby-root species are the important nematode problems for cabbage grown in Florida. Infested plants are generally smaller than normal, and heavy infestations can result in crop losses. In addition, damage to root systems caused by nematodes can increase the chance of secondary infection by fungi and bacteria. Nematode infestations typically result in 15-20% yield reductions in Florida cabbage.

With the withdrawal from the market of dichloropropene (Telone®II), formerly their nematicide of choice, California cole crop growers switched to fenamiphos (Nemacur®), metam-sodium, and some methyl bromide. These three products were used in 1995. Telone® II has since been reinstate in California, but with restrictions on its use.

Sweet Potatoes

Sweet potatoes represented a $4 million market for soil fumigants and nematicides in 1995. Nematodes were a threat to successful sweet potato production on up to 75% of the

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87,400 acres planted to this crop. Fumigant/nematicide treatments were made on 52–60% of the total crop acreage.

Root-knot species are the primary nematode pests of U.S. sweet potatoes. Damage caused by root-knot nematodes (cracked tubers) affects their value and marketability, resulting in lower market grade and price or rejection of an entire lot. In the Atlantic states, lesion and stunt nematodes are secondary nematode pests of sweet potatoes. These two species usually cause less damage than root-knot species, although their occurrence is more widespread. Reniform nematodes are secondary nematode pests of sweet potatoes in Mississippi and Louisiana; when they occur, they can cause substantial yield reductions. Spiral nematodes, which reduce tuber size, sometimes cause problems in Louisiana.

Telone® II and Temik® are considered the most effective nematicides for sweet potatoes in North Carolina and are the most widely used. In addition to nematodes, soil pox, a disease caused by *Streptomyces ipomoea*, sometimes occurs in a small percentage of North Carolina's sweet potato acreage. Multipurpose fumigants are used as a preplant treatment where both soil pox and nematodes are potential problems. Dichloropropene + chloropicrin (Telone® C-17) is the leading multipurpose fumigant. Use of straight chloropicrin (e.g., Chlor-O-Pic®-100), has increased in recent years.

Nematode problems and nematicide treatments for sweet potatoes in Louisiana have increased substantially since the mid-1980s as a result of a dramatic shift to the nematode-susceptible sweet potato variety, "Beauregard". Mocap® is the most popular nematicide among Louisiana's sweet potato growers. Texas growers primarily use dichloropropene (Telone® II).

Telone® II was the nematicide of choice for sweet potatoes in California before its suspension in the state in April 1990. In 1995, most of California's sweet potato growers used either methyl bromide or metam-sodium, and a few used Mocap®. Soil pox disease also occurs in California; infected soil is fumigated with chloropicrin.

Onions

Onion growers' expenditures for fumigants and nematicides amounted to approximately $2 million in 1995. Preplant treatments were made on 8–10% of the 168,900 acres planted to onions. Telone® II was the principal product used, except in California. Metam-sodium, methyl bromide, chloropicrin, and Telone® C-17 (except in California), were also used. In California, metam-sodium was the principal soil fumigant used for onions. Root-knot (*M. hapla*) and bulb and stem nematodes are the principal nematode problems of onions.

Lettuce

Lettuce is a relatively small market for fumigants and nematicides, with an estimated grower level value of less than $2 million in 1995. Although 45–50% of U.S. lettuce acreage is considered to have potentially damaging nematode infestations, only 2.5–3.0% of the total acreage was treated in 1995.

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Root-knot, needle, stunt (*Merlinius* spp.), and spiral (*Rotylenchus* spp.) nematodes are found in California's lettuce fields. Root-knot nematodes cause economic damage in most areas of the state. The needle nematode damages lettuce plantings in the Imperial Valley growing area, and can cause delayed maturity and reduced head size. Yield losses have been associated with large populations of spiral and stunt nematodes; however, direct proof of these nematodes' pathogenicity has not been established.

Root-knot species constitute the main nematode problem for lettuce in both Arizona and Florida. Stubby-root (*Trichodorus* spp.) and sting (*Belonolaimus* spp.) nematodes are also present in some Florida lettuce fields. Lesion nematodes have caused significant economic losses in lettuce grown in Michigan.

Nonchemical methods are generally relied on to control nematodes in lettuce. Crop rotation and resistant varieties are used in California and Arizona, and some Arizona growers also use flooding to reduce nematode populations. Florida growers employ these three nonchemical methods for nematode control.

Metam-sodium is the principal nematode control product used for lettuce in California and Arizona. A few acres were treated with methyl bromide-chloropicrin mixtures in 1995.

Sweet Corn

Sweet corn is not a significant market for nematode control products. Only 0.1-0.3% of the nation's total planted acreage received chemical treatments specifically targeted at nematodes.

New Nematode Control Technologies

Biological Nematicides

New biological nematicides recently commercialized for U.S. vegetable crop markets include DiTera® from Abbott Laboratories, Deny® from CCT Corp., and Intercept® from Soil Technologies. Ecogen's subsidiary in Israel, EIP, is conducting field trials of a new nematicide reported to be based on *Telluria mixta*, a bacterium, for root-knot nematode control in tomatoes.

New Chemical Nematicides

Fosthiazate from ISK Biosciences and phosphocarb from BASF are under development for nematode control in vegetable crops. Soilzone, Inc. (Sunnyvale, Californiais developing ozone as a soil fumigant. The product, being developed in cooperation with University of California nematologists and plant pathologists, is intended as a less toxic, more environmentally benign alternative to methyl bromide. Tomatoes and carrots are two of thetarget crop market for this new technology.

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COTTON

Fumigant and Nematicide Market, 1995

Cotton is the second largest single crop market for soil fumigants and nematicides, following potatoes, and the largest field crop market. The grower level value of this market was an estimated at $44 million in 1995 An estimated 10–11% of the 16.9 million acres of U.S. cotton crop land received nematicide treatments. Texas, the leading state in cotton acreage (38% of U.S. plantings in 1995), has the most widespread cotton nematode problems; as much as 50% of that state's cotton land is infested with potentially damaging nematode populations.

Several nematode species cause economic losses in cotton (see Table 28). The most important are races 3 and 4 of the southern root-knot nematode (*M. incognita*), sting, reniform, and lance nematodes. Southern root-knot, sting, and reniform nematodes are involved in cotton disease complexes; infection by these parasites increases the incidence and severity of Fusarium wilt and of postemergence "damping-off" caused by various pathogenic fungi. Southern root-knot nematodes are widely distributed and, except in local situations, are the most damaging nematodes in all U.S. cotton growing regions.

TABLE 28

NEMATODE PROBLEMS OF U.S. COTTON

Common Name	Scientific Name
Lance	*Hoplolaimus columbus*
	H. macrostylus
Sting	*Belonolaimus longicaudatus*
Reniform	*Rotylenchulus reniformis*
Southern root-knot	*Meloidogyne incognita*

Source: University and USDA nematologists and plant pathologists

The reniform nematode represents an increasing problem of cotton growers in the Southeast and Mid-South regions and in Texas. This pest has been found in many new areas of the U.S. cotton belt in recent years and is now the most severe nematode problem for cotton in Alabama. As much as 18% of that state's approximately 550,000 acres of cotton growing land is infested to some degree with reniform nematodes, and 5–6% of the annual plantings sustain heavy damaged. Yield losses on 30,000–35,000 aces average 40–50%, and in "stress years," losses have been as high as 75%. Lance nematodes are important in the Southeast, particularly in South Carolina.

Nonchemical techniques, including planting resistant varieties, crop rotation, and fallowing, are most often employed to minimize recognized nematode problems in

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cotton. Chemical control, although effective and expedient, is not economically feasible for many growers.

Aldicarb (Temik®) is the most widely used nematicide for cotton. Fenamiphos (Nemacur®), 1,3-dichloropropene (Telone® II), and metam-sodium are also used. Temik® is the most popular nematicide among Texas cotton growers. Nonfumigant nematicides are generally preferred by Texas cotton growers because of their dual activity against thrips and nematodes. Alabama growers with nematode problems use Temik®, which is routinely applied in the furrow at planting for thrip control, at a higher rate than for thrips alone. Some Alabama cotton growers use Telone® II for nematode control with good results.

Before it was withdrawal from the California market in 1990, Telone® II was the most widely used nematicide for cotton in that state. California cotton growers who applied nematicides in 1995 used Temik® and metam-sodium. Temik® was applied for thrips and/or nematode control on 343,560 acres at an average rate of about 1 pound a.i. per acre. Metam-sodium was applied on 35,295 acres at an average rate of 34.4 pounds a.i. per acre. Although use of Telone® II has been reinstated for cotton in California, the product has not been used so far. Most growers with nematode problems are planting resistant varieties and/or using cultural control methods.

New Nematode Control Technologies

Various commercial companies and university researchers are working on transgenic nematode resistance in cotton, but the work is believed to be in early stages. No field trial permits have been issued for nematode-resistant cotton by the USDA.

Two products based on the bacteria *Pseudomonas cepacia* are currently available for control of nematodes and soilborne fungi in cotton—Deny® from CCT Corp. and Intercept® from Soil Technologies. Abbott Laboratories' new biological nematicide, DiTera® (*Myrothecium verrucaria*) was registered for nematode control in cotton and other crops in 1997. Ecogen's Israeli subsidiary, EIP, has a biological nematicide based on a bacterium in the early development stage for use against root-knot nematodes in cotton. Texas nematologists believe that to be successful for root-knot nematode control in cotton, a biological nematicide must have "high knock-down power."

New chemical nematicides under development for U.S. cotton include fosthiazate from ISK Biosciences and SM-9 from SMI. Both products were evaluated for reniform nematode control in field trials in 1995.

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TOBACCO

Fumigant and Nematicide Market, 1995

In 1995, U.S. tobacco growers spent $36 million for soil fumigants and nematicides used for field applications. An estimated 47–48% of the 663,100 acres of U.S. tobacco fields was treated. Growers spent an additional $4 million-$5 million for plant bed fumigants.

Field treatments are made to control nematodes and/or soilborne diseases. Potentially damaging nematodes are widespread in tobacco fields in states along the Mid- and South Atlantic coast, from Virginia to Florida, as are soilborne diseases such as black shank, black root rot, and Granville wilt. These states annually account for more than 85% of the fumigant/nematicide treatments made for tobacco. Table 29 lists the principal nematode problems of tobacco.

TABLE 29

NEMATODE PROBLEMS OF U.S. TOBACCO

Common Name	Scientific Name
Lesion	*Pratylenchus* spp
	M. hapla
	M. incognita
	M. javanica
Stunt	*Tylenchorynchus* spp.
Tobacco cyst	*Globodera solanacearum*

Source: University and USDA nematologists and plant pathologists

Root-knot nematodes are the most widespread and economically important nematode parasites of flue-cured tobacco grown in North Carolina, South Carolina, Georgia, and Florida. Several root-knot species are present throughout these states, and their relative importance varies from state to state. In addition to the direct damage nematodes cause, these pests are associated with various tobacco root diseases, including Fusarium wilt, black shank, and Granville wilt.

The tobacco cyst nematode (*Globodera solanacearum*) poses a serious problem in Virginia. Although the nematode is not widely distributed, it is the major pathogen where it occurs and takes precedence in crop management practices over black shank disease and all other disease and nematode problems. Historically, it has been confined to the eastern section of Virginia's flue-cured tobacco growing region; but in 1990, it was found in root samples taken from a tobacco field in an adjacent county of North Carolina.

Lesion nematodes are secondary nematode problems for tobacco in Virginia and some other areas. In general, lesion nematodes compete poorly for infection and feeding

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sites when other nematode genera are present. However, they have been associated with the increase in various root diseases.

Kentucky and Tennessee have major tobacco acreage but do not perceive they have nematode problems because of climatic and crop variety differences. However, plant beds are fumigated to control weeds and soilborne diseases.

New Nematode Control Technologies

North Carolina State University conducted field trials of transgenic root-knot nematode resistant tobacco plants during 1993-1995.

Fosthiazate, ISK Biosciences' new organophosphate insecticide-nematicide product, has been evaluated in tobacco field trials for several years.

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FRUITS AND NUTS

Fumigant and Nematicide Market, 1995gure 13 and Table 30 show the relative sizes of U.S. fruit and nut crop markets for soil fumigants and nematicides. Overall, 6-7% of the total fruit and nut crop acreage was treated. The total value of the products applied was an estimated $33 million.

Figure 13
U.S. FRUIT AND NUT CROP MARKETS FOR SOIL FUMIGANTS AND NEMATICIDES, 1995

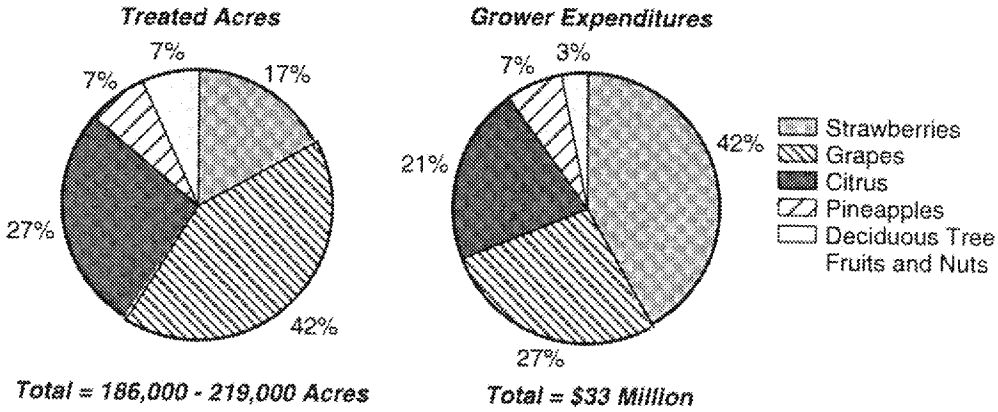

Table 30
END-USER VALUE OF U.S. FRUIT AND NUT CROP MARKETS FOR SOIL FUMIGANTS AND NEMATICIDES, 1995

Market	Millions of Dollars
Strawberries	14
Grapes	9
Citrus[a]	7
Pineapple	2
Deciduous Tree Fruits and Nuts[a]	<1
Total	33

[a] Grower expenditures for postplant nematicides only; products used for preplant soil fumigation are excluded.

Source: SRIC estimates

Table 31 lists the principal economically important nematode parasites of U.S. fruit and nut crops.

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TABLE 31

PRINCIPAL NEMATODE PROBLEMS OF FRUIT AND NUT CROPS

Crop	Common Name	Scientific Name
Citrus	Burrowing	*Radopholus similis*
	Citrus	*Tylenchulus semipenetrans*
Deciduous Tree Fruits and Nuts	Dagger	*Xiphinema americanum*
		X. index
		X. rivesi
	Pin	*Paratylenchus* spp.
	Ring	*Criconemella xenoplax*
	Root-knot	*Meloidogyne. incognita*
		M. javanica
	Root lesion	*Pratylenchus neglectus*
		P. penetrans
		P. vulnus
Grapes	Citrus	*Tylenchulus semipenetrans*
	Dagger [a]	*Xiphinema americanum*
		X. index
		X. pachtaicum
	Ring	*Criconemella xenoplax*
	Root-knot	*Meloidogyne spp.*
	Root lesion [b]	*Pratylenchus vulnus.*
		P. penetrans
Pineapple	Reniform	*Rotylenchulus reniformis*
	Root-knot	*Meloidogyne javanica*
	Root lesion	*Pratylenchus* spp.
Strawberries	Dagger	*Xiphinema americanum*
	Root-knot	*Meloidogyne arenaria*
		M. hapla
		M. incognita
		M. javanica
	Root lesion	*Pratylenchus* spp.

[a] *X. Americanum* and *X. Index* are problems of grapes grown in California. *X. Pachtaicum* affects grapes in Washington.
[b] *P. Vulnus* affects grapes in California and *P. Penetrans* affects grapes in Michigan and Ohio.
Source: University and USDA nematologists and plant pathologists

Strawberries

Strawberries represented a $14 million market for preplant soil fumigants in 1995. Growth in this market since 1985 has been driven mainly by increasing strawberry plantings in California

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Virtually 100% of the strawberry plantings in both California and Florida receives preplant soil fumigant treatment. The treatments are targeted primarily for control of soilborne disease organisms, although they also effectively prevent crop losses due to nematodes. Nematodes are present in 30–40% of California's strawberry acreage and in at least 50% of Florida's crop acreage, but are of minor concern compared with other soilborne pathogens.

Verticillium wilt is a major hazard to successful strawberry cultivation in California, where it is particularly prevalent in land previously planted to tomatoes, potatoes, or cotton, or infested with weeds of the genera *Solanum*, *Senecio*, or *Xanthium*.

In Washington and Oregon, strawberries are generally grown as a three-year crop. Root lesion nematodes are a problem for some growers in these states, and unless controlled, they can reduce the productive lives of plantings to two years at most. Recommended controls are rotation to new land and preplant soil fumigation with 1,3-D or 1,3-D + chloropicrin.

In most other eastern and midwestern strawberry growing areas, fumigation generally has not been considered economical because of shorter production periods and lower yields per acre compared with those in California and Florida. In a number of states, however, strawberry growers have begun to adopt plasticulture systems similar to those of California and Florida strawberry growers; that is, soil fumigation and annual plantings to produce earlier strawberry crops.

Grapes

The grape market for preplant soil fumigants and postplant nematicides amounted to about $9 million at the grower level in 1995. Preplant soil fumigants accounted for about 30% of the market value, and postplant nematicides accounted for about 70%.

Although potentially damaging nematode infestations exist in an estimated 45–50% of the 754,200 acres of bearing vineyards in the United States, 10–11%% of the total acres was treated with postplant nematicides. Most of the postplant treatments were in California, which has 86% of the total U.S. grape acreage.

In California, root-knot nematodes, primarily *M. incognita*, are the most widespread and important nematode pests. Lesion nematodes rank second, and dagger nematodes, because of their more restricted distribution, are considered third in importance. Dagger nematodes cause serious damage themselves and also transmit the fanleaf virus. The citrus nematode is found in a few localities in the central and southern San Joaquin Valley and in the Southern Interior region where both citrus and grapes are grown. Ring nematodes affect grapes grown in the San Joaquin Valley.

Although nematodes pose the greatest threat to grapes in California, other potentially damaging soilborne pests and diseases, including oak root fungus (*Armillaria mellea*), the fanleaf virus (vectored by *Xiphinema index*), and grape phylloxera occur in all of the state's major grape growing regions. An estimated 18–20% of California's vineyard acreage is currently infested with grape phylloxera. A new phylloxera biotype, designated

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Biotype B, has recently been discovered and is seriously affecting vines planted on rootstocks resistant to phylloxera biotype A.

About 90% of the land to be planted or replanted to grapes in California is fumigated before planting. Methyl bromide is the principal fumigant used. Preplant soil fumigation lowers nematode populations to levels permitting vines to become established; however, populations again build up to damaging levels within a very few years. Unless a vineyard is treated periodically with a nonphytotoxic nematicide, the general weakening of vines over time can result in a drastic reduction in their productive life span. In 1995, 1.7 million pounds of methyl bromide were applied to 4,963 vineyard acres.

Fenamiphos (Nemacur®) and carbofuran (Furadan®) are the two nonfumigant nematicide products that are currently registered for postplant treatment of grapes. Furadan® is labeled for control of both nematodes and grape phylloxera, but in California it is used mainly against phylloxera. Furadan® treatments totaled 16,196 treatment acres in 1995. Nemacur® is generally applied at very low rates, mainly through drip irrigation systems. Nemacur® treatments totaled 75,399 treatment acres in 1995; the average application rate was 1.54 pounds a.i. per acre. Although the nonfumigant nematicides do not kill nematodes, they stun and disorient them, and thereby prevent their feeding on grape roots. Enzone®, a liquid soil fumigant from Entek Corporation, was fully registered by the EPA in June 1993 for postplant treatment of grapes for management of plant-parasitic nematodes, phylloxera, and oak root fungus. Enzone® treatments of California grapes totaled nearly 13,000 acres in 1995. Nearly two-thirds of the treated acres were for wine grapes.

Citrus

The U.S. citrus market for postplant nematicides amounted to $7 million at the grower level in 1995. An estimated 49,000–61,000 acres (5-6% of the total U.S. citrus acreage) received postplant nematicide treatment in 1995. The two nematicide products used were (fenamiphos) Nemacur® and aldicarb (Temik®). Nemacur® is applied strictly for nematode control, but most Temik® treatments are targeted for control of the citrus rust mite, other mites, and certain insects, as well as nematodes. Nemacur® is the only postplant nematicide product used for California citrus, whereas Texas growers use only Temik®. Both products are used for citrus in Florida.

For all U.S. citrus growing regions, the citrus nematode (*Tylenchulus semipenetrans*) constitutes the principal problem, causing the "slow decline" of citrus. In Florida, the burrowing nematode (*Radopholus citrofilus*), which causes "spreading decline" of citrus is also of major economic importance.

Two methods of control are used in the burrowing nematode containment program in Florida. In the "push and treat" method, affected groves are first bulldozed and burned. Root pieces are then removed and the soil broken and treated with a soil fumigant. The land is finally maintained vegetation-free for at least six months and can be replanted after two years. In the "buffer" method, disease spread is controlled by strips of fumigated land.

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The citrus nematode is controlled by preplant soil fumigation, the use of tolerant or resistant rootstock, and periodic postplant chemical treatments. Dichloropropene is used for preplant soil). Temik® and Nemacur® are the two products currently available for postplant treatment.

In Florida, citrus acreage with treatable nematode levels has declined in recent years. Following several severe winter freezes that destroyed many citrus groves in the early-to-mid 1980s, Florida's citrus growing industry has been moving southward. Most of the new citrus plantings are on nematode-resistant rootstocks in soils that are relatively free of nematodes.

Entek Corporation's liquid soil fumigant, sodium tetrathiocarbonate (Enzone®) was approved by the EPA in June 1993 for preplant treatments for control of citrus nematodes, *Phytophthora* root rot, and oak root fungus, as well as for periodic postplant treatments for citrus nematode control. Enzone® is registered for use in grapefruit, lemons, and oranges. Results of field trials of FMC's organophosphate nematicide, cadusafos (Rugby®) for control of the citrus nematode in Arizona citrus are promising.

Pineapples

The pineapple market for soil fumigants and nematicides amounted to an estimated $2.0–$2.5 million at the grower level in 1995. This market has declined over the past 30 years as pineapple plantings have declined. Hawaii, which had 64,000 acres of pineapple in 1965, had just 19,900 acres in 1995.

Nematodes are a major economic problem to Hawaiian pineapple producers. All of the pineapple land in the state is infested. The reniform nematode infests most pineapple fields and is the crop's most serious nematode problem. According to researchers estimates, without some form of nematode control, Hawaii's pineapple crop would not be harvestable for the fresh market. Problems with the reniform nematode have increased over the years as a result of monoculture, the use of a single cultivar, soil fumigation, and other agricultural practices.

The Javanese root-knot nematodes (*Meloidogyne javanica*) is also a serious problem for Hawaiian pineapple where it occurs, but it generally is limited to areas within fields or to fields of small acreage within plantations. As with the reniform nematode, monoculture with a single cultivar and reduction of natural antagonists by soil fumigation have caused increased problems with root-knot nematodes. Lesion nematodes can also be serious pests of pineapple in Hawaii.

To control nematodes, a 3-6 month fallow period between plantings is an integral component of the Hawaiian pineapple cropping system. Nearly all of the crop acreage is fumigated two weeks before planting, with either methyl bromide or 1,3-dichloropropene (Telone® II). Telone® II is used for about 75% of preplant treatments.

To ensure successful ratoon crops, postplant nematicides are applied at three-month intervals after planting. Two nonfumigant products, fenamiphos (Nemacur®) and oxamyl (Vydate®), are the principal products used for postplant treatments. They typically are used in rotation to prevent biodegradation of Nemacur®. Ethoprop (Mocap®) was

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recently registered and has been shown in field trials to be a viable alternative to fenamiphos and oxamyl. Fosthiazate from ISK Biosciences has been under evaluation.

Deciduous Tree Fruits and Nuts

This market for nematode control products includes apples, stone fruits, almonds, and walnuts. Sales of postplant nematicides to growers of these deciduous tree fruit and nut crops amounted to less than $1 million in 1995. (Growers spent an additional $2–$3 million for products used for preplant/replant soil fumigation.)

Although nematode problems exist for a substantial percentages of the bearing acreage of most of these crops, only small percentages of the total acreage receive postplant nematicide treatment. Apples and peaches represented the largest deciduous tree crop markets for postplant nematicides in 1995; however, postplant treatments were applied to only 1.0–1.5% of U.S. apple acreage and to just 2-3% of U.S. peach acreage

P. penetrans probably causes the most widespread and extensive damage to deciduous tree fruits and nuts. Root lesion nematodes damage apples, stone fruits, and tree nuts in most U.S. growing regions; however, they are not considered a problem of peaches and other tree fruits in the Southeast. Root-knot nematodes have been of minor importance for California stone fruits and almonds in recent years because of a shift to Nemaguard rootstock, which is generally resistant to root-knot species. Nemared, a more recently introduced rootstock, has higher resistance to root-knot nematodes than Nemaguard.

The ring nematode is a severe problem for almonds and peaches planted in sandy soils in the three northern counties of California's San Joaquin Valley. This nematode is believed to predispose trees to bacterial canker, a disease caused by an airborne bacterium, *Pseudomonas syringae*. The shift to Nemaguard and Nemared rootstocks, which are resistant only to root-knot nematode species, may be a cause of increasing problems with both ring and lesion nematodes. University of California nematologists have found evidence that these species cause more severe injury to Nemaguard and Nemared than to other stone fruit and almond rootstocks.

Root-knot and ring nematodes result in the most extensive damage to the peach industry in the southeastern United States. The ring nematode predisposes peach trees to cold injury, the primary causal agent of tree death associated with the peach tree short life (PTSL) disease complex.

"Replant disease"—poor or uneven growth of trees planted on old orchard sites—is a problem for growers of pome and stone fruits in the northeastern United States. Nematodes, especially root lesion nematodes, have been closely associated with replant failure; however, several other soilborne microorganisms are also involved

Fenamiphos (Nemacur®) was the only available postplant nematicide for deciduous fruit and nut trees in 1995. In May 1997, however, Entek Corp.'s Enzone® was registered for pre- and post-plant use on almonds, other tree nuts, peaches, plums, and prunes to control nematodes as well as oak root fungus and Phytophthora root rot.

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New Nematode Control Technologies

The University of California- Kearney Horticultural Station has obtained a USDA permit to conduct field trials of grapes with genetically engineered resistance to Lepidopteran insects, and to ring and root-knot nematodes in 1997. In July 1997, the University of California-Davis applied for a permit to conduct a field trial of root lesion nematode-resistant walnuts.

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SUGAR BEETS

Fumigant and Nematicide Market, 1995

Sugar beets represent a $27 million market for soil fumigants and nematicides. In 1995, an estimated 18–20% of the total U.S. sugar beet acreage received nematicide treatments.

The sugar beet cyst nematode and root-knot species are the most damaging nematodes associated with sugar beet production in the United States (see Table 32). The sugar beet cyst nematode causes the most economic loss and ranks as one of the most economically important nematode parasites of all U.S. agricultural crops. This major pest has since been found in all major sugar beet producing areas. Root-knot nematodes are considered a major problem of sugar beets grown in California. The false root-knot nematode is of secondary importance in certain localized regions (e.g., western Nebraska) and occasionally causes severe damage.

TABLE 32

NEMATODE PROBLEMS OF U.S. SUGAR BEETS

Common Name	Scientific Name
False root-knot	*Nacobbus aberrans*
Root-knot	*Meloidogyne* spp
Sugar beet cyst	*Heterodera schachtii*

Source: University and USDA nematologists and plant pathologists

The sugar beet cyst nematode is controlled by cultural and chemical methods. Fortunately, this pest has a relatively narrow host plant range, and crop rotation is the traditional method employed for control. However, a four- to five-year rotation is required to reduce nematode populations to numbers low enough to allow sugar beet plants to become established. Because some nonhost crops (legumes, grains, potatoes, onions) produce lower income, growers generally cannot afford more than a two- to three-year rotation. Therefore, chemical control is often used in combination with crop rotation.

Root-knot nematodes are more widespread than sugar beet cyst nematodes in California's sugar beet producing regions. They are difficult to control by crop rotation because of their wide range of host plants. Where mixed populations of more than one root-knot species are present, rotation is virtually impossible and chemical control is necessary.

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Since April 1990, when 1,3-dichloropropene (Telone® II) was suspended in California, either aldicarb (Temik®) or high rates of metam-sodium have been used for nematode control for the state's sugar beets.

Temik®) is used to control the sugar beet cyst nematode in northern sugar beet growing regions. This product's advantages include its nonphytotoxicity (it can be applied at planting or as a side dress at the time of thinning), its systemic activity, and its insecticidal activity against a number of sugar beet insect pests.

New Nematode Control Technologies

Research in Europe may lead to the availability of transgenic nematode-resistant sugar beet varieties before 2005. Organizations that are conducting this research are identified hin Table 21 in the Overview section.

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PEANUTS

Fumigant and Nematicide Market, 1995

Peanut growers spent and estimated $13 million for soil fumigants and nematicides in 1995. An estimated 23–25% of the U.S. peanut crop received fumigant/nematicide treatments. States in the Mid-Atlantic and Southeast account for about 90% of the annual peanut fumigant/nematicide treatments. Table 33 indicates the principal nematode pests of peanuts.

TABLE 33

PRINCIPAL NEMATODE PROBLEMS OF U.S. PEANUTS

Common Name	Scientific Name
Ring	*Criconemella* spp.
Root-knot	*Meloidogyne arenaria*
	M. hapla
Root lesion	*Pratylenchus* spp.
Sting	*Belonolaimus longicaudatus*

Source: University and USDA nematologists and plant pathologists

Overall, the peanut root-knot nematode (*M. arenaria*) is the most destructive nematode affecting peanuts. In addition to reducing crop yields, this nematode causes odd-shaped discolored pods that have lower market grade and value. Root lesion nematodes (*P. brachyurus*) are widely distributed in all peanut growing regions of the Southeast and can cause yield losses of several hundred pounds per acre

Ring nematodes occur in high populations in peanut fields in Virginia and North Carolina peanut fields and are involved in the pod rot complex. Sting nematodes are also implicated in the pod rot complex and cause significant damage in some southeastern states. Sting nematodes are the most serious nematode problem of peanuts grown in North Carolina.

Nematode-resistant peanut varieties are not commercially available. Chemicals are employed to control nematodes when they cannot be controlled by cultural practices or by crop rotation. For growers with limited peanut land or those who grow peanuts under irrigation, crop rotation is not economically feasible. Peanuts are a relatively high income crop compared with rotation crops such as corn and small grains. Irrigation systems are costly, and growers need to grow crops that provide sufficient income to justify their irrigation costs.

Granular nonfumigant nematicides are popular with peanut growers in the Mid-Atlantic states because most have dual insecticidal and nematicidal activity, and because

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they are less expensive than fumigant nematicides. Temik® is the most popular granular nonfumigant nematicide, followed by fenamiphos (Nemacur®) and ethoprop (Mocap®). Soil fumigants used for peanuts include dichloropropene (Telone® II) and metam-sodium. Metam-sodium is used by peanut growers in Mid-Atlantic states to control black root rot (*Cylindrocladium crolalariae*), a soilborne fungal disease that interacts with root-knot nematodes.

New Nematode Control Technologies

University of Florida nematologists are working on biological control of nematodes in peanuts. A bacterial parasite of root-knot nematodes, *Pasteuria penetrans*, has shown great potential as a biological control.

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CORN

Fumigant and Nematicide Market, 1995

The corn market for nematicides had an end-user value of approximately $13 million in 1995. Although an estimated 15-20% of the total U.S. field corn acreage was infested with nematodes at potentially damaging population levels, only slightly more than 1% of the total crop acreage was treated with nematicides. Nematode problems in corn are generally the most severe in the Mid-Atlantic and Southeast regions where typically, 15–18% of the annual corn plantings receive nematicide treatments. Nematode parasites of corn are indicated in Table 34.

TABLE 34

NEMATODE PROBLEMS OF U.S. CORN

Common Name	Scientific Name
Dagger	*Xiphinema americanum*
Lance	*Hoplolaimus* spp.
	H. columbus
	H. galeatus
Needle	*Longidorus* spp.
Root-knot	*Meloidogyne incognita*
	M. arenaria
	M. javanica
Root lesion	*Pratylenchus* spp.
	P. penetrans
	P. scribneri
Spiral	*Helicotylenchus* spp.
Sting	*Belonolaimus* spp.
Stubby root	*Paratrichodorus* spp.
Stunt	*Tylenchorynchus* spp.

Source: University and USDA nematologists and plant pathologists

Root lesion nematodes are probably the most widespread and potentially destructive nematode pests on corn in the Corn Belt, Lake States, and Northern Plains regions. Sting and stubby root nematodes are serious problems that limit corn production in sandy soils in the Southeast. Uncontrolled infestations have caused yield reductions as high as 50%. Although present in the Southeast, root lesion nematodes are not a serious problem except in heavier soils.

In general, corn nematode problems are most commonly associated with continuous corn (i.e., corn planted after corn), but some problems have occurred in corn rotated with

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forage legumes (e.g., red clover, alfalfa), soybeans, or small grains. Nematode problems in some of the principal corn-producing states (e.g., Illinois) have only recently been recognized by nematologists and plant pathologists. Farmers generally do not recognize nematode problems unless yield losses or plant growth effects are dramatic; however, yield losses of 5–10% may occur without dramatic above-ground symptoms.

Terbufos (Counter®) and ethoprop (Mocap®), both dual-activity insecticide-nematicide products, are the two products used for nematode control in 1995. Both products are labeled for suppression of a broad spectrum of nematode species.

New Nematode Control Technologies

Transgenic nematode resistance traits may be available in corn hybrids before 2005.

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SOYBEANS

Fumigant and Nematicide Market, 1995

The grower level value of the U.S. soybean nematicide market was less than $7 million in 1995. Although approximately 30% of the total annual crop acreage is infested with nematodes, only 1% or less of the 62.6 million acres of U.S. soybean plantings received nematicide treatment in 1995. Most of the treatments occurred in southern states.

Table 35 lists nematode problems of soybeans. The soybean cyst nematode (SCN), the most important nematode parasite for soybeans, causes a destructive "yellow dwarf" disease and infests as much as 70% of the soybean acreage in southern U.S. growing regions.

Root-knot nematodes rank as the second most important soybean nematode problem on a national basis, but in most southeastern states, root-knot species represent a more serious threat to soybean production than does SCN. Lance, reniform, dagger, sting, stubby root, and root lesion nematodes are also problems in some southeastern U.S. localities.

TABLE 35

NEMATODE PROBLEMS OF U.S. SOYBEANS

Common Name	Scientific Name
Dagger	*Xiphinema americanum*
Lance	*Hoplolaimus columbus*
	Hoplolaimus macrostylus
Reniform	*Rotylenchulus reniformis*
Root-knot	*Meloidogyne arenaria*
	M. incognita
	M. incognita
	M. javanica
Root lesion	*P. alleni*
	P. penetrans
	P. scribneri
Soybean cyst	*Heterodera glycines*
Sting	*Belonolaimus* spp.
	Belonolaimus longicaudatus
Stubby root	*Paratrichodorus christiei*

Source: University and USDA nematologists and plant pathologists

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Because soybeans have relatively low market value, the use of chemicals for nematode control is not feasible for many growers. Currently available nonfumigant nematicides are not considered effective in soils that are heavily infested with root-knot nematodes or against the soybean cyst nematode. The only available fumigant nematicide, Telone® II, is considered too expensive. In addition, it must be applied well ahead of planting, which limits growers' flexibility.

Because of the lack of affordable chemical nematicides, more and more southern soybean growers are practicing crop rotation as a means to lessen nematode problems. Planting resistant varieties is another important means of nematode control in soybeans. However, because nematodes are able to overcome plant resistance by adapting, affordable and effective soybean nematicides will continue to be needed. Each time a different SCN race is found, resistance to that new race must be developed and several years' of plant breeding research is required to transfer resistance to soybean cultivars. In addition, because some race 4-resistant varieties have less desirable agronomic traits than susceptible soybean varieties, growers with race 4 problems may prefer to plant susceptible varieties and use a nematicide. Some nematologists in the Southeast believe that the use of ineffective nematicides (or insecticidal rates of contact nematicides, which are not adequate for nematode control) has resulted in selection of nematode species that are more difficult to control (e.g., *Meloidogyne javanica*).

New Nematode Control Technologies

Transgenic nematode-resistant soybean varieties are expected to be developed and on the market after 2000. The market potential for nematode-resistant soybeans is expected to be 15–20% of the total annual soybean crop acreage.

In December 1995, Pioneer Hi-Bred International and Mycogen Corporation formed a research collaboration to develop technology for transgenic crops with built-in pest resistance using Mycogen's proprietary Bt genes. The soybean cyst nematode is one of the target pests of this collaboration. Pioneer also has obtained world and U.S. patents covering a method for introgressing soybean cyst nematode resistance into elite soybean germ plasm.

The USDA/ARS is evaluating a mutant strain of *Verticillium lecanii* for control of the soybean cyst nematode in soybeans.

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OTHER FIELD CROPS

Sugar cane and mint are other field crop markets for nematode control products, which amounted to about $2 million at the grower level in 1995. Sugar cane accounted for most of the total. Nonfumigant insecticide-nematicide products are applied for sugar cane, whereas preplant soil fumigants are used for mint in the Pacific Northwest.

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BIOLOGICAL PESTICIDES

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INTRODUCTION

Biological pesticides are based on naturally occurring or modified pathogenic organisms and biochemical pest control agents. They include microbial organisms, i.e., bacteria, fungi, viruses, and protozoa; products based on entomophagous nematodes; and botanical pesticides produced from chemicals found in plants, e.g., pyrethrins, azadiractin, nicotine, others. Insect control products based on synthesized insect pheromones are also classified as biological insecticides.

Microbial pesticides are target specific; nontarget species are unlikely to be affected by their use, and their application requires only a small amount of an active ingredient that already exists in nature. Botanical pesticides typically have a broader spectrum of pesticidal activity than microbial pesticides, and some are toxic to fish and other cold-blooded animals. However, they tend to be short-lived and break down rapidly in the environment when exposed to light, air, and/or water.

Insect pheromones and attractants (classified as semiochemicals or behavior-modifying chemicals) are biochemicals that are used mainly in products for detection and monitoring of pest populations. However, several companies market pheromone-based insect control products for use in integrated pest management programs for cotton, tree and vine crops, tomatoes, and other specialty and niche markets.

This report—which completes SRI Consulting's 1997-1998 *Biotechnology and New Chemistry* multiclient program—reviews recent trends in world and U.S. sales of commercial biological pesticide products by product type and provides projections for sales in 2002; identifies market participants and their biological pesticide products; and lists the biological insecticide, fungicide, herbicide, and nematicide products that are currently on the market or under development worldwide. Although estimates of world and U.S. pheromone product sales are provided, a very limited amount of information on pheromone product suppliers was developed for this report. The market size estimates and projections for each product group are based on interviews with more than 20 executive officers and marketing directors of U.S.-based biological pesticide companies.

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OVERVIEW

WORLD MARKET

In 1997 the world market for biological pesticides amounted to an estimated $245 million at the end-user level. Insecticides accounted for 94% of the total market, fungicides for 4%, and herbicides for about 2% (Figure 1)

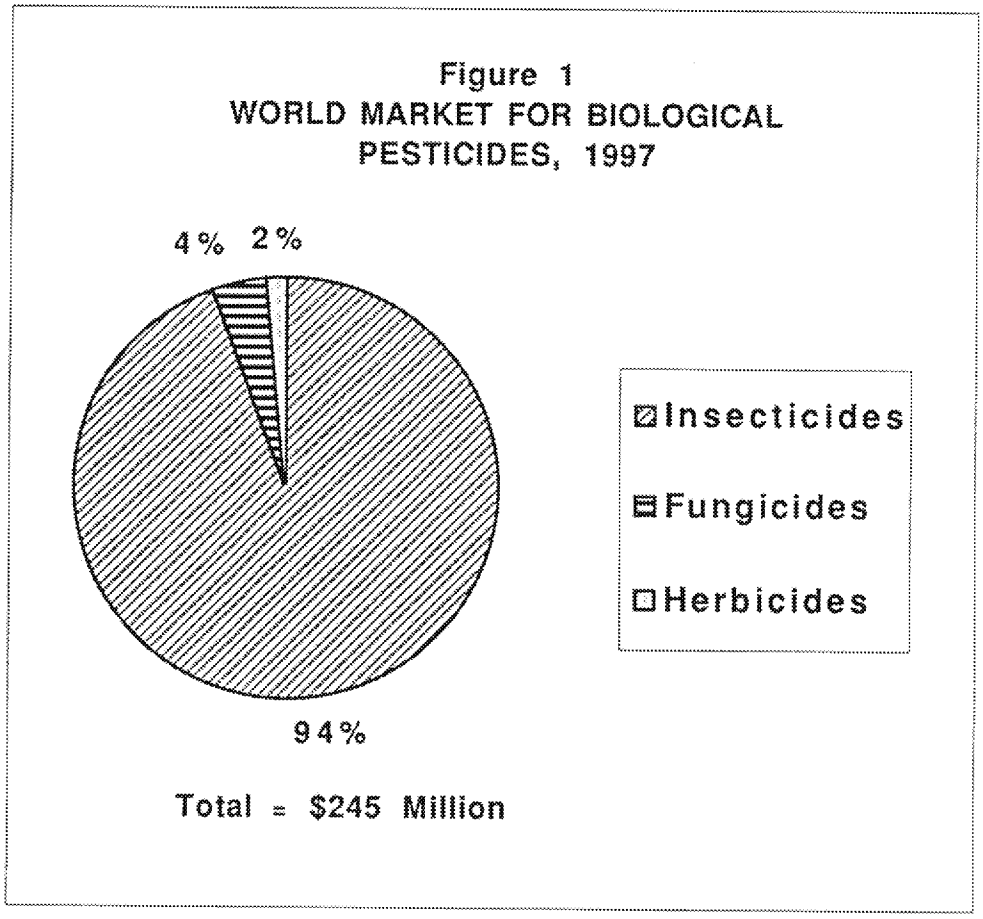

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Figure 2 and Table 1 summarize estimated world sales of biological pesticides by product type in 1995-1998 and provide projections for sales in 2002. Biological insecticide sales declined by 25% between 1995 and 1998, but sales of each of the three other biopesticide product groups increased.

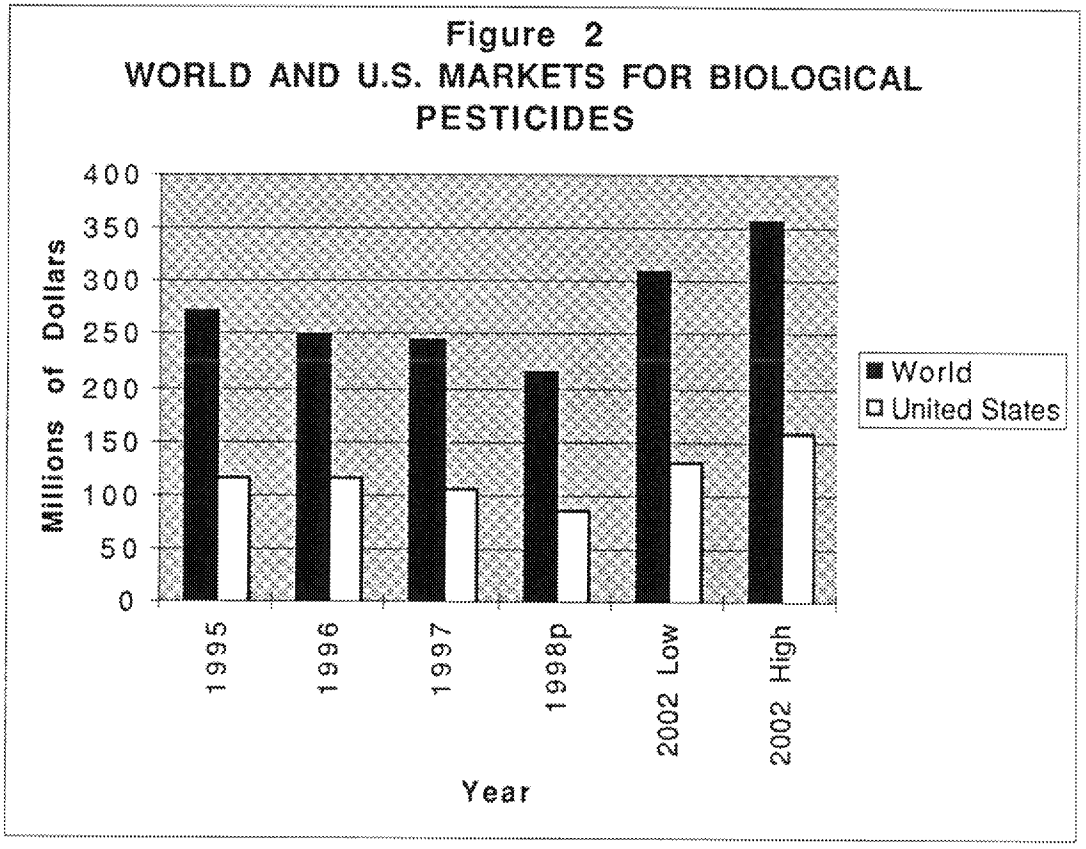

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Table 1
WORLD MARKET FOR BIOLOGICAL PESTICIDES, 1995-2002
(Millions of Dollars, End-User Sales)

Product Group	1995	1996	1997	1998p	2002
Insecticides					
Bts	125	120	105	97	115-120
Fungi	2	3	4	5	10-15
Viruses	5	3	3	3	10-15
Nematodes	8	5	2	3	5-6
Pheromones	45	30	32	33	40-50
Botanicals					
Pyrethrins[a]	67	69	70	35	70-75
Azadiractin	11	13	15	20	20-25
Total	263	243	231	196	270-306
Fungicides	6	4	10	13	20-25
Herbicides	4	4	4	5	16-20
Nematicides	–	–	NEG	< 2	4-7
Total	273	251	245	216	310-358

a Estimates for pyrethrins are manufacturer level sales.

Source: SRIC estimates.

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The United States is the largest world regional market for biological pesticides, and accounted for about 44% of the total market in 1997 and about 41% in 1998. Table 2 provides estimates of biological pesticide sales in the United States by product type in 1995-1998 and presents projections for 2002.

Table 2
U.S. MARKET FOR BIOLOGICAL PESTICIDES, 1995-2002

Product Group	1995	1996	1997	1998p	2002
Insecticides					
Bts	50	50	40	38	45-48
Fungi	1	1	2	2	3-4
Viruses	–	NEG	NEG	1.5	4-5
Nematodes	4	4	1	2	3-4
Pheromones	10	10	10	11	15-20
Botanicals					
Pyrethrins[a]	49	46	47	24	35-38
Azadiractin	1	2	3	3	5-8
Total	115	113	103	82	111-129
Fungicides	1	1	2	3	10-15
Herbicides	2	2	2	2	8-10
Nematicides	–	–	NEG	< 1	2-4
Total	118	116	107	88	131-158

a Estimates for pyrethrins are manufacturer level sales.

Source: SRIC estimates.

Insecticides

Worldwide commercial sales of biological insecticides declined from $263 million in 1995 to an estimated $196 million in 1998. The U.S. market declined from $115 million in 1995 to $82 million in 1998. The 25% decline in the world market and 29% decline in the U.S. market resulted primarily from reduced demand for Bt-based products and a declining supply of natural pyrethrum for production of pyrethrins-based insecticides.

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Bts

The world market for Bts declined by 22% during 1995-1998 due to the introduction of transgenic insect-resistant cotton, over-production of Bt, and lower Bt prices. The U.S. market for applied Bt products declined both because of the rapid acceptance of transgenic Bt cotton and potatoes, and a decline in the forestry market caused by cyclic pest problems.

The United States is the largest world regional market for Bt-based insecticides, accounting for 38% of the total world market in 1997 and for 39% in 1998, based on estimated sales at the end-user level. Table 3 provides estimates of U.S. and Canadian Bt sales by market in 1998.

Table 3
U.S. AND CANADIAN MARKETS FOR BT, 1998
(Millions of U.S. Dollars, End-User Sales)

	United States	Canada	Total
Agricultural Crops			
Vegetables	16	<1	17
Deciduous tree crops	4	<1	5
Grapes	2	–	2
Citrus	3	–	3
Corn	<1	–	<1
Cotton	1	–	1
Other field crops[a]	3	–	3
Total	30	<2	32
Nonagricultural			
Blackfly and/or mosquito control	5	<1	6
Forestry	2	2	4
Other[b]	1	1	2
Total	8	4	12
Total, All Markets	38	6	44

a Mainly alfalfa and tobacco.

b Includes stored products, commercial ornamentals, professional turf, and consumer home and garden markets.

Source: SRIC estimates.

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Agricultural crop markets accounted for 79% of the total U.S. Bt market, the aquatic/public health market (for mosquito and blackfly control) accounted for about 13%, and forestry accounted for about 5%. Forestry represents the largest market for Bts in Canada, followed by specialty agricultural crops (i.e., vegetables and deciduous tree crops).

Although many industry experts contacted in this study believe that the world and U.S. Bt markets have "bottomed out" in 1998, most expect only modest growth (1.8%-2.7% per year, on average) for 1998-2002. World and U.S. Bt sales are expected to remain below the 1995 levels through 2002. The Bt market projections are based on the following:

- There will be increasing world demand for Bt var. *israelensis (Bti)* for black fly and mosquito control
- Demand for Bts in the European forestry market will increase
- Demand for Bts in the European fruit and vegetable crop markets will increase because of food safety concerns
- Increasing competition from new "softer" biologically based insecticides such as Dow AgroSciences' spinosad (Tracer®, other trade names), Novartis' Proclaim®, and new insect growth regulator products will limit growth in demand for Bts.
- Plantings on transgenic insect-resistant crops will continue to increase.

Fungi

The world market for fungal insecticides amounted to an estimated $5 million in 1998, based on end-user sales of commercial products. By 2002, sales of this biological insecticide group are expected to amount to $10 million-$15 million. Most of the growth will be outside the United States. The U.S. market will grow from about $2 million in 1997 and 1998 to $3 million -$4 million in 2002. These projections assume the following:

- Availability of new fungal insecticides that are as effective as—or more effective than—chemical insecticides against whitefly and mosquito larvae
- Development and commercialization of other new fungus-based products
- Improvements in fermentation technology for production of fungal products
- Unless new products are commercialized, the biofungicides market will be flat.

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Viruses

The world market for viral insecticides currently amounts to about $3 million at the end-user level, and the U.S. market accounts for about half of the total market. By 2002, the world market is expected to grow to $10 million-$15 million, and the U.S. market to $4 million -$5 million based on the following:

- Food Quality Protection Act (FQPA) regulations favor the use of softer pesticides, including virus-based products.
- Improved virus formulations are becoming available and offer better persistence and better shelf life.
- There is increasing market awareness and knowledge of how to use viruses and incorporate them into crop pest management programs.
- Should recombinant virus-based products be commercialized, their market acceptance will depend on growers' determination of their benefits and cost effectiveness. It is unlikely that recombinant viruses will gain easy acceptance in Europe; however, the United States and Southeast Asia are potential markets.

Nematodes

The U.S. market for insect control products based on beneficial nematodes declined during 1995-1998 because of supply constraints. Thermo Trilogy Corporation had difficulty in producing nematodes following its acquisition of Biosys at the end of 1996.

Growth markets for beneficial nematodes during 1997-2002 are expected to be in the United States and Europe. Nematodes, like viruses, will be helped in the U.S. market by FQPA regulations and possible restrictions on conventional insecticide products.

Newer nematode-based products have more consistency of field performance and better shelf life than earlier products, and they are expected to fit well in the ornamental nurseries, professional turf, and cranberries markets.

There is a trend toward small-scale production of nematodes adapted for specific niches. Overall, there have been improvements in nematode production efficiency.

Pheromones

The U.S. market for pheromone-based insect control products has been flat during 1995-1998, primarily because of replacement of pheromones in the cotton market by transgenic Bt cotton. Tree and vine crop markets for pheromone-base products have been stable since 1995, and the U.S. tomato market has declined due to tomato acreage cutbacks in Florida and California.

Competition from Bt cotton may also result in loss of a large Egyptian cotton market for pheromone-based products. However, the Egyptian government may encourage continued use of pheromone products in order to keep farm workers employed. A considerable amount of hand labor is used to apply pheromone-based products to cotton plants.

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Insect resistance to organophosphate insecticides, wider acceptance of pheromone control products by growers of tree crops, and FQPA regulations are factors that are expected to lead to growth in the U.S. pheromones market.

Botanicals

The principal botanical insecticides in use today are products derived from pyrethrum or extracted from neem seed. A weather-induced pyrethrum production shortage in East Africa (drought followed by floods) caused the decline in the world market for pyrethrins-based products in 1998. Prior to this shortage, both the world and U.S. markets were fairly constant from year-to-year. The world market is expected to recover to about the 1997 level by 2002, and may increase by as much as 5-7%. However, availability of lower-cost alternatives such as synthetic pyrethroid insecticides and a questionable supply are factors that may limit sales of natural pyrethrins-based products.

World commercial sales of azadiractin (neem seed extract)-based insecticides amounted to an estimated $15 million in 1997 and $20 million in 1998. The U.S. market amounted to about $3 million per year in 1997 and 1998. The world market has nearly doubled since 1995.

By 2002, world sales of azadiractin-based pesticides may grow to $25 million and U.S. sales may increase to $5-8 million, based on the following:

- The price of neem seed extract imported from India is declining, allowing neem-based products to be sold at prices affordable in agricultural crop markets.
- South America represents an expanding market for azadiractin-based products.
- Amvac Chemical Company, a new supplier of azadiractin-based products in the United States, 's bringing an additional azadirachtin product to market
- Recent new European registrations for azadirachtin-based products.

Fungicides

The world and U.S. markets for biological fungicides are expected to increase rapidly during 1998-2002. By 2002, the world market is projected to amount to $20 million -$25 million, of which the United States will account for $10 million-$15 million. These projections are based on the following:

- Increasing popularity of biofungicides in professional turf markets, especially golf courses, because of turf managers' needs to comply with "green" politics and environmental concerns.
- Increasing awareness of the new concept of biological disease control in U.S. markets

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- Expected market launch before 2002 of at least two new efficacious biofungicide products for control of *Botrytis* and *Phytophthora*
- Major growth based on market acceptance in the fruit and vegetable crop market sectors
- The ability of biofungicides to offer equal—or better—efficacy and cost effectiveness than chemical fungicides for higher-value specialty agricultural crops, turf, and ornamentals
- Switching from synthetic chemical fungicides to more user-friendly biological fungicides by growers concerned about worker safety.

However, most existing biofungicide products have limited efficacy, particularly when applied under adverse weather conditions.

Currently, microorganisms sold as biological fungicides by "mom and pop" operations without EPA or other country registrations account for approximately 20% of the world biofungicides market. In the United States, this occurs because of a legal loophole that allows such products to be sold as long as specific fungicidal claims are not made for them.

Herbicides

For 1998, worldwide sales of biological herbicides are estimated at about $5 million, and U.S. sales at about $2 million. By 2002, the U.S. market is expected to grow to $8 million -$10 million and the world market to $16 million-$20 million. FQPA regulations and increased government emphasis on "sustainable" agriculture will spur strong growth in U.S. demand for bioherbicides.

Nematicides

World sales of biological nematicides totaled less than $2 million in 1998. The United States accounted for about half of the total bionematicide market. By 2002, the world market is expected to grow to $4 million-$7 million, and the U.S. market to $2 million-$4 million.

MARKET PARTICIPANTS

Table 4 is an alphabetical listing of companies and other organizations worldwide that are commercial producer/suppliers of biological pesticides. The table identifies the microbial, nematode-based, and botanical pesticide products marketed or under development by each company. Information on pheromone-based suppliers and products was not developed for this report, although a limited amount of available information on pheromone-based products is included in the table.

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Table 4
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
Abbott Laboratories					
North Chicago, Illinois, USA	F	Fungi	*Trichoderma* spp. Strain T-39	--	EUP in 1997; registration trials
	H	Fungi	*Phytophthora palmivora*	DeVine®	This product was discontinued in 1993 and reactivated in 1995
	I	Bacteria	*Bacillus sphaericus*	Spherimos®	Product acquired from Novo Bio Kontrol
	I	Bacteria	*Bacillus sphaericus*	VectoLex®	
	I	Bacteria	*Bacillus thuringiensis* subsp. *aizawai*	Florbac®	Product acquired from Novo Bio Kontrol
	I	Bacteria	*Bacillus thuringiensis* subsp. *aizawai*	XenTari®	
	I	Bacteria	*Bacillus thuringiensis* subsp. *israelensis*	Bactimos®	Product acquired from Novo Bio Kontrol
	I	Bacteria	*Bacillus thuringiensis* subsp. *israelensis*	Vectobac®	
	I	Bacteria	*Bacillus thuringiensis* subsp. *israelensis*	Gnatrol®	
	I	Bacteria	*Bacillus thuringiensis* subsp. *israelensis*	Skeetal®	Product acquired from Novo Bio Kontrol
	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki*	ABG-6389	Public testing
	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki*	Biobit®	Product acquired from Novo Bio Kontrol.
	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki*	Dipel®	Registered for use on more than 200 different crops.
	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki*	Foray®	Product acquired from Novo Bio Kontrol

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Table 4 (Continued)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
Abbott Laboratories (Continued)	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki* and *Bt* subsp. *aizawai*	ABG-6415 and ABG-6422	Field screening
	I	Bacteria	*Bacillus thuringiensis* subsp. *tenebrionis*	Novodor®	Product acquired from Novo Bio Kontrol
	I, F	Fungal metabolite	NA	BK-226	Under development. A fermentation product acquired from Novo Bio Kontrol
	N	Fungi	*Myrothecium verrucaria* Strain AARC-0255	DiTera®	A soil applied contact nematicide for application pre- or post-planting.
AgBioChem, Inc. Orinda, California, USA	F	Bacteria	*Agrobacterium radiobacter* Strain 84	Galltrol-A®	
AgraQuest, Inc. Davis, California, USA	F	Bacteria	NA	Serenade® AQ 713	U.S. registration pending. A product for control of *Botrytis cinerea.*
	F	Bacteria	NA	Sonata® AQ 153	U.S. registration pending. A product for control of *Phytophthora, Alternaria,* and other pathogens.
	I	Fungi	*Lagenidium giganteum*	Laginex™	Active ingredient is a naturally occurring water mold fungus.
Agri Phi Inc. Logan, Utah, USA	F	Bacteria	*Xanthomonas campestris*, var. *vesicatoria*	--	

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Table 4 (Continued)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
Agri Tech					
Crowley, Louisiana, USA	I	Fungi	*Verticillium lecanii*	Vertalec®, Mycotal®	
Agrimm Technologies, Ltd.					
Christchurch, New Zealand	F	Fungi	*Trichoderma harzianum* and *T. viride*	Trichopel®, Trichoject® Trichodowels®, Trochoseal®	
American Cyanamid Company					
Parsippany, New Jersey, USA	I	Viruses	*Lymantria dispar* NPV	--	Development discontinued?
	I	Viruses, Recombinant	*Autographica californica* NPV (AcNPV)	--	Development discontinued?
Andermatt Biocontrol AG					
Grossdietvil, Switzerland	I	Fungi	*Beauveria brogniartii* Strain 96	Engerlingspliz	
	I	Nematodes	*Heterorhabditis* spp	Nemotoden®	
	I	Viruses	*Adoxophyes orana* Granulosis Virus	Capex® 2	
	I	Viruses	*Cydia pomonella* Granulosis Virus	Madex®	
BASF					
Limburgerhof, Germany	F	Bacteria	Reynoutria sachalinensis	Milsana®	
Becker Microbial					
Plantation, Florida, USA	I	Bacteria	*Bacillus thuringiensis* subsp. *israelensis*	AquaBac®	Technical grade powder is sold to formulators
	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki* Strain 123	BMP 123	

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Table 4 (Continued)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
Bio Agri					
Sweden	F	Bacteria	*Pseudomonas* chlororaphis		
Bio-Care technology Pty. Ltd.					
Somersby, Australia	F		*Agrobacterium radiobacter* Strain K84	Norbac 84-C™	
Bio-Innovation AB					
Algaras, Sweden	F	Fungi	*Trichoderma harzianum* and *T.polysporum*	BINAB® T	Product is licensed to Binab Bio-Innovation AB in Europe where it is used to combat silver leaf fungus.
BioLogic Company					
Willow Hill, Pennsylvania, USA	I	Nematodes	*Steinernema carpocapsae*	Ecomask®	
	I	Nematodes	*Heterorhabditis bacteriophora*	Heteromask®	
	I	Nematodes	*Steinernema carpocapsae*	Scanmask®	
	I	Nematodes	*Steinernema carpocapsae*	Termask®	
BioWorks Inc.					
Geneva, New York, USA	F	Fungi	*Trichoderma harzianum* Strain T22	Biotrek®	Distributed exclusively by Wilbur-Ellis Company.
	F	Fungi	*Trichoderma harzianum* Strain T22	Rootshield®	Sold through distributors in the United States, Europe, and Japan.
	F	Fungi	*Trichoderma harzianum* Strain T22	T22™ Planterbox	Patented strain of T. *harzianum*. Sold through 15 U.S. distributors.

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Table 4 (Continued)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
Borregaard and Reitzel					
Denmark	F	Fungi	*Trichoderma harzianum*	Supresivit®	Also available from Fytovita, Czech Republic
CCT Corp.					
Carlsbad, California, USA	F, N	Bacteria	*Burkholderia cepacia* *Pseudomonas* cepacia) Type Wisconsin	Deny®	A peat-based formulation is sold for seed or hopper box treatment. A liquid formulation is sold for transplant treatment and for soil application in irrigation water.
DuPont Agricultural Products					
Wilmington, Delaware, USA	I	Viruses, Recombinant	*Autographica californica* NPV (AcMNPV)	--	
	I	Viruses, Recombinant	*Heliothis* NPV	--	
Eco Soil Systems					
San Diego, California, USA	H	Bacteria	*Xanthomonas campestris*	X-PO™	Acquired rights to product from Mycogen in 1998.
Ecogen					
Langhorne, Pennsylvania, USA	F	Fungi	*Anpelomyces quisqualis* Isolate M-IO	AQ IO™	
	F	Yeast	*Candida oleophia* isolate I-182	Aspire™	Distributed to packing houses by Decco.
	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki* strain 2371	Cutlass®	This product is being replaced by the newer and more active Crymax.

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Table 4 (Continued)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
Ecogen (Continued)	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki* Strain EG 2348	Condor®	This product is available in different formulations aimed at different markets.
	I	Bacteria, Recombinant	*Bacillus thuringiensis* subsp. *kurstaki* strain 7826	Lepinox®	
	I	Bacteria, Recombinant	*Bacillus thuringiensis* subsp. *kurstaki* Strain EG 7841	Crymax™	Replaced older nonrecombinant product, Cutlass®.
	I	Bacteria, Recombinant	*Bacillus thuringiensis* subsp. *kurstaki* strain 7673	Raven™	Replaced Foil®, launched in 1989.
	I	Nematodes	*Heterorhabditis bacteriophora*	Cruiser™	
EcoScience Corp					
East Brunswick, New Jersey, USA	I	Fungi	*Metarhizium anisopliae* Strain ESCI	Bio-Blast™	Produced for Terminix.
	I	Fungi	*Metarhizium anisopliae* Strain ESFI	Bio-Path™ Cockroach Control Chamber	
Produce Systems Division					
Orlando, Florida, USA	F	Bacteria	*Pseudomonas* syringae Strain ESC-IO	Bio-Save® 100, Bio-Save® 1000	Products for postharvest application to fruit as drench, dip, or spray.
	F	Bacteria	*Pseudomonas* syringae Strain ESC-I1	Bio-Save® 110	Product for postharvest application to pears. ESC-I1 is licensed from the USDA
	F	Yeast	*Cryptococcus lauentii*	--	Under development for postharvest disease control on fruits. A beneficial yeast with fungicidal activity.

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Table 4 (Continued)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
Forestry Canada, Forest Pest Management Institute					
	I	Viruses	Douglas Fir Tussock Moth NPV	Vitruss®	
Forward International					
Taipei, Taiwan	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki*	Forwabit®	
Grondortsmettingen DeCuester n.v.					
Katelijne-waver, Belgium	F	NA	*Trichoderma* spp.	Bio-Fungus	
Gustafson Inc.					
Dallas, Texas, USA	F	Bacteria	*Bacillus subtilus* MB 600 ATCC-SD +414	GUS-376	Under development. A biological seed treatment fungicide.
	F	Bacteria	*Bacillus subtilis*	Kodiak®, Epic®	Kodiak® is usually applied with chemical fungicides in seed treatments or as a hopper box treatment. Epic® is a commercial seed treatment product.
	F	Bacteria	*Bacillus subtilus*	Quantum 4000® HB	

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Table 4 (Continued)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
Helena Chemical Company					
Memphis, Tennessee, USA	F	Bacteria	*Bacillus subtilus* and chemical pesticides	System 3	A dust formulation of B. *subtilis* with chemical pesticides that is sold for seed treatment in planter boxes.
Hydro-Gardens Inc.					
Colorado Springs, CO, USA	I	Nematodes	*Heterorhabditis bacteriophora*	Lawn Patrol	
IGENE Technology					
Iowa State University					
Ames, Iowa, USA	I	Viruses, Recombinant	*Rochiplusia ou* (Ro NPV)	--	
Japan Tobacco					
Tokyo, Japan	F	Bacteria	*Pseudomonas gladioli*	AM-301	Under development for vegetable crops.
	H	Bacteria	*Epicoccosorus nematosorus*	JTH-103	Under development for rice
	H	Bacteria	*Exserohiilum monoceras*	JTH-102	Under development for rice.
	H	Bacteria	*Xanthomonas campestris*	JTH-101	Licensed from Michigan State University and developed jointly with Mycogen Corp.
JH Biotech					
Ventura, California, USA	F	Fungi	*Trichoderma harzianum* and *T. viride*	Promote®	

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Table 4 (Continued)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
Kemira Agro OY					
Helsinki, Finland	F	Bacteria	*Streptomyces griseoviridis* Strain K61	Mycostop®	Sold in Europe and the United States. Used to control pathogens that cause seed, root, and stem rots and wilt diseases of vegetables, field crops, greenhouse crops, and ornamentals.
	F	Fungi	*Gliocladium catenulatum*	Glio Mix®	
	F	Fungi	*Gliocladium catenulatum*	NA	Under development for horticultural crops.
	F	Fungi	*Gliocladium catenulatum* Strain J1446	Primastop®	EPA registration applied for.
	F	Fungi	*Phlebia gigantea*	Rotstop®	Used as a stump treatment for felled trees.
KFZB Biotechnik GmbH					
Berlin, Germany	F	Bacteria	*Bacillus subtilus* FZB24	Rhizo-Plus, Rhizo-Plus Konz.	
Koppert B.V.					
KoppertBiological					
Veilingweg, The Netherlands	I	Fungi	*Verticillium lecanii*	Microgermin®	Produced for Chr Hansen Biosystems.
	I	Nematodes	*Heterohabditis* spp.	Larvanem®	
	I	Fungi	*Verticillium lecanii*	Mycotal®	
	I	Fungi	*Verticillium lecanii*	Vertalec®	

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Table 4 (Continued)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
Kubota Biotech					
Japan	I	Bacteria	*Bacillus thuringiensis* subsp. *aizawai*	KM 303	Under development in collaboration with Mycogen.
	I	Bacteria	*Bacillus thuringiensis* subsp. *japonensis* strain *buibui*	KM 503	Under development in collaboration with Mycogen.
	I	Nematodes	*Steinernema kushidai*	NA	Under development for turf.
Lipha Tech					
Milwaukee, Wisconsin, USA	F		*Bacillus cereus*	UW 85	A biological seed treatment fungicide. Licensed from the University of Wisconsin.
Makhteshim Chemical Works, Ltd.					
Beer Sheva, Israel	F	Fungi	*Trichoderma harzianum* Strain T39	Trichodex®	Marketed in Australia
Mauri Foods					
North Ryde, Australia	F		*Pseudomonas flourescens* Strain NCIB-12089	Conquer®, Victus®	Marketed in the United States as Victus® by Sylvan Spawn Laboratory, Kittanning, PA.
MicroBio Ltd.					
Cambridge, England	F	Bacteria	*Bacillus subtilis*	--	Under development for suppression of root and soil pathogens of ornamentals and residential landscape plants.

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Table 4 (Continued)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
MicroBio Ltd. (Continued)	I	Nematodes	*Heterorhabditis megidis*	Nemasys® H	Marketed in the UK, Denmark, and the Netherlands for control of black vine weevil on ornamentals.
	I	Nematodes	*Steinernema feltiae*	Nemasys®, Nemasys® M	MicroBio is a subsidiary of Agricultural Genetics Company, Ltd. Product is marketed in the UK, Denmark, and the Netherlands. The Geiger Companies, Harleysville, PA have the rights to market and distribute this product in the United States. Nemasys® M is a product for mushrooms.
Mycogen					
San Diego, California, USA	I	Bacteria, recombinant	*Bacillus thuringiensis* subsp. *kurstaki*, encapsulated delta endotoxin	M-C™	Under development for international markets only.
	I	Bacteria, recombinant	*Bacillus thuringiensis* subsp. *kurstaki* (encapsulated delta endotoxin)	M-Peril®	
	I	Bacteria, recombinant	*Bacillus thuringiensis* subsp. *kurstaki* and Bt subsp. *aizawai*, encapsulated delta endotoxins	Match®	
	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki* (encapsulated delta endotoxin)	MVP® II	
Mycontrol, Ltd.					
Nazereth Elit, Israel	F	Fungi	*Trichoderma* spp.	Trichoderma 2000	Formerly "TY"

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Table 4 (Continued)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
Mycotech Corporation					
Butte, Montana, USA	I	Fungi	*Beauveria bassiana* Strain GHA	BotaniGard®	
	I	Fungi	*Beauveria bassiana* Strain GHA	Mycotrol®	Developed in cooperation with the USDA.
	I	Fungi	*Beauveria bassiana* Strain MYCO-9701	Stemgard®	Under development for corn.
Natural Plant Protection S.A.					
Nogueres, France	F	Bacteria	*Pseudomonas solanacearum*	PSSOL™	
	F	Fungi	*Fusarium oxysporum* Strain FO 47	Fusaclean®	A biological fungicide based on a naturally occurring mutant antagonistic strain of *F. oxysporum*. *On the market in Europe.*
	F	Fungi	*Trichoderma harzianum Strain TH 11*	Harzian®	
	I	Allelochemical substances and a chitin enzyme inhibitor	NA	Biomite®	A biological acaricide composed of allelochemical substances that increase the mobility of mites; acts as a chitin enzyme inhibitor.
	I	Fungi	*Beauveria bassiana* Strain 147	Ostrinil®	
	I	Fungi	*Beauveria brogniartii* Strain Bb 96	Betel®	Product for control of the sugar cane white grub in sugar cane.
	I	Pheromones	Cornstalk borer pheromone	Sesaline®	Mating disruptant product formulated as micro granules and EC.
	I	Viruses	*Cydia pomonella* Granulosis Virus	Carpovirusine	Marketed in Europe for pome fruits.

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Table 4 (Continued)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
Natural Plant Protection S.A. (Continued)	I	Viruses	*Lymantria dispar* NPV	Lymantrin®	Sold in Europe for gypsy moth control in forests.
	I	Viruses	*Manestra brassica* NPV	Mamestrin®	
	I	Viruses	*Spodoptera littorallis* NPV	Spodopterin®	
New Bio Products, Inc.		Bacteria			
Corvallis, Oregon, USA	F		*Agrobacterium radiobacter*	Nogall™, Diegall™	
Nitto Denko Corporation					
Osaka, Japan	I	Fungi	*Beauveria brogniartii*	BioLisa™	
Philom Bios					
Saskatoon, Saskatchewan, Canada	H	Fungi	*Colletotrichum gloeosporiodes* f sp *malvae*	BioMal®	
Plant Health Technologies					
Boise, Idaho, USA	F	Bacteria	*Pseudomonas flourescens* A 506	Blight Ban™ A506	Company is a division of J.R. Simplot Co., Boise, ID. Product is applied post harvest to fruit as a drench, dip, or spray.
	F	Bacteria	*Pantoea agglomerans*	Blight Ban™ C9-1	A product for control of fire blight on apples and pears.
	F	Bacteria	*Streptomyces lydicus*	--	Patented bacterium licensed from the Idaho Research Foundation, Inc. Also licensed to Natural Industries, Inc. (Houston, TX). Plant Health Technologies is conducting small-scale field tests and has applied for an EPA registration.

Table 4 (Continued)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
Plant Production Institute					
Bratislava, Slovak Republic		Fungus	*Pythium oligandrum*	Polygandron™	Applied to sugar beets as a seed treatment or soil incorporated.
Prophyta Biologischer Pflanzenschutz GmbH					
Malchow/Poel, Germany	F	Fungi	*Coniothyrium minitans*	Contans™	A product for control of *Sclerotinia* spp. in greenhouse vegetables.
Radonja					
India	I	Bacteria	*Bacillus thuringiensis* subsp. *israelensis*	Moskitocid®	Commercial product for mosquito control.
S.I.A.P.A.					
Bologna, Italy	F	Fungi	*Fusarium oxysporum*	Biofox™ C	Sold in Europe for tomatoes and ornamentals. Application methods include seed treatment and soil incorporation.
SafeScience, Inc.					
Boston, Massachusetts, USA	F	Other	Carbohydrate compounds, naturally derived	Elexa®	Company was formerly IGG International. Product is a nontoxic compound that stimulates a plant's internal immune system to make it less susceptible to diseases.
Sanex, Inc.					
Ontario, Canada	I	Bacteria	*Bacillus thuringiensis* subsp. israelensis	Vectocide®	Sanex, Inc. is a wholly owned subsidiary of Wilson Laboratories, Inc. The product is toll manufactured for export.

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Table 4 (Continued)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
Sanex, Inc (Continued)	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki*	Bactosid® K	Toll manufactured for export.
Seabright Corporation					
St. Johns, Newfoundland, Canada	I	Fungi	Entomophaga aulicae	--	Under development for forestry. Fermentation technology has been developed and patented and the company is looking for commercial partners.
	I	Fungi	Entomophaga gryili	--	Under development for grasshopper control in rangeland and pastures and some agronomic crops.
	I	Fungi	Entomophaga maimaiga	--	Under development for gypsy moth control in forests.
Soil Technologies Corp.					
Fairfield, Iowa, USA	F, N	Bacteria	*Pseudomonas* cepacia	Intercept®	A biological product for control of fungal pathogens and nematodes in a wide variety of agricultural crops, greenhouse crops, and ornamentals.
Toagosei Chemical Industry Co., Ltd.					
Tokyo, Japan	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki*	Toarow® CT	Commercial product for vegetables, tree fruits, and tobacco.
Tecomag SRL					
Formigine (Modena), Italy	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki*	Agrobac®	Marketed for field crops and vegetables in Europe.

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Table 4 (Continued)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
Thermo Trilogy Corporation Columbia, Maryland, USA	F	Fungi	Gliocladium virens Type GL21	SoilGard®	Originally a product of W.R. Grace.
	F, I, M	Botanical	Neem oil	Trilogy®, Triact®	Trilogy® is sold for agricultural crop use and Triact® for ornamentals and landscapes.
	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki*	Able®	Acquired from Novartis Crop Protection.
	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki*	CoStar®	New more potent strain of Btk. Acquired from Novartis; originally a Sandoz Agro product.
	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki*	Javelin®, Delfin®	Acquired from Novartis Crop Protection. Sold in Europe as Delfin®;
	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki*	Thuricide®	Acquired from Novartis Crop Protection. Originally a Sandoz Agro product.
	I	Bacteria	*Bacillus thuringiensis* subsp. *aizawai*/kurstaki transconjugant	Agree®, Turex®	Product is sold in Europe as Turex®. Acquired from Novartis Crop Protection.
	I	Bacteria	*Bacillus thuringiensis* subsp. *aizawai*/*kurstaki* transconjugant	Design®	Acquired from Novartis Crop Protection.
	I	Fungi	*Paecilomyces fumosoroseus*	PFR-97	Licensed from the University of Florida.
	I	Viruses	*Anagrapha falcifera* NPV (celery looper virus)	--	Product acquired from Novartis Crop Protection. Licensed from the U.S. Department of Agriculture

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Table 4 (Continued)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
Thermo Trilogy Corporation (Continued)	I	Viruses	*Helicoverpa zea* NPV	GemStar®	Distributed by Helena Chemical
	I	Viruses	*Spodoptera exigua* NPV	Spod-X®	Distributed by Helena Chemical Company.
	I	Nematodes	*Steinernema carpocapsae*	BioSafe®, Savior® Millennium®	
	I	Nematodes	*Steinernema feltiae*	X-Gnat®, Magnet®	Distributed to nurseries and greenhouses by EC Geiger and to mushroom houses by Spawnmate™.
	I, N	Nematodes	*Steinernema riobravis*	BioVector® 355	Distributed by UAP, Florida Fertilizer, and Diamond R Fertilizer
	I, N	Nematodes	*Steinernema riobravis*	Devour® Vector®	Marketed as Devour® by United Agri Products and as Vector® by Lesco, Inc.
	I	Botanical	Azadirachtin	Neemix®, Azatin®, Neemazad®	
Troy Biosciences, Inc.					
Phoenix, Arizona, USA	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki*	Troy Bt™	Formerly Larvo Bt.
	I	Fungi	*Beaveria bassiana* Strain ATCC 74040	Naturalis®	This product was originally discovered and developed by Fermone Crop., which was purchased by Troy Bio-sciences in 1995
Uniroyal Chemical Company					
Middlebury, Connecticut, USA	I	Bacteria	*Bacillus thuringiensis* subsp. *kurstaki*	Biocot®	

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Table 4 (Continued)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
United States Department of Agriculture	H	Fungi	*Colletotrichum truncatum*	--	Soil applied product for control of hemp sesbania in cotton, soybeans, and peanuts. Public testing.
	H	Fungi	*Puccinia carduorum*	--	Biocontrol organism obtained from Turkey. In registration trials for control of musk thistle.
	I	Fungi	*Edhazardia aedis*	--	Field screening stage for mosquito control.
	N	Fungi	*Verticillium lecanii*, mutant strain		Field screening for control of soybean cyst nematode in soybeans.
University of California Davis, California, USA	I	Viruses	Codling moth granulosis virus (CMGV)	Specific-T-I	Registered with the US EPA; available for licensing.
University of Florida Gainesville, Florida, USA	I	Fungi	*Beauveria bassiana*	--	Patented product for control of fire ants and household pests. Available for licensing.
	I	Nematodes	*Steinernema scapterisci*	--	A product for control of mole crickets in turf. Patented and available for licensing.
University of Minnesota St. Paul, Minnesota, USA	I	Protozoa	*Nosema fumacali*, NMP microsporidian	--	Field screening for control of European corn borer in corn.

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Table 4 (Concluded)
WORLD SUPPLIERS OF BIOLOGICAL PESTICIDES, 1998

Company/ Headquarters Location	Type	Technology	Pathogen	Trade Name	Remarks
University of Wisconsin					
Madison, Wisconsin, USA	F	Bacteria	*Bacillus cereus* UW85	Zwittermicia A	Public testing for control of damping-off in alfalfa.
	F	Bacteria, Recombinant	*Pseudomonas* syringae pv syringae	--	Field screening for control of bacterial brown spot in green beans.
	F	Bacteria, Recombinant	*Rhizobium and Sinorhizobium*	--	Genetically modified nitrogen-fixing bacteria in field screening for control of bacteria-caused soil diseases in alfalfa, beans, and clover.
USDA Forest Service					
Hamden, Connecticut, USA	I	Viruses	*Lymantria dispar* NPV	Gupchek™	
Morgantown, West Virginia, USA	I	Viruses	*Orgyia psuedotsugata* NPV	TM Biocontrol™	

Sources: Communication with industry and trade literature.

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PRODUCTS AND MARKETS

INSECTICIDES

The most successful biological pesticides to date are microbial insecticides based on strains of the bacterium *Bacillus thuringiensis* (Bt) that control Lepidopteran, dipteran, and coleopteran pests. Bt-based insecticides have been available since the mid-1930s and over the years, thousands of Bt strains have been isolated and screened for pesticidal activity. The most widely used strains have been Bt variety *kurstaki* for control of Lepidoptera (i.e., caterpillars) and Bt variety *israelensis* for control of diptera—specifically mosquito and blackfly larvae. In the last ten years, new Bt products based on Bt subspecies *tenebrionis* (for control of Colorado potato beetle) and Bt subspecies *aizawai* (for Lepidopteran insect control, especially the diamondback moth and armyworms) have been commercialized.

The first generation of Bts and other biological insecticides had limited ability to compete with conventional chemical pesticides because of characteristic shortcomings, including:

- Narrow spectrum of activity
- Short shelf life
- Slow action
- Lower efficacy than chemical pesticides
- Higher cost than most chemical pesticides.

In the early 1990s, the first products in second-generation Bt insecticides, based on transconjugated or genetically engineered Bt strains, were commercialized by Mycogen, Ecogen, Abbott Laboratories, and Ciba–Geigy (now Novartis). In the mid-to-late 1990s, Ecogen and Mycogen launched new Bt products based on recombinant strains of Bt.

Table 5 lists commercial microbial, nematode-based, and botanical insecticide products and new products under development worldwide as of fall 1998. For each product the table indicates the supplying company, product trade name(s), target pests, and current or target markets. The table also indicates the development stage of each product.

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Table 5
BIOLOGICAL INSECTICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Pest(s)	Markets	Development Stage
Bacteria				
Bacillus sphaericus				
Spherimos®	Abbott Laboratories North Chicago, Illinois, USA	Mosquito larvae	Aquatic/public health	Marketed outside the United States. Acquired from Novo Bio Kontrol.
VectoLex®	Abbott Laboratories North Chicago, Illinois, USA	Mosquito larvae; most effective on *Calex* species	Aquatic/public health	Commercial
Bacillus thuringiensis subsp. *aizawai*				
Florbac®	Abbott Laboratories North Chicago, Illinois, USA	Diamondback moth	Vegetables	Commercial
KM 303	Kubota Biotech Japan	*Spodoptera spp.*	Vegetables	Registration trials; developed in collaboration with Mycogen.
XenTari®	Abbott Laboratories North Chicago, Illinois, USA	Lepidopteran larvae, especially armyworms and diamondback moth	Vegetables, fruits, field crops, nursery and greenhouse crops	Commercial
Bacillus thuringiensis subsp. *aizawai/kurstaki* transconjugant				
Agree®, Turex®	Thermo Trilogy Corporation Columbia, Maryland, USA	Lepidopteran larvae	Vegetables, tree and vine crops, field crops, forestry	Commercial
Design®	Thermo Trilogy Corporation Columbia, Maryland, USA	Lepidopteran larvae	Cotton, soybeans	Commercial

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Table 5 (Continued)
BIOLOGICAL INSECTICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Pest(s)	Markets	Development Stage
Bacteria (Continued)				
Bacillus thuringiensis subsp. *Israelensis*				
AquaBac®	Becker Microbial Plantation, Florida, USA	Mosquito and blackfly larvae	Public health/aquatic	Commercial
Bactimos®	Abbott Laboratories North Chicago, Illinois, USA	Mosquito larvae	Public health/aquatic	Commercial
Gnatrol®	Abbott Laboratories North Chicago, Illinois, USA	Fungus gnats	Greenhouse ornamentals	Commercial
Moskitocid®	Radonja India	mosquito larvae	Public health, mosquito control	Commercial
Skeetal®	Abbott Laboratories North Chicago, Illinois, USA	Mosquitoes and blackfly larvae	Public health/aquatic	Commercial
Vectobac®	Abbott Laboratories North Chicago, Illinois, USA	Blackfly and mosquito larvae	Public health/aquatic	Commercial
Vectocide®	Sanex, Inc. Ontario, Canada	Mosquito and blackfly larvae	Public health	Commercial
Bacillus thuringiensis subsp. *Japonensis* strain buibui				
KM503	Kubota Biotech Japan	Cupreous chafer, other soil insects	Sweet potatoes, turf	Registration trials to initial marketing; developed in collaboration with Mycogen.

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Table 5 (Continued)
BIOLOGICAL INSECTICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Pest(s)	Markets	Development Stage
Bacteria (Continued)				
Bacillus thuringiensis subsp. *kurstaki*				
ABG-6389	Abbott Laboratories North Chicago, Illinois, USA	European corn borer	Corn	Public testing
Able®	Thermo Trilogy Corporation Columbia, Maryland, USA	Lepidopteran larvae	Vegetables, tree and vine crops	Commercial
Agrobac®	Tecomag Formigine (Modena), Italy	Lepidopteran larvae	Field crops and vegetables	Commercial
Bactosid®K	Sanex, Inc. Ontario, Canada	Lepidopteran larvae	Vegetables	Commercial
Biocot®	Uniroyal Chemical Company Middlebury, Connecticut, USA	Lepidopteran larvae	Cotton	Commercial
CoStar®	Thermo Trilogy Corporation Columbia, Maryland, USA	Lepidopteran larvae	Tree and vine crops	Commercial
Forwabit®	Forward International Taipei, Taiwan	Lepidopteran larvae	Corn, cotton, soybeans, vegetables, fruits and nuts	Commercial
Javelin®, Delfin®	Thermo Trilogy Corporation Columbia, Maryland, USA	Beet armyworm, cabbage looper, other Lepidopteran pests	Vegetables, tree and vine crops, cotton, other field crops, ornamentals	Commercial
Thuricide®	Thermo Trilogy Corporation Columbia, Maryland, USA	Forest Lepidopteran pests	Forestry	Commercial
Toarow® CT	Taogosei Chemical Industry Co., Ltd. Tokyo, Japan	Lepidopteran larvae	Vegetables (crucifers), tree fruits, tobacco	Commercial
Troy Bt™	Troy Biosciences Phoenix, Arizona, USA	Lepidopteran larvae	Vegetables, field crops, stored products, ornamentals	Commercial

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Table 5 (Continued)
BIOLOGICAL INSECTICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Pest(s)	Markets	Development Stage
Bacteria (Continued)				
Bacillus thuringiensis subsp. *Kurstaki* (Continued)				
Biobit®	Abbott Laboratories North Chicago, Illinois, USA	Lepidopteran larvae	Vegetables, tree and vine crops, field crops	Commercial
Dipel®	Abbott Laboratories North Chicago, Illinois, USA	Lepidopteran larvae	Vegetables, tree and vine crops, cotton, corn, other field crops, forestry, ornamentals	Commercial
Foray®	Abbott Laboratories North Chicago, Illinois, USA	Spruce budworm, gypsy moth, other forest Lepidopteran		Commercial
Bacillus thuringiensis subsp. *kurstaki* and subsp. *aizawai*				
ABG-6415 and ABG-6422	Abbott Laboratories North Chicago, Illinois, USA	European corn borer	Corn	Field screening
Bacillus thuringiensis subsp. *kurstaki* Strain 123				
BMP 123	Becker Microbial Plantation, Florida, USA	Lepidopteran larvae	Field crops, vegetables	
Bacillus thuringiensis subsp. kurstaki Strain 2371				
Cutlass®	Ecogen Inc. Langhorne, Pennsylvania, USA	Lepidopteran larvae	Vegetables, fruits and nuts, field crops, ornamentals, herbs	Discontinued.
Bacillus thuringiensis subsp. *kurstaki* Strain EG 2348				
Condor®	Ecogen Inc. Langhorne, Pennsylvania, USA	Lepidopteran larvae	Vegetables, fruits and nuts, field crops, ornamentals, forestry	Commercial

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Table 5 (Continued)
BIOLOGICAL INSECTICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Pest(s)	Markets	Development Stage
Bacteria (Continued)				
Bacillus thuringiensis subsp. *san diego*				
M-Trak®	Mycogen San Diego, California, USA	Colorado potato beetle, other leaf beetle	Vegetables (tomatoes and eggplant), ornamentals, shade trees	Commercial
Bacillus thuringiensis subsp. *tenebrionis*				
Novodor®	Abbott Laboratories North Chicago, Illinois, USA	Colorado potato beetle	Vegetables, potatoes	Commercial
Bacteria, Recombinant				
Bacillus thuringiensis subsp. *kurstaki* Strain 7673				
Raven™	Ecogen Inc. Langhorne, Pennsylvania, USA	Colorado potato beetle	Vegetables (tomatoes and eggplant)	Commercial
Bacillus thuringiensis subsp. *kurstaki* Strain 7826				
Lepinox®	Ecogen Inc. Langhorne, Pennsylvania, USA	European corn borer	Vegetables (sweet corn)	Commercial
Bacillus thuringiensis subsp. kurstaki Strain EG 7841				
Crymax™	Ecogen Inc. Langhorne, Pennsylvania, USA	Lepidopteran larvae	Vegetables, fruits and nuts, field crops, ornamentals, herbs	Commercial

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Table 5 (Continued)
BIOLOGICAL INSECTICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Pest(s)	Markets	Development Stage
Bacteria. Recombinant (Continued)				
Bacillus thuringiensis subsp. Kurstaki, encapsulated delta endotoxin				
M-C™	Mycogen Corp. San Diego, California, USA	Beet armyworm, other Lepidopteran pests	Cotton, others	Registration trials, international only
M-Peril®	Mycogen Corp. San Diego, California, USA	European corn borer, southwestern corn borer, all armyworm	Corn, Tobacco	Commercial
MVP® II	Mycogen Corp. San Diego, California, USA	Beet armyworm, diamond-back moth, cabbage looper, leaf rollers, and certain other Lepidopteran	Vegetables, fruits, field crops	Commercial
Bacillus thuringiensis subsp. *kurstaki* and subsp. *aizawai*, encapsulated delta endotoxins				
Mattch®	Mycogen San Diego, California, USA	Lepidopteran larvae especially beet armyworm, diamond back moth, and cabbage looper	Vegetables, tree fruits and nuts, cotton, ornamentals	Commercial
Fungal metabolite				
BK-226	Abbott Laboratories North Chicago, Illinois, USA	Lepidopteran pests, broad spectrum of fungi	Wide range	Field screening-Public testing; acquired from Novo Bio Kontrol

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Table 5 (Continued)
BIOLOGICAL INSECTICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Pest(s)	Markets	Development Stage
Fungi				
Beauveria bassiana	--			
Naturalis®	Troy Biosciences, Inc. Phoenix, Arizona, USA	Whitefly, aphids, thrips, mites, mole crickets, armyworms, grabs, grasshoppers, weevils, cucumber flea beetles	Cotton, vegetables, other field crops, ornamentals, greenhouse crops, turf	Commercial
--	University of Florida Gainesville, Florida, USA	Fire ants and household pests	Home and garden	NA
Beauveria bassiana Strain 147				
Ostrinil®	Natural Plant Protection S.A. Nogueres, France	European corn borer, Asiatic corn borer	Corn	Commercial
Beauveria bassiana Strain GHA				
Mycotrol®, BotaniGard®	Mycotech Corporation Butte, Montana, USA	Whiteflies, aphids, thrips, lygus, psyllids, mealybugs, leafhoppers	Vegetables, potatoes, tree and vine crops, berries, cotton, other field crops, herbs, greenhouse crops, ornamental nursery crops, commercial landscape, interiorscape, turf	Commercial
Beauveria bassiana Strain MYCO-9701				
Stemgard®	Mycotech Corporation Butte, Montana, USA	European and Southwestern corn borers	Corn	Registration trials

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Table 5 (Continued)
BIOLOGICAL INSECTICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Pest(s)	Markets	Development Stage
Fungi (Continued)				
Beauveria brogniartii Strain 96				
Betel®	Natural Plant Protection S.A. Nogueres, France	Sugar cane white grub	Sugarcane	Commercial
Engerlingspliz™	Andermatt Biocontrol AG Grossdietvil, Switzerland	Melolontha spp. pasture grubs	Pasture	Commercial
Beauveria brogniartii				
BioLisa™	Nitto Denko Corporation Osaka, Japan	Longicorns (adult)	Citrus, mulberries	Commercial
Entomophaga aulicae				
--	Seabright Corporation St. Johns, Newfoundland, Canada	Eastern spruce budworm and Eastern hemlock looper	Forestry	Public testing; company is seeking commercial partners.
Entomophaga gryili				
--	Seabright Corporation St. Johns, Newfoundland, Canada	Grasshoppers	Some agronomic crops, range, pasture	Public testing; company is seeking commercial partners.
Entomophaga maimaiga				
--	Seabright Corporation St. Johns, Newfoundland, Canada	Gypsy moth	Forestry	Public testing; company is seeking commercial partners.
Lagenidium giganteum				
Laginex™	AgraQuest, Inc. Davis, California, USA	Mosquito larvae	Rice, soybeans, irrigated pasture, freshwater marshes, wetlands, etc.	Commercial

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Table 5 (Continued)
BIOLOGICAL INSECTICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Pest(s)	Markets	Development Stage
Fungi (Continued)				
Metarhizium anisopliae Strain ESCI				
Bio-Blast™	EcoScience Corp East Brunswick, New Jersey, USA	Termites	Professional pest control	Commercial
Metarhizium anisopliae Strain ESFI				
Bio-Path™Cockroach Control Chamber	EcoScience Corp. East Brunswick, New Jersey, USA	Cockroaches	Professional pest control	Not on the market currently
Paecilomyces fumosoroseus				
PFR-97	Thermo Trilogy Corporation Columbia, Maryland, USA	Whiteflies, aphids, spider mites, thrips	Greenhouse ornamentals and vegetables	Public testing
Verticillium lecanii				
Microgermin®	Koppert B.V. Koppert Biological Veilingweg, The Netherlands	Aphids, whitefly, thrips, mites	Greenhouse vegetables, ornamentals	Commercial
Mycotal®	Koppert B.V. Koppert Biological Veilingweg, The Netherlands	Whiteflies, thrips	Greenhouse vegetables	Commercial
Vertalec®	Koppert B.V. Koppert Biological Veilingweg, The Netherlands	Aphids	Greenhouse vegetables	Commercial
Vertalec®, Mycotal®	Agri Tech Crowley, Louisiana, USA	Whiteflies, aphids	Greenhouse vegetables	Registration trials

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Table 5 (Continued)
BIOLOGICAL INSECTICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Pest(s)	Markets	Development Stage
Protozoan				
Nosema fumacali, NMP microsporidian				
--	University of Minnesota St. Paul, Minnesota, USA	European corn borer	Corn	Field screening
Viruses				
Adoxophyes orana granulosis Virus				
Capex® 2	Andermatt Biocontrol AG Grossdietvil, Switzerland	Grape rootworm	Vineyards	Commercial
Anagrapha falcifera NPV (celery looper virus)				
--	Thermo Trilogy Corporation Columbia, Maryland, USA	Celery looper, other Lepidopteran spp.	Vegetables, cotton, other field crops	Registration trials; U.S. registration anticipated in 1998-1999.
Cydia pomonella granulosis virus (Codling moth granulosis virus)				
Specific-T-I	University of California Davis, California	Codling moth (*Cydia pomonella*)	Apples, pears, walnuts	
Carpovirusine®	Natural Plant Protection S.A. Nogueres, France	Codling moth	Apples, pears	Commercial
Madex®	Andermatt Biocontrol AG Grossdietvil, Switzerland	Coddling moth	Apples, pears	Commercial
Douglas Fir Tussock Moth NPV				
Vitruss®	Forestry Canada Forest Pest Management Institute	Douglas fir tussock moth	Forestry	

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Table 5 (Continued)
BIOLOGICAL INSECTICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Pest(s)	Markets	Development Stage
Viruses (Continued)				
Helicoverpa zea NPV				
GemStar®	Thermo Trilogy Corporation Columbia, Maryland, USA	Cotton bollworm/corn ear-worm/tomato fruitworm , tobacco budworm	Cotton, vegetables	Commercial
Lymantria dispar NPV				
--	American Cyanamid Company Parsippany, New Jersey, USA	Gypsy moth (Lymantria dispar)	Forestry	Field trials
Gypchek	USDA Forest Service Hamden, Connecticut, USA	Gypsy moth (Lymantria dispar)	Forest habitat, lumber	
Lymantrin®	Natural Plant Protection S.A. Nogueres, France	Gypsy moth	Forestry	Commercial
Mamestra brassica NPV				
Mamestrin®	Natural Plant Protection S.A. Nogueres, France	Cabbage moth, loopers, potato tuber moth	Vegetables (cabbage)	Commercial
Orgyia psuedotsugata NPV				
TM Biocontrol	USDA Forest Service Morgantown, West Virginia, USA	Douglas fir tussock moth (Orgyia psuedotsugata)	Forest habitat, lumber	
Spodoptera exigua NPV				
SPOD-X®	Thermo Trilogy Corporation Columbia, Maryland, USA	Beet armyworm	Vegetables, cotton, other field crops, floriculture	Commercial
Spodoptera littorallis NPV				
Spodopterin®	Natural Plant Protection S.A. Nogueres, France	Spodoptera littorallis	Cotton, corn, tomatoes	Commercial

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Table 5 (Continued)
BIOLOGICAL INSECTICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Pest(s)	Markets	Development Stage
Viruses, Recombinant				
Autographica californica NPV				
--	American Cyanamid Company Parsippany, New Jersey, USA	Tobacco budworm, cotton bollworm	Cotton, vegetables	
--	DuPont Agricultural Products Wilmington, Delaware, USA	Tobacco budworm, cotton bollworm, beet armyworm, cabbage looper	Cotton, vegetables, tobacco	Field trials
Heliothis NPV				
--	DuPont Agricultural Products Wilmington, Delaware, USA	Tobacco budworm, cotton bollworm	Cotton, vegetables	Field trials
Rochiplusia ou (Ro NPV)				
--	Iowa State University Ames, Iowa, USA	European corn borer	Corn	Experimental product
Nematodes				
Heterorhabditis spp.				
Larvanem®	Koppert BV Veilingweg, The Netherlands	Lepidopteran larvae	Corn, vegetables	
Nemotoden®	Andermatt Biocontrol AG Grossdietvil, Switzerland	Black vine weevil, strawberry root weevil	Ornamentals	Commercial
Heterorhabditis bacteriophora				
Cruiser™	Ecogen Inc. Langhorne, Pennsylvania, USA	Japanese beetles, other grubs, black vine weevils, cranberry and citrus root pests, others	Cranberries	Commercial
Heteromask®	BioLogic Company Willow Hill, Pennsylvania, USA	Japanese beetle, grubs, others	Turf	Commercial
Lawn Patrol™	Hydro-Gardens Inc. Colorado Springs, CO, USA	Japanese beetle, other grubs	Lawns and turf	

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Table 5 (Continued)
BIOLOGICAL INSECTICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Pest(s)	Markets	Development Stage
Nematodes (Continued)				
Heterorhabditis megidis				
Nemasys® H	MicroBio Ltd. Cambridge, England	Black vine weevil	Ornamentals	Commercial
Steinernema carpocapsae				
BioSafe®, Savior®, Millennium®	Thermo Trilogy Corporation Columbia, Maryland, USA	Root weevils, fleas, fungus gnats, borers, cutworms	Turf, landscapers, nurseries, greenhouses	Commercial
Ecomask®	BioLogic Company Willow Hill, Pennsylvania, USA	Cutworms, other soil dwelling insects	High-value crops	Commercial
Scanmask®	BioLogic Company Willow Hill, Pennsylvania, USA	Dipterans, other soil dwelling larvae	Horticultural & other high value crops	Commercial
Termask®	BioLogic Company Willow Hill, Pennsylvania, USA	Termites	Consumers, residential and commercial properties	Commercial
Steinernema feltiae				
Nemasys®	MicroBio Ltd. Cambridge, England	Greenhouse sciarids Bradysia paupera & Bradysia aprica	Greenhouse ornamentals,greenhouse vegetables	Commercial
Nemasys® M	MicroBio Ltd. Cambridge, England	Greenhouse sciarids, mushroom flies		Commercial
X-Gnat®, Magnet®	Thermo Trilogy Corporation Columbia, Maryland, USA	Fungus gnats, mushroom flies	Mushrooms, ornamentals	Commercial
Steinernema kushidai				
--	Kubota Biotech Japan		Turf	Registration trials
Steinernema riobravis				
BioVector® 355	Thermo Trilogy Corporation Columbia, Maryland, USA	Root weevils	Citrus, cranberries	Commercial
Devour®, Vector®	Thermo Trilogy Corporation Columbia, Maryland, USA	Mole crickets, plant parasitic nematodes	Turfgrass	Commercial

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Table 5 (Continued)
BIOLOGICAL INSECTICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Pest(s)	Markets	Development Stage
Nematodes (Continued)				
Steinernema scapterisci	University of Florida Gainesville, Florida, USA	Mole crickets	Turf	Patented and available for licensing
Botanical				
Azadirachtin				
Neemix®, Azatin®, Neemazad®	Thermo Trilogy Corporation Columbia, Maryland, USA	Whiteflies, leafminers, Lepidopteran larvae	Vegetables, fruits, nuts, cotton, ornamentals, forestry	Commercial
Neem oil				
Trilogy®, Triact®	Thermo Trilogy Corporation Columbia, Maryland, USA	Whiteflies, aphids, mites, scales; mildews, rusts, scab	Vegetables, citrus, other tree fruits and nuts, field crops, outdoor-grown ornamentals, residential and commercial landscapes	Commercial. An insecticide/miticide/ fungicide product.

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Table 5 (Concluded
BIOLOGICAL INSECTICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Pheromones[a]				
Cornstalk borer pheromone				
Sesaline®	Natural Plant Protection S.A. Nogueres, France	Cornstalk borer (*Sesamia nonagroides*)	Corn	Registration trials in Europe.
Pink bollworm pheromone				
Frustrate™ PBW	Thermo Trilogy Corporation Columbia, Maryland, USA	Pink bollworm	Cotton	Commercial
Other				
Allelochemical substances and a chitin enzyme inhibitor				
Biomite®	Natural Plant Protection Nogueres, France	Lesser meal worm	Field crops, others	Registration trials to initial marketing; Registered in Egypt in 1997.

a Incomplete list of pheromone-based insect control products..

Sources: Communication with industry and trade literature.

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FUNGICIDES

Table 6 lists biological fungicide products on the market or under development worldwide in 1998. A number of products based on bacteria and fungi have been commercialized since the early 1990s and several new biological fungicide products are expected to be launched before 2000. In addition to bacterial and fungal products, a biological fungicide based on a yeast isolate (Aspire™ from Ecogen) is marketed for postharvest disease control for citrus and pome fruits, and a botanical product (a neem oil-based fungicide/insecticide/miticide product from Thermo Trilogy Corporation) is marketed for control of a range of diseases and pests that affect fruit, vegetable, and ornamental crops and landscape plants.

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Table 6

BIOLOGICAL FUNGICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Disease(s)	Markets	Development Stage
Bacteria				
Agrobacterium radiobacter				
Nogall™, Diegall™	New BioProducts, Inc. Corvallis, Oregon, USA	Crown gall disease caused by *Agrobacterium tumifaciens*	Tree fruits and nuts, ornamental nursery stock	Commercial
Agrobacterium radiobacter Strain K84				
Norbac™ 84C	Bio-Care technology Pty. Ltd. Somersby, Australia	Crown gall disease caused by *Agrobacterium tumifaciens*	Trees	Commercial
Galltrol-A®	AgBioChem, Inc. Orinda, California, USA	Crown gall disease caused by *Agrobacterium tumifaciens*	Tree and vine crops, nurseries	Commercial
Bacillus cereus				
UW 85	Lipha Tech Milwaukee, Wisconsin, USA	*Pythium, Phytophthora*	Seed treatment fungicide for cereals, other crops	Registration trials
Bacillus subtilis				
Kodiak®, Epic®	Gustafson, Inc. Dallas, Texas, USA	*Rhizoctonia solani, Fusarium* spp., *Alternaria* spp., and *Aspergillus* spp. that attack roots	Seed treatment fungicide for cotton, legumes	Commercial
Quantum 4000® HB	Gustafson Inc. Dallas, Texas, USA	Root diseases	Seed treatment fungicide for cotton, vegetables	Commercial
--	MicroBio Ltd. Cambridge, England	Root and soil pathogens (suppression)	Ornamentals, home and garden	Registration trials
Bacilllus subtilus and chemical pesticides				
System 3	Helena Chemical Company Memphis, Tennessee, USA	Seedling pathogens	Barley, beans, cotton, peanuts, peas, rice, soybeans	Commercial

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Table 6 (Continued)
BIOLOGICAL FUNGICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Disease(s)	Markets	Development Stage
Bacteria (Continued)				
Bacillus subtilus FZB24				
Rhizo-Plus, Rhizo-Plus Konz.	KFZB Biotechnik GmbH Berlin, Germany	*Rhizoctonia solani, Fusarium* spp., *Alternaria* spp., Sclerotinia, *Verticillium, Streptomyces scabies*	Potatoes, corn, vegetables, ornamentals	Commercial
Bacillus subtilus MB 600 ATCC-SD +414	Gustafson Inc. Dallas, Texas, USA	*Rhizoctonia solani, Fusarium* spp.	Vegetables	Registration trials
Burkholderia cepacia (Pseudomonas cepacia) Type Wisconsin				
Deny®	CCT Corp. Carlsbad, California, USA	*Fusarium , Rhizoctonia, and Pythium* spp.; lance, sting, and spiral nematodes	Vegetables, fruits, nuts, vines, potatoes, cotton, other field crops, herbs, spices, ornamentals, greenhouse crops, turfgrass	Commercial
Pantoea agglomerans				
Blight Ban™C9-1	Plant Health Technologies Boise, Idaho, USA	Fire blight	Apples, pears	
Pseudomonas cepacia				
Intercept®	Soil Technologies Corp. Fairfield, Iowa, USA	Damping-off fungi, nematodes	Vegetables, fruits, nuts, vines, potatoes, cotton, other field crops, herbs, spices, ornamentals, greenhouse crops, turfgrass	Commercial

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Table 6 (Continued)
BIOLOGICAL FUNGICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Disease(s)	Markets	Development Stage
Bacteria (Continued)				
Pseudomonas chlororaphis				
MA-342	Bio Agri (a company within Svenska Lanmennen) Sweden	*Drechslera* spp., *Tilletia caries, Ustilago avena*	Seed treatment for cereals	Commercial
Pseudomonas flourescens Strain *NCIB-12089*				
Conquer®, Victus®	Mauri Foods North Ryde, Australia	*Pseudomonas tolassii* that causes bacterial blotch disease	Mushrooms	Commercial
Pseudomonas flourescens A 506				
Blight Ban™ A506	Plant Health Technologies Boise, Idaho, USA	Frost, *Erwinia armylovora*	Almonds, apples, cherries, peaches, pears, potatoes, strawberries, tomatoes.	Commercial
Pseudomonas gladioli				
AM-301	Japan Tobacco Tokyo, Japan	Bacterial wilt	Vegetables (tomatoes, eggplant, peppers)	Public testing
Pseudomonas solanacearum (nonpathogenic)				
PSSOL™	Natural Plant Protection Nogueres, France	NA	Vegetables	NA
Pseudomonas syringae Strain ESC-IO				
Bio-Save® 100, Bio-Save® 1000	EcoScience Corp., Produce Systems Division Orlando, Florida	*Botritis cinerea, Penicillium* spp., *Mucor pyroformis, Geotrichum candidum*	Pome fruits (Bio-Save® 100), citrus (BioSave ®1000)	Commercial

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Table 6 (Continued)
BIOLOGICAL FUNGICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Disease(s)	Markets	Development Stage
Bacteria (Continued)				
Pseudomonas syringae Strain ESC-11				
Bio-Save® 110	EcoScience Corp., Produce Systems Division Orlando, Florida	*Botritis cinerea, Penicillium* spp., *Mucor pyroformis, Geotrichum candidum*	Pome fruits	Commercial
Reynoutria sachalinensis				
Milsana®	BASF AG Limburgerhof, Germany	Powdery mildew	Vegetables, ornamentals	Commercial
Streptomyces griseoviridis Strain K61				
Mycostop®	Kemira Agro OY Helsinki, Finland	*Alternaria brassicola, Fusarium, Phomopsis, Botrytis, Pythium*, and *Phytophthora* spp.	Cucumbers, other vegetables, field crops, greenhouse crop, ornamentals	Commercial
Streptomyces lydicus				
--	Plant Health Technologies Boise, Idaho, USA	NA	Tomatoes, peppers, peas, lentils	Field trials; EPA registration applied for
Xanthomonas campestris, var. *vesicatoria*				
NA	Agri Phi Inc. Logan, Utah, USA	Bacterial spot	Tomatoes. peppers	Commercial
NA				
Serenade® (AQ 713)	AgraQuest, Inc. Davis, California, USA	*Botrytis cinerea*	Tree and vine crops, vegetables	U.S. registration pending
NA				
Sonata® (AQ 153)	AgraQuest, Inc. Davis, California, USA	*Phytophthora* spp., *Alternaria* spp, *other pathogens*	Tree and vine crops, vegetables	U.S. registration pending

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Table 6 (Continued)
BIOLOGICAL FUNGICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Disease(s)	Markets	Development Stage
Bacteria (Continued)				
Pseudomonas syringae pv *syringae*	University of Wisconsin Madison, Wisconsin, USA	Bacterial brown spot	Green beans	Field screening
Bacteria, Recombinant				
Rhizobium and Sinorhizobium				
--	University of Wisconsin Madison, Wisconsin, USA	Bacteria-caused soil diseases	Alfalfa, beans, clover	Field screening
Fungal metabolite				
NA	Abbott Laboratories North Chicago, Illinois, USA	Powdery mildew, other diseases	Vegetables, others	Public testing; acquired from Novo Bio Kontrol
Fungi				
Anpelomyces quisqualis Isolate M-IO				
AQ IO™	Ecogen Inc. Langhorne, Pennsylvania, USA	Powdery mildew	Apples, grapes, strawberries, vegetables, ornamentals	Commercial
Coniothyrium minitans				
Contans®	Prophyta Biologischer Pflanzenschutz BmbH Malchow/Poel, Germany	*Sclerotinia sclerotiorum* and *S. minor*	Greenhouse vegetables, oilseed rape	Initial marketing in Germany; European registration applied for under Directive 91/414.
Fusarium oxysporum (nonpathogenic)				
Biofox C™	S.I.A.P.A. Bologna, Italy	*Fusarium oxysporum*, *Fusarium moniliforme*	Tomatoes, carnations, cyclamen	Commercial

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Table 6 (Continued)
BIOLOGICAL FUNGICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Disease(s)	Markets	Development Stage
Fungi (Continued)				
Fusarium oxysporum Strain FO 47				
Fusaclean®	Natural Plant Protection S.A. Nogueres, France	*Fusarium oxysporum*	Tomatoes, asparagus, carnations, cyclamen, gerbera, basil	Registration pending
Gliocladium catenulatum				
Glio Mix®	Kemira Agro Oy Helsinki, Finland	*Pythium* spp., *Rhizoctonia* spp.	Vegetables, ornamentals, bedding plants, herbs	Commercial
Gliocladium catenulatum, Strain J1446				
Primastop®	Kemira Agro Oy Helsinki, Finland	*Pythium* and *Rhizoctonia* spp. that cause damping-off, seed rot, root and stem rot, and wilt diseases	Vegetables, herbs, spices, ornamentals, turf, home gardens	EPA registration applied for
Gliocladium virens Type GL21				
SoilGard®	Thermo Trilogy Corporation Columbia, Maryland, USA	Damping-off and other soil-borne diseases	Greenhouse ornamentals and vegetables	Commercial
Phlebia gigantea				
Rotstop®	Kemira Agro Oy Helsinki, Finland	*Heterobasidium annosum*	Trees; used as stump treatment	Commercial
Pythium oligandrum				
Polygandron	Plant Production Institute Bratislava, Slovak Republic	NA	Sugar beet	NA

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Table 6 (Continued)
BIOLOGICAL FUNGICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Disease(s)	Markets	Development Stage
Fungi (Continued)				
Trichoderma spp.				
Bio-Fungus™	Grondortsmettingen DeCuester n.v. Katelijne-waver, Belgium	*Sclerotinia, Phytophthora, Rhizoctonia solani, Pythium* spp., *Fusarium, Verticillium*	Strawberries, trees, vegetables, flowers	NA
Trichoderma 2000	Mycontrol, Ltd. Nazareth Elit, Israel	*Rhizoctonia solani, Sclerotium rolfsii, Pythium* spp., *Fusarium,*	Field crops, nursery crops	NA
Trichoderma harzianum Strain TH 11				
Harzian®	Natural Plant Protection S.A. Nogueres, France	*Armillaria* root rot	Tree and vine crops	Commercial
Trichoderma harzianum and *T. polysporum*				
BINAB® T	Bio-Innovation AB Algaras, Sweden	Pathogenic fungi that cause wilt, take-all, root rot in plants; internal decay of wood products; and decay in tree wounds	Tree fruits, vegetables, cut flowers, ornamentals, turf	Commercial. Distributed in the United States by E.R. Butts International.
Trichoderma harzianum				
Supresivit®	Borregaard and Reitzel Denmark	Various fungi	NA	NA
Trichoderma harzianum Strain T22				
Biotrek®	BioWorks Inc. Geneva, New York, USA	*Pythium* spp., *Rhizoctonia solani, Fusarium* spp., and *Sclerotinia homeocarpa*	Vegetables, corn, cotton, other field crops, potatoes, turf, greenhouse ornamentals	Commercial. Distributed exclusively by Wilbur-Ellis Co.

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Table 6 (Continued)
BIOLOGICAL FUNGICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Disease(s)	Markets	Development Stage
Fungi (Continued)				
Trichoderma harzianum and T. viride				
Promote®	JH Biotech Ventura, California, USA	*Pythium* spp., *Rhizoctonia solani*, *Fusarium* spp.	Greenhouse and nursery transplants, seedlings	Commercial
Trichopel®, Trichoject®, Trichodowels®, Trochoseal®	Agrimm Technologies, Ltd. Christchurch, New Zealand	*Armillaria, Botryosphaeria, Chondrosternum, Fusarium, Nectria, Phytophthora, Pythium, Rhizoctonia*	Greenhouse and nursery transplants, seedlings	Commercial
Trichoderma harzianum Strain T22				
Rootshield®	BioWorks Inc. Geneva, New York, USA	*Pythium* spp., *Rhizoctonia solani*, *Fusarium* spp.	Greenhouse crops and vegetable transplants.	Commercial. Sold through distributors in the United States, Europe, and Japan.
T22™ Planterbox	BioWorks Inc. Geneva, New York, USA	*Pythium* spp., *Rhizoctonia solani*, *Fusarium* spp., *Sclerotinia homeocarpa*	Vegetables, potatoes, corn, cotton, peanuts, turf, greenhouse ornamentals	Commercial. Sold through 15 U.S. distributors.
Trichoderma harzianum Strain T39				
Trichodex®	Makhteshim Chemical Works, Ltd. Beer Sheva, Israel	Primarily *Botrytis cinerea*. Also *Colletotrichum* spp., *Fulia fulva, Monilinia laxa, Plasmopara viticola, Pseudoperonospora cubensis, Rhizopus stolonifer, Sclerotinia sclerotiorum*	Vegetables, grapes, nectarines, strawberries, soybeans, sunflowers, ornamentals	Commercial
Trichodex®, ABG-8007	Abbott Laboratories North Chicago, Illinois, USA	*Botrytis cinerea*	Grapes, vegetables, ornamentals	Commercial

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Table 6 (Concluded)
BIOLOGICAL FUNGICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Disease(s)	Markets	Development Stage
Fungi (Continued)				
Trichoderma harzianum Strain T41 G-41	BioWorks Inc. Geneva, New York, USA	*Pythium* spp., *Phytophthora* spp.	NA	Currently sold in Japan only. Licensed from Cornell Rsch. Inst.
Yeast				
Candida oleophia isolate I-182 Aspire™	Ecogen Inc. Langhorne, Pennsylvania, USA	Postharvest decay pathogens, e.g., *Penicillium, Botrytis*	Postharvest disease control for citrus, pome fruits	Commercial
Cryptococcus lauentii --	EcoScience Corp., Produce Systems Division Orlando, Florida, USA	*Botrytis cinerea, Penicillium* spp., *Mucor pyroformis, Geotrichum candidum*	Post harvest disease control on fruit.	Under development
Botanical				
Neem oil Trilogy®, Triact®	Thermo Trilogy Corporation Columbia, Maryland, USA	Mildews, rusts, scab, whiteflies, aphids, mites, and scales	Vegetables, citrus, other tree fruits and nuts, field crops, outdoor-grown ornamentals, residential and commercial landscapes	Commercial
Carbohydrate compounds, naturally derived Elexa®	SafeScience, Inc. Boston, Massachusetts, USA	Downy mildew, powdery mildew, *Botrytis cinerea, Colletotrichum* spp., *Phytophthora infestans, Pythium* spp., others	Grapes, potatoes, rice, vegetables, others.	Commercial

Sources: Communication with industry and trade literature.

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HERBICIDES

Microorganisms that induce diseases in weeds can be exploited as active ingredients for biological herbicides. Table 7 lists the biological herbicides that are on the market or under development as of fall 1998. Two fungal herbicides (DeVine® from Abbott Laboratories and BioMal® from Philom Bios of Canada) are on the market in North America. A bacterial herbicide based on *Xanthomonas campestris*, jointly developed by Mycogen Corp. and Japan Tobacco, has been commercialized in Japan for control of annual bluegrass in turfgrass. Eco Soil Systems (San Diego, CA) recently acquired from Mycogen the rights to market the product for turf in the United States

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Table 7
BIOLOGICAL HERBICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1988

Technology/Pathogen/ Product	Producer/Supplier and Headquaters Location	Target Weeds(s)	Markets	Development Stage
Bacteria				
Exserohiilum monoceras				
JTH-102	Japan Tobacco Tokyo, Japan	*Echinochloa* spp.	Rice	Public testing
Epicoccosorus nematosorus				
J TH-103	Japan Tobacco Tokyo, Japan	*Eleocharia kuroguwai*	Rice	Public testing
Xanthomonas campestris				
X-PO	Eco Soil Systems San Diego, CA, USA	Annual bluegrass	Turf	Rights to product acquired from Mycogen.
Xanthomonas campestris				
JTH-101	Japan Tobacco Tokyo, Japan	Annual bluegrass	Turf	Commercial
Fungi				
Colletotrichum gloeosporiodes f sp *malvae*				
BioMal®	Philom Bios Saskatoon, Saskatchewan, Canada	Round- leafed mallow	Field crops (Barley, buckwheat, canola, flax, lentils, mustard, oats, rye, soybeans, sugar beets and wheat	Commercial
Colletotrichum truncatum				
--	United States Department of Agriculture	Hemp sesbania	Cotton, soybeans, peanuts	Public testing

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Table 7 (Concluded)
BIOLOGICAL HERBICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1988

Technology/Pathogen/ Product	Producer/Supplier and Headquaters Location	Target Weeds(s)	Markets	Development Stage
Fungi (Continued)				
Colletotrichum truncatum				
--	United States Department of Agriculture	Musk thistle	NA	Registration trials
Phytophthora palmivora				
DeVine®	Abbott Laboratories North Chicago, Illinois, USA	Milkweed vine	Citrus	Commercial

Sources: Communication with industry and trade literature.

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NEMATICIDES

Table 8 lists four biological nematicide products that are commercially available in 1998 and two potential fungal products that the U.S. Department of agriculture is evaluating for nematode control in field trials.

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Table 8
BIOLOGICAL NEMATICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Pest(s)	Markets	Development Stage
Bacteria				
Burkholderia cepacia (*Pseudomonas cepacia*) Type Wisconsin				
Deny®	CCT Corp Carlsbad, California, USA	*Fusarium*, *Rhizoctonia*, and *Pythium* spp.; lance, sting, and spiral nematodes	Vegetables, fruits, nuts, vines, potatoes, cotton, other field crops, herbs, spices, ornamentals, greenhouse crops, turfgrass	Commercial
Pseudomonas cepacia				
Intercept®	Soil Technologies Corp. Fairfield, Iowa, USA	Damping-off fungi, nematodes	Vegetables, fruits, nuts, vines, potatoes, cotton, other field crops, herbs, spices, ornamentals, greenhouse crops, turfgrass	Commercial
Fungi				
Hirsutella rhossiliensis	U.S. Department of Agriculture Agricultural Research Service	Root lesion nematodes	Potatoes	Under evaluation in New York for suppression of root lesion nematode populations.
Myrothecium verrucaria Strain AARC-0255				
DiTera®	Abbott Laboratories North Chicago, Illinois, USA	Citrus, cyst, dagger, reniform, root-knot, root lesion, stubby-root, other plant parasitic nematodes	Cotton, potatoes, cucurbits, other vegetables, citrus, other fruits, ornamentals	Commercial

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Table 8 (Concluded)
BIOLOGICAL NEMATICIDES ON THE MARKET OR UNDER DEVELOPMENT, 1998

Technology/Pathogen/ Product	Producer/Supplier and Headquarters Location	Target Pest(s)	Markets	Development Stage
Fungi (Continued)				
Verticillium lecanii	United States Department of Agriculture	Soybean cyst nematode	Soybeans	Field screening; mutant strain of *V. lecanii*
Nematodes				
Steinernema riobravis				
Devour®, Vector®	Thermo Trilogy Corporation Columbia, Maryland, USA	Mole crickets, plant parasitic nematodes	Turfgrass	Commercial
Other				
Pyrrolidine alkaloid (DMDP)	British Technology Group London, UK	Several nematode species	All crops	A botanical nematicide derived from *Lonchocarpus costeriensis.*

Source: Communication with industry and trade literature.

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TRANSGENIC PLANTS

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INTRODUCTION

This report provides an overview of transgenic crop plant development worldwide and as of year-end 1997. It identifies the companies and other organizations that market and/or are developing transgenic or otherwise genetically modified varieties of major food, feed, and fiber crop plants in North America, Western Europe, Japan, and other world regions. The 11 crop sections—corn, cotton, potatoes, rapeseed and canola, rice, soybeans, sugar beets, tobacco, tomatoes, other vegetable, and wheat—indicate genetically modified traits and identify the organizations that are developing plant varieties with each trait.

This is one of two "Early Indicator" reports issued to first-year subscribers to SRI Consulting's new multiclient program, *Biotechnology and New Chemistry: Their Impacts on Agricultural Pest Control.*

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WORLD OVERVIEW OF DEVELOPERS AND PRODUCTS

NORTH AMERICA

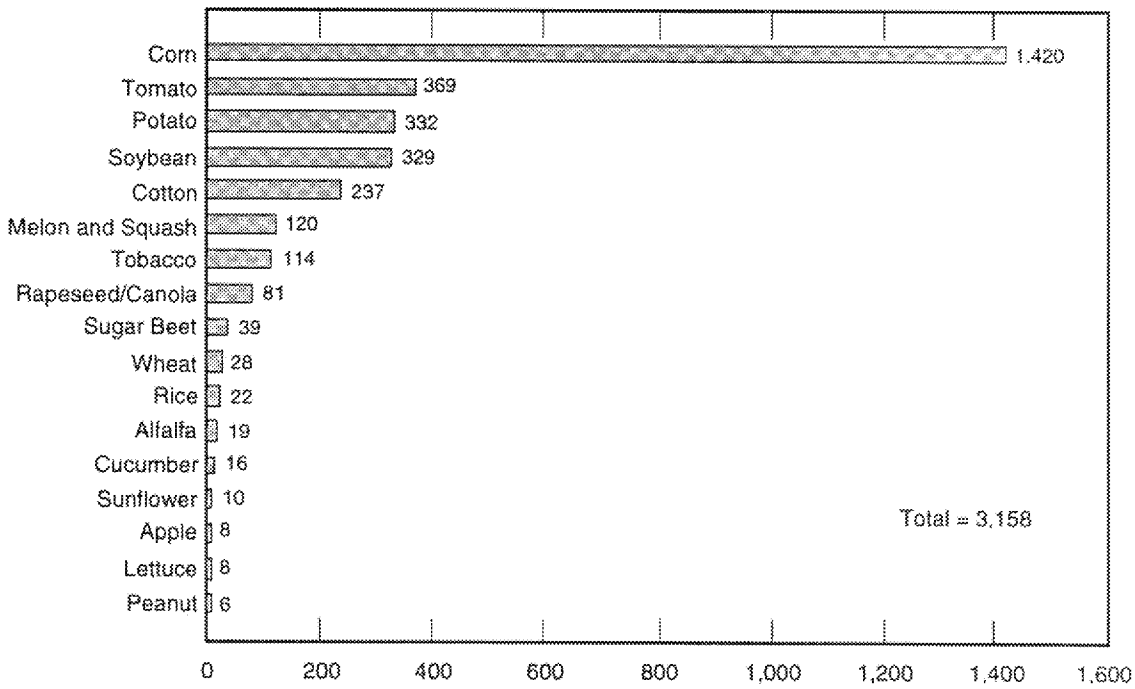
North America's large market makes it attractive for developers of genetically modified crops and helps justify the significant investments needed to develop these plants. In addition, U.S. and Canadian regulations and public opinion are more accepting of genetically engineered crops than is currently the case in the European Union (EU), the next largest potential market.

Field Trials

Since 1987, more than 3,100 field releases of genetically modified crop plants have taken place in the United States. Figure 1 shows the number of U.S. field trials by crop. Corn trials accounted for 45% of the total permits issued and notifications acknowledged for transgenic crop field trials as of November 30, 1997. Tomatoes, potatoes, soybeans, and cotton together accounted for 40%. Figure 2 shows the categories of transgenic plants evaluated in U.S. field trials since 1987.

Figure 1

U.S. TRANSGENIC PLANT FIELD TRIALS BY PRINCIPAL CROP, 1987-1997*



*Includes permits and notifications. Crops for which fewer than 6 permits have been issued are not included.

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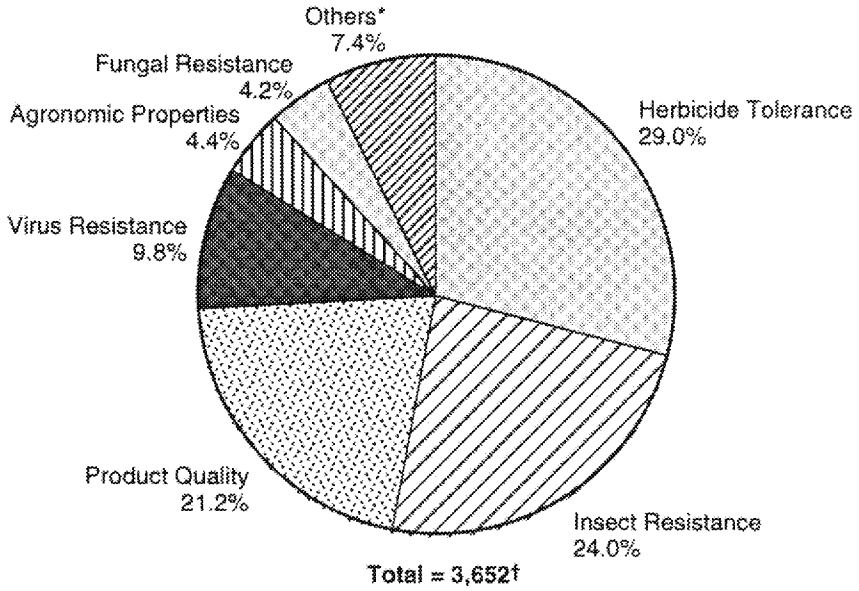
Figure 2
U.S. TRANSGENIC PLANT FIELD TRIALS BY TRAIT, 1987-1997



* Includes marker genes, selectable markers, bacterial resistance, and nematode resistance.
† Traits of crops with two or more transgenic traits are counted separately.

Most transgenic plant field trials in Canada have been for canola (see Figure 3). In 1997, canola accounted for two-thirds of field trials in the country, followed by potatoes (about 19% of the field trials), and soybeans (7%). Figure 4 shows the principal categories of transgenic plants evaluated in 1997 Canadian field trials.

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Figure 3

CANADIAN TRANSGENIC PLANT FIELD TRIALS BY CROP, 1997

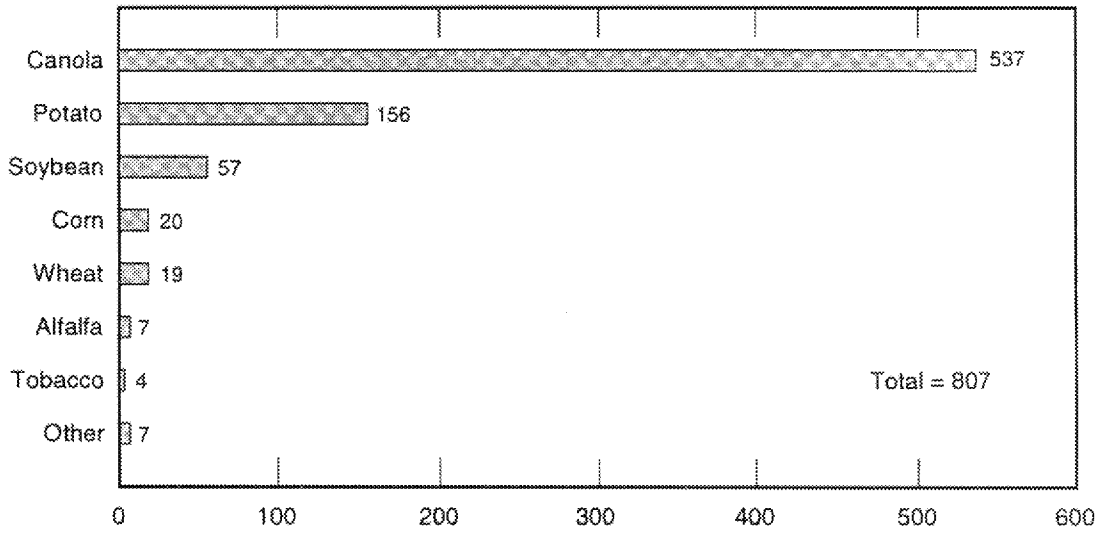
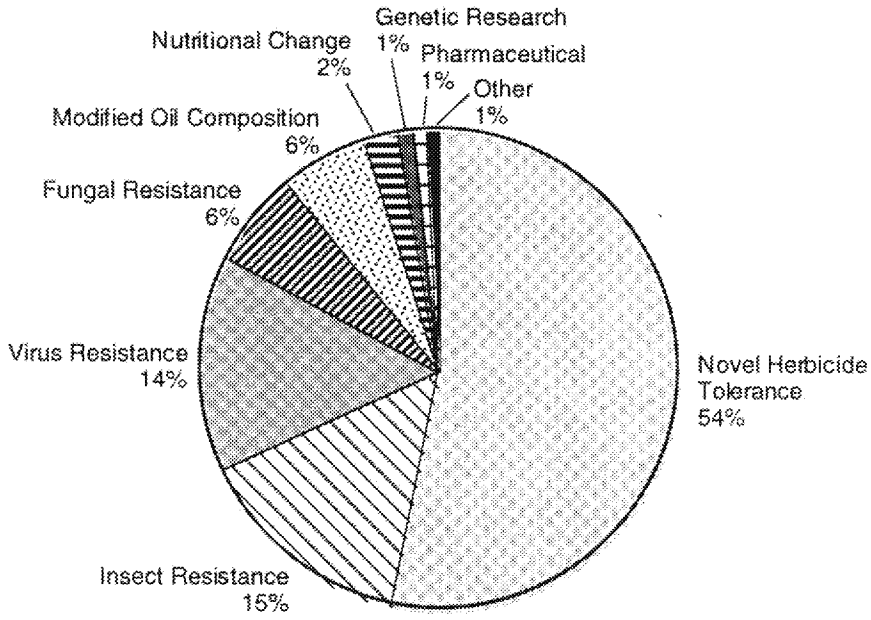


Figure 4

CANADIAN TRANSGENIC PLANT FIELD TRIALS BY TRAIT, 1987-1997



Total = 979*

*Traits of crops with two or more transgenic traits are counted separately.

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To date, herbicide tolerance and insect resistance have been transgenic plant developers' principal focuses, and most of the new plants commercialized have one of these two traits. Now, however, biotechnology research for food plants is concentrating on enhanced crop quality traits such as increased nutritional value, higher oil content, delayed ripening, and higher yield. Nonfood crops with high-value uses as additives in cosmetics, plastics, and pharmaceuticals are also being developed.

Developers and Products

Table 1 lists companies that are developing transgenic crop plant products in North America and the products of each firm that have been approved for marketing and use in the United States and/or Canada.

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Table 1
COMPANIES CONDUCTING TRANSGENIC PLANT RESEARCH AND DEVELOPMENT IN NORTH AMERICA: PRODUCTS APPROVED FOR MARKETING IN THE UNITED STATES AND/OR CANADA

Developing Company	Crop	G-M Trait(s) [a]	Date Approved	
			United States [b]	Canada [c]
AgrEvo	Canola	Glufosinate tolerance	June 1995	February 1995
	Canola [d]	Glufosinate tolerance	--	February 1997
	Corn	Glufosinate tolerance	June 1995	April 1997
	Corn	Glufosinate tolerance + ECB resistance	Under review	--
	Rapeseed	Male sterile + fertility restorer	1996 (FDA)	--
	Rapeseed	Glufosinate tolerance	Pending	--
	Soybean	Glufosinate tolerance	July 1996	--
	Sugar Beet	Glufosinate tolerance	Under review	--
Agritope	Tomato	Altered fruit ripening	March 1996	--
Bejo Zaden BV The Netherlands	Radicchio Rosso (Chicory)	Male sterile	October 1997	--
Calgene	Canola	High laurate	October 1994	April 1996
	Cotton	Bromoxynil tolerance	February 1994	August 1996
		Bromoxynil tolerance + Lepidopteran insect resistance	April 1997	--
	Tomato	Delayed fruit ripening (FlavrSavr™)	October 1992	February 1995
	Tomato [d]	Delayed fruit ripening	October 1994	--

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Table 1 (Continued)

Developing Company	Crop	G-M Trait(s) [a]	Date Approved	
			United States [b]	Canada [c]
Calgene (Continued)	Tomato [d]	Delayed fruit ripening	November 1994	--
	Tomato [d]	Delayed fruit ripening	March 1995	--
	Tomato [d]	Delayed fruit ripening	October 1996	--
Cornell University	Papaya	Virus resistance	September 1996	--
DeKalb Genetics	Corn	ECB resistance	March 1997	--
	Corn	ECB resistance + glufosinate tolerance	--	April 1997
	Corn	Glufosinate tolerance	December 1995	December 1996
DNA Plant Technology	Tomato	Delayed ripening	January 1995	November 1995
DuPont	Cotton	Male sterile + sulfonylurea tolerance	January 1996	--
	Soybean	High oleic acid	May 1997	--
Monsanto	Canola	Glyphosate tolerant	--	November 1994
	Canola	Glyphosate tolerance	--	September 1997
	Corn	Glyphosate tolerance	--	December 1996
	Corn	ECB insect resistance	August 1995	--
	Corn [d]	ECB resistance	March 1996	February 1997
	Corn	Glyphosate tolerance + ECB resistance	May 1997	September 1997
	Cotton	Lepidopteran insect resistance	June 1995	April 1996
	Cotton	Glyphosate tolerance	July 1995	--

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Table 1 (Continued)

Developing Company	Crop	G-M Trait(s)[a]	Date Approved: United States[b]	Date Approved: Canada[c]
Monsanto (Continued)	Potato	Colorado potato beetle resistance	March 1995	September 1995
	Potato[d]	Colorado potato beetle resistance	May 1996	November 1996
	Potato[d]	Colorado potato beetle resistance	Under review	--
	Soybeans	Glyphosate tolerance	May 1994	April 1996
	Tomato	Altered fruit ripening	September 1995	--
	Tomato	Lepidopteran insect resistance	Pending	--
Novartis (Ciba Seeds)	Corn	ECB resistance	May 1995	December 1995
Novartis (Northrup King Co.)	Corn	ECB resistance	January 1996	August 1996
Pioneer Hi-Bred International	Canola	Imidazolinone resistance	--	April 1995
	Canola	High oleic acid/Low linolenic acid	--	August 1996
	Corn	Insect resistance	--	December 1996
	Corn	Imidazolinone resistance	--	May 1994
Plant Genetic Systems	Corn	Male sterile (hybridization system based on male sterility)	February 1996	July 1997
		Male sterile + glufosinate tolerance	February 1996	--
	Rapeseed/Canola	New Hybridization system (male sterility) in oilseed rape	--	September 1994
	Rapeseed/Canola	Fertility restorer line in an new hybridization system	--	April 1995
	Rapeseed/Canola[d]	New Hybridization system MS8/RF3 (male sterility)	--	March 1997

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Table 1 (Concluded)

Developing Company	Crop	G-M Trait(s) [a]	Date Approved	
			United States [b]	Canada [c]
Rhone-Poulenc	Canola	Bromoxynil tolerance	--	July 1997
Seminis Vegetable Seeds				
Asgrow Seeds, subsidiary	Squash	Virus resistance (WMV2, ZYMV)	December 1994	--
	Squash	Virus resistance (CMV, WMV2, ZYMV)	June 1996	--
Zeneca Plant Science and Petoseed	Tomato, Processing	Reduced pectin degradation/ Decreased fruit polygalacturonase level	June 1995	June 1996
Zeneca Seeds Canada	Corn	Imazethapyr tolerance	--	July 1997

[a] ECB = European corn borer; CMV = cucumber mosaic virus; WMV2 = watermelon mosaic virus 2; ZYMV = zucchini yellows mosaic virus.

[b] Unless noted otherwise, approval dates for the United States are dates the products were determined by USDA/APHIS to have no potential for plant pest risk and should no longer be regulated. Pending = a decision on the company's petition for deregulation is pending as of December 4, 1997; Under review = supporting data submitted by the product developer are under review for completeness.

[c] Date of food safety approval by Health Canada

[d] Additional lines or varieties.

Sources: USDA/APHIS/BSS and Health Canada

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WESTERN EUROPE

Field Trials

As of June 1997, 936 field trials of genetically modified organisms (GMOs) had been conducted in EU member states (see Figure 5). Maize (corn) and rapeseed are the most frequently field tested GMOs in Western Europe, followed by sugar beets, potatoes, and tomatoes.

Figure 5
FIELD RELEASES OF GMOs IN WESTERN EUROPE BY CROP / OTHER ORGANISM

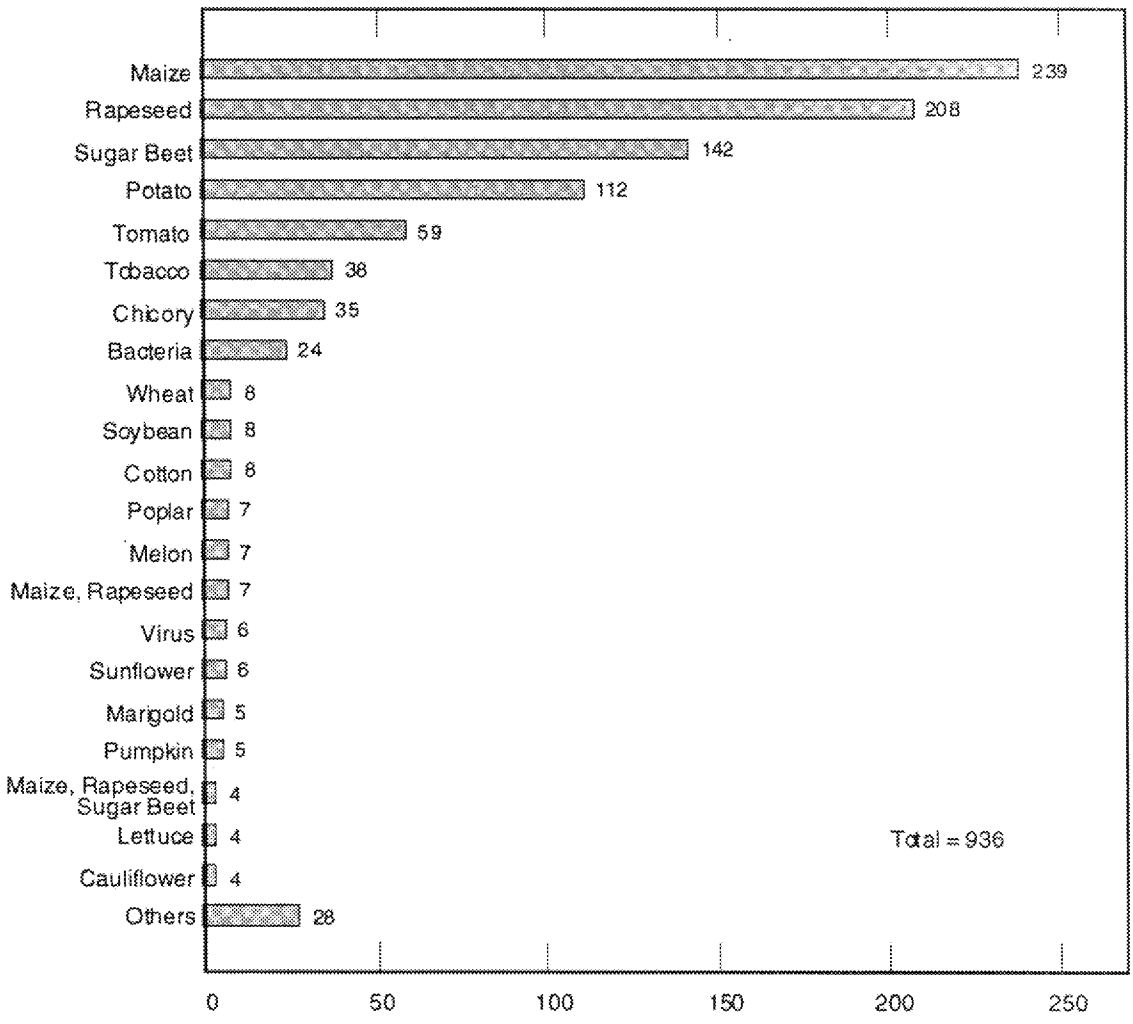

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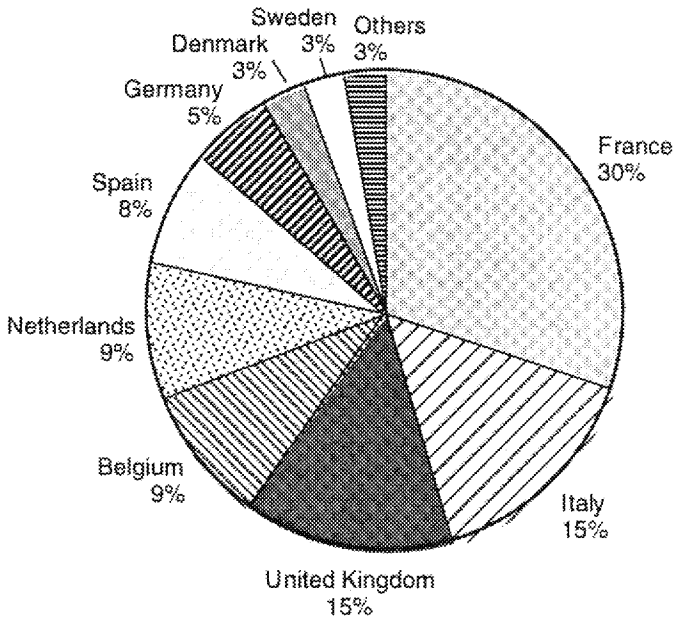
Figure 6 shows the percentages of total GMO field trials by EU member state. France accounts for the largest share—30%—followed by Italy and the United Kingdom (each with 15%) and Belgium and the Netherlands (each with 9%).

Figure 6
FIELD RELEASES OF GMOs IN WESTERN EUROPE BY COUNTRY



Developers and Products

Table 2 summarizes transgenic crop plant research and development in the EU. Thus far, approval of genetically modified food crops in the EU has taken much more time than in North America, with only four genetically modified food crops approved at the end of 1997 for import and/or marketing. This is the case in part because the approval process is complicated by differing views of the 15 EU member states, and in part because environmental groups have campaigned aggressively against genetically modified crops. In addition, European consumers are wary, given scares about food safety such as beef infected by "mad cow" disease.

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Table 2
COMPANIES CONDUCTING TRANSGENIC PLANT RESEARCH AND DEVELOPMENT IN WESTERN EUROPE: PRODUCTS APPROVED FOR MARKETING IN THE EUROPEAN UNION

Applicant	Crop	G-M Trait	Country and Year Submitted	Year Approved/ Remarks
AgrEvo	Maize	Herbicide tolerance (glufosinate)	France 1995	Pending
	Rapeseed	Herbicide tolerance (glufosinate)	United Kingdom 1995	Pending
	Rapeseed	Herbicide tolerance (glufosinate)	Germany 1996	Pending
Bejo Zaden BV	Radicchio	Male sterile (production of hybrid seeds) + Herbicide-tolerance (glufosinate)	Netherlands 1994	1996. For cultivation and seed production but not for human consumption or animal feed.
	Radicchio	Male sterile (production of hybrid seeds) + Herbicide-tolerant (glyphosate)	Netherlands 1995	Pending
Monsanto	Maize	Insect resistance	France 1995	Pending
	Soybean	Herbicide tolerance (glyphosate)	United Kingdom 1994	1996. Importation, storage, processing; no admission for cultivation.
Novartis (Ciba-Geigy)	Maize	Insect-resistance + herbicide tolerance (glufosinate)	France 1994	1997
Novartis (Northrup King)	Maize	Insect-resistance	United Kingdom 1996	Pending

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Table 2 (Concluded)

Applicant	Crop	G-M Trait	Country and Year Submitted	Year Approved/ Remarks
Pioneer Hi-Bred	Maize	Insect resistance	France 1995	Pending
Plant Genetic Systems	Rapeseed (2 applications, 2 lines)	Male sterile (production of hybrid seeds) + Herbicide tolerance (glufosinate)	United Kingdom 1994	1996. Not for human consumption or animal feed.
	Rapeseed	Male sterile (production of hybrid seeds) + Herbicide tolerance (glufosinate)	France 1995	1997
	Rapeseed	Male sterile (production of hybrid seeds) + Herbicide tolerance (glufosinate)	Belgium 1995	Pending
Prifolium	Fodder beet	Herbicide tolerance (glyphosate)	Denmark	Pending
Seita	Tobacco	Herbicide tolerance (bromoxynil)	France 1993	1994
Verkoop-en Productie Vereniging van Coöperatieve aardappel-meelen derivaten "AVEBE" b.a.	Potato	Altered starch composition	Netherlands 1995	Pending

Source: Robert Koch Institute.

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Other EU developments include the British National Institute of Agricultural Botany's field trials of Monsanto's glyphosate-tolerant (Roundup Ready®) sugar beet, and of G-M virus-resistant sugar beets developed by KWS Breeding in Germany, with market launch of both products scheduled for 2001. Virus disease-resistant (i.e., *Rhizomania*-resistant) sugar beets are also being developed in Germany, with commercialization expected within the next 3 years.

On December 3, 1997, the European Commission recommended labels for foods containing genetically modified maize or soybeans. If the decision is approved, the rules will take effect on February 1, 1998. Labels will be compulsory on all foods that are "no longer equivalent" to conventional ones because they contain genetically altered DNA. The label must say "produced from genetically modified maize/soya." (Some 60% of all prepared foods contain soya in one form or another.) Moreover, when it is unclear whether or not a foodstuff or one of its ingredients contains GMOs—for example, products made from maize imported as part of an unsegregated bulk shipment—manufacturers must label the product to show that it "may contain" GMOs.

These restrictions indicate that, at least initially, the European market will be problematic for genetically modified food products. However, pressures from other parts of the world may hasten acceptance of these products in order for European farmers and processors to remain competitive.

JAPAN

Transgenic canola, corn, cotton, potato, rice, soybean, tobacco, cole crop, melon, and tomato plant products are on the market or under development for food and/or animal feed uses in Japan. Table 3 lists the developing companies and other organizations and the products of each organization and indicates the development status of each product. As of December 1997, 20 genetically modified crop plant products had passed food safety control and been approved for marketing for food use in Japan. An additional 11 products have been deemed to pose no hazard to the environment and are undergoing final-stage evaluation in "ordinary" field tests (i.e., nonconfined trials in normal farmland cultivation).

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Table 3
ORGANIZATIONS CONDUCTING TRANSGENIC PLANT RESEARCH AND DEVELOPMENT IN JAPAN: STATUS OF PRODUCTS AT YEAR-END 1997

Company/Organization	Product(s)				Status/Remarks
	Crop	Event/Line/ Trade Name	Trait(s)[a]	Gene(s)[b]	
AgrEvo	Canola	HCN92 Liberty Link™	Glufosinate tolerance	PAT	Food use approved August 1996; feed use approved September 1996. Imported from Canada
	Canola	T-45 Liberty Link™	Glufosinate tolerance	PAT	Food use approved May 1997; feed use approved June 1997. Imported from Canada
	Canola	HCN 10 Liberty Link™	Glufosinate tolerance	PAT	Food use approved December 1997. Imported from Canada
	Corn	T-14, T-25 Liberty Link™	Glufosinate tolerance	PAT	Food and feed uses approved December 1997. Imported from the United States.
Calgene	Cotton	10211, 10215, 10222, 10224 BXN™	Bromoxynil tolerance	BXN	Food use approved December 1997. Imported from the United States.
Calgene and Kirin Brewery	Tomato	FlavrSavr™	Delayed ripening	AS-PG	Food use approved December 1997. Jointly developed in Japan by Calgene and Kirin Brewery.
DeKalb	Corn	DBT418, DLL25	Insect resistance	Bt (CryIA(b)), PAT	Nonconfined field trials in 1997. Imported from the United States.

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Table 3 (Continued)

Company/Organization	Product(s)				Status/Remarks
	Crop	Event/Line/ Trade Name	Trait(s)[a]	Gene(s)[b]	
Hokkaido Green-Bio Institute	Potato	Mayqueen	PLRV resistance	CP	Confined field trials since 1994.
Japan Tobacco	Rice	Tsuki-no-hikari: H39 and H75	Low-protein	AS-gluterin	Confined field trials in 1997. Improved product for Sake brewing.
	Tobacco	NA	CMV resistance	Satellite RNA	Confined field trials since 1994.
Japan Tobacco /Kakomai Breeding Institute	Rice	Akihikari	Low-protein	AS-gluterin	Confined field trials since 1994. Improved product for Sake brewing.
Ministry of Agriculture, Forestry and Fisheries (MAFF)	Melon	Prince	CMV resistance	CP	Nonconfined field trials since 1996.
	Rice	16-2	RSV resistance	CP	Nonconfined field trials since 1994.
	Rice	20-2, 21-3	RSV resistance	CP	Confined field trials since 1996
	Tomato	405, 707	CMV resistance	CP	Nonconfined field trials since 1996.
	Tomato	117, 1046, 1204, 1208	CMV resistance	CP	Nonconfined field trials in 1997. Variety Syugyoku.
	Tomato	NA	TMV resistance	CP	Nonconfined field trials since 1992. Experimental variety.
Mitsubishi Chemical Corporation Plantech Research Institute	Rice	Kinuhikari	RSV resistance	CP	Nonconfined field trials since 1994.

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Table 3 (Continued)

Company/Organization	Product(s)				Status/Remarks
	Crop	Event/Line/ Trade Name	Trait(s)[a]	Gene(s)[b]	
Mitsui Toatsu	Rice	Kinuhikari	Low-allergen	AS -Albanian	Nonconfined field trials since 1995. Product for consumers with allergy diseases.
Monsanto	Canola	GT73 Roundup Ready®	Glyphosate tolerance	EPSPS	Food use approved August 1996; feed use approved September 1996. Imported from Canada
	Corn	MON832 Roundup Ready®	Glyphosate tolerance	EPSPS	Confined field trials in 1997. Imported from the United States.
	Corn	MON810 YieldGard®	Insect resistance	Bt (CryIA(b))	Food use approved May 1997; feed use approved June 1997. Imported from the United States.
	Corn	MON802	Insect resistance + Glyphosate tolerance	Bt (CryIA(b))	Nonconfined field trials in 1997. Imported from the United States.
	Cotton	1145 Roundup Ready®	Glyphosate tolerance	EPSPS	Food use approved December 1997. Imported from the United States.
	Cotton	531 Ingard®	Insect resistance	Bt (CryIA(c))	Food use approved May 1997; feed use approved June 1997. Imported from the United States.
	Potato	NewLeaf® (See remarks)	Insect resistance	Bt (CryIIIA)	Seven lines approved for food use August 1996. Imported from the United States.

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Table 3 (Continued)

Company/Organization	Product(s)				Status/Remarks
	Crop	Event/Line/ Trade Name	Trait(s)[a]	Gene(s)[b]	
Monsanto (Continued)	Potato	NewLeaf® (See remarks)	Insect resistance	Bt (CryIIIA)	Six additional lines approved for food use May 1997. Imported from the United States.
	Soybean	40-3-2 Roundup Ready®	Glyphosate tolerance	EPSPS	Food use approved August 1996; Feed use approved September 1996. Imported from the United States.
Novartis (Ciba Seeds)	Corn	Event 176	Insect resistance	Bt (CryIA(b))	Food use approved August 1996; Feed use approved September 1996. Imported from the United States.
Novartis (Northrup King)	Corn	Bt11	Insect resistance	Bt (CryIA(b))	Food use approved August 1996; Feed use approved September 1996. Imported from the United States.
Pioneer Hi-Bred International Inc.	Corn	MON809	Insect resistance	Bt (CryIA(b))	Nonconfined field trials in 1997. Imported from the United States.
Plant Genetic Systems	Canola	PGS1	Glufosinate tolerance	PAT, MS	Food use approved August 1996; Feed use approved September 1996. Imported from Canada.

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Table 3 (Concluded)

Company/Organization	Product(s)				Status/Remarks
	Crop	Event/Line/ Trade Name	Trait(s)[a]	Gene(s)[b]	
Plant Genetic Systems (Continued)	Canola	MS8RF3	Glufosinate tolerance	PAT, MS, RF	Food use approved December 1997. Imported from Canada.
	Canola	PGS2	Glufosinate tolerance	PAT, MS, RF	Food use approved May 1997; feed use approved June 1997. Imported from Canada.
	Canola	PHY36	Glufosinate tolerance	PAT, MS, RF	Food use approved May 1997; feed use approved June 1997. Imported from Canada.
	Canola	PHY14, PHY35	Glufosinate tolerance	PAT, MS	Food use approved May 1997. Imported from Canada.
	Corn	CBH351	Insect resistance + Glufosinate tolerance	Bt (CryIA(b)), PAT	Confined field trials in 1997. Imported from the United States.
Rhone-Poulenc	Corn	Westar-Oxy-235	Bromoxynil tolerance	BXN	Confined field trials in 1997. Imported from Canada
Takii	Broccoli	TBR101	Glufosinate tolerance	PAT, MS	Confined field trials in 1997.
	Cauliflower	TSB201	Glufosinate tolerance	PAT, MS	Confined field trials in 1997.
Zeneca and Kagome	Tomato	ICI 9, ICI 13	High pectin	AS-PG	Nonconfined field trials since 1996. Jointly developed in Japan by Zeneca and Kagome.

[a] CMV = cucumber mosaic virus; PLRV = potato leaf roll virus; RSV = rice stripe virus; TMV = tobacco mosaic virus.

[b] AS - antisense; Bt = *Bacillus thuringiensis*; BXN = bromoxynil; CP = coat protein gene; EPSPS - enolpyruvyl-shikimate-phosphate synthase; MS = male sterile; PAT = phosphinotricin acetyl transferase; PG = polygalactoronase gene; RF = fertility restoration.

Source: Ministry of Agriculture, Forestry and Fisheries (MAFF), Japan.

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In keeping with rules based on international agreements, Japanese authorities rigorously examine genetically modified food products. Because the Japanese public is unfamiliar with genetic modification, some anxiety about genetically modified foods exists in the country. Surveys indicate that Japanese consumers want food products labeled to state that genetic modification techniques have been used.

To improve the public's awareness of biotechnology and its perceptions about the safety of genetically modified foods, Japan's Ministry of Agriculture, Forestry and Fisheries is conducting lectures, seminars, and symposia to provide the public with precise information about biotechnology and about recombinant DNA in particular.

OTHER REGIONS

Eastern Europe

Field trials of transgenic tobacco with bacterial- and virus-resistance traits have been conducted in Bulgaria by the Institute of Genetic Engineering, Tobacco Experiment Station.

Australia and New Zealand

Table 4 lists public and private organizations that are developing transgenic crop plant products in Australia.

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Table 4
ORGANIZATIONS CONDUCTING TRANSGENIC PLANT RESEARCH AND DEVELOPMENT IN AUSTRALIA

Company/Organization	Crop	G-M Trait(s)	Remarks
Applied Horticultural Research Pty Ltd	Tomato	Lepidopteran insect resistance	1997 field trials
Calgene Pacific	Potato	Yield improvement	Field trials approved in 1992
CSIRO Division of Plant Industry	Clover, Subterranean	Bromoxynil resistance	1996-1997 field trials
	Clover, White	Virus resistance	1996-1999 field trials
	Cotton	Bromoxynil resistance	Field release approved December 1996
	Cotton	Insect resistance (*Helicoverpa* spp.)	Field trials to examine field performance in controlling the main caterpillar pest of cotton, and to allow seed increase of selected material for further breeding and evaluation; part of an ongoing program to produce commercially useful varieties.
	Field Pea	Insect resistance	1996-1997 field trials
		Improved nutritional quality + glufosinate resistance	1996-1997 field trials
	Potato	Browning resistance	Field trials approved in 1995
		Virus resistance (PLRV)	Field trials approved in 1991, 1993, and 1995
	Tobacco	Insect resistance	Field trials approved in 1995

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Table 4 (Continued)

Company/Organization	Crop	G-M Trait(s)	Remarks
CSIRO Division of Plant Industry (Continued)	Wheat	Glufosinate resistance	1996-1997 field trials
		Altered starch composition	
Deltapine Australia Pty Ltd.	Cotton	Glyphosate resistance	Field release approved for winter nursery seed increase of Roundup Ready® transgenic cotton plants, 1997
	Cotton	Insect resistance (*Helicoverpa* spp.)	Winter nursery seed increase of Bt transgenic cotton plants, 1996
Hoechst Schering AgrEvo Pty Ltd.	Canola	Glufosinate tolerance	1996-2001 field trials
La Trobe University for Agriculture Victoria, Plant Sciences and Biotechnology	Clover, White	Virus resistance	1996-1999 gield trials. Alfalfa mosaic virus is widespread in clover in Victoria and causes 60% losses in clover production.
Monsanto Australia Limited	Cotton (Ingard®)	Lepidopteran insect resistance	Commercialized in 1996
	Soybean	Glyphosate resistance	Imports of Roundup Ready® soybeans for processing into oil and meal approved October 1996
Seedex Pty Ltd.	Canola	High lauric acid	1996-1997 field trials
	Canola	Male sterile/fertility restorer lines; for production of hybrid seed	1996-1997 field trials

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Table 4 (Concluded)

Company/Organization	Crop	G-M Trait(s)	Remarks
Seedex Pty Ltd. (Continued)	Canola	Disease resistance + male sterile/fertility restorer	1996-1997 field trials
Unifoods	Tomato	Altered fruit ripening	1993 field trials
University of Queensland	Sugar Cane	Leaf scald disease resistance	Field trials approved for 1996-2000

Source: Genetic Manipulation Advisory Committee (GMAC), Australia.

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Australian cotton farmers planted 75,000 acres of insect-resistant cotton in 1996 and 150,000 acres in 1997.

Transgenic plant research in New Zealand is emphasizing the development of improved pest and disease resistance in fruits, vegetables, and animal feed. Researchers are also seeking improved postharvest storage, flavor, nutrition, and color in response to consumer demand for high-quality, blemish-free produce with reduced chemical residues.

In 1990, New Zealand's Department of Scientific & Industrial Resources conducted field trials of broccoli tolerant of the herbicide atrazine, and during 1989-1993 this agency conducted field trials of virus-resistant potatoes and potatoes tolerant of Du Pont's sulfonylurea herbicide, chlorsulfuron. New Zealand field trials of European corn borer-resistant and herbicide-tolerant (glufosinate) maize developed by Ciba-Geigy (now Novartis) were conducted in 1993.

Latin America

Mexican farmers planted 2,200 acres of Monsanto's Bollgard® Bt cotton in 1996. In 1997, they planted 40,000 acres of Bollgard® cotton, as well as 10,000 acres of Monsanto's Roundup Ready® (glyphosate-tolerant) cotton.

Argentine farmers planted 250,000 acres of Roundup® Ready soybeans in 1996 and 3.5 million acres in 1997. At the end of 1997, Argentina's Agriculture Secretary stated that Argentine farmers will plant 1.5 million hectares (3.7 million acres) with genetically modified soybeans in 1998 and would have planted a larger area if more seeds were available. The government estimates that half of Argentina's 1999 soybean crop will be genetically modified.

In early December 1997, D&M International, a 50/50 partnership between Delta and Pine Land and Monsanto, announced a joint venture with Centro Integral Agropecuario (CIAGRO), an agricultural inputs distributor in the Argentine cotton region, for the production and sale of genetically improved cotton seeds. The new joint venture, to be known as CDM Mandiyu, will be owned 60% by D&M and 40% by CIAGRO. Initially, CDM Mandiyu will be licensed to sell cotton varieties containing Monsanto's Bollgard® Bt gene. Monsanto is continuing Argentine field trials of Bollgard® cotton with commercialization planned for 1998, after final government approval. Production and sale of Roundup Ready® Cotton in Argentina is planned for 1999. Delta and Pine Land is the managing member of the D&M International partnership.

After deciding that no basic difference existed between conventional soybeans and genetically modified varieties, Brazil recently announced its intention to authorize imports of 1.5 million metric tons of U.S. soybeans. The decision reversed an existing ban on imports of genetically modified soybeans, imposed because of a lack of evidence about their safety and effect on human beings. Thus far, genetically modified soybeans can only be planted experimentally in Brazil.

In November 1997, Monsanto acquired control of Sementes Agroceres S.A., the leading seed corn company in Brazil, with about a 30% share of the Brazilian seed corn

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market. This acquisition will enable Monsanto to market its insect-resistant and herbicide-tolerant corn technologies to Brazilian corn farmers.

South Africa

Table 5 identifies the organizations that conducted field trials of transgenic cotton, maize, and soybeans in South Africa in 1995.

Table 5
ORGANIZATIONS CONDUCTING GENETICALLY MODIFIED PLANT DEVELOPMENT IN SOUTH AFRICA: APPROVED FIELD TRIALS, 1995

Company/Organization	Crop	G-M Trait
Calgene	Cotton	Imidazolinone herbicide tolerance
	Cotton	Lepidopteran insect resistance + herbicide tolerance (bromoxynil)
Camia	Soybean	Herbicide tolerance (glyphosate)
Delta and Pine Land	Cotton	Herbicide tolerance (glyphosate)
	Cotton	Lepidopteran insect resistance + herbicide tolerance (glyphosate)
Monsanto	Maize	Herbicide tolerance (glyphosate)
	Maize	Lepidopteran insect resistance
PHI	Maize	Lepidopteran insect resistance

Sources: *BioTrack Database of Field Trials*, Organisation for Economic Cooperation and Development (OECD).

POTENTIAL MARKET SIZE INDICATORS

No commercial plantings of genetically engineered crops occurred in 1994, and North American plantings totaled less than 3.5 million acres in 1996. In 1997, however, more than 22 million acres of novel crop varieties, most with genetically engineered herbicide-tolerance or insect resistance traits, were grown in the United States and Canada.

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Growers' demand for the two categories of "input train" crops is expected to continue to expand rapidly. Table 6 summarizes projections for North American plantings of herbicide-tolerant and insect-resistant corn, cotton, soybeans, potatoes, and vegetable crop varieties in 2000 and 2005. Annual plantings are expected to reach 86 million to 109 million acres by 2000 and 137 million to 161 million acres by 2005.

Table 6
PROJECTED NORTH AMERICAN PLANTINGS OF HERBICIDE-TOLERANT AND INSECT-RESISTANT CROP PLANTS, 2000 AND 2005
(Millions of Acres)

	2000		
	Herbicide-Tolerant Plants[a]	Insect-Resistant Plants	Total
Corn	23.1-31.1	20.0-25.0	43.1-56.1
Cotton	1.8-2.5	4.0-5.0	5.8-7.5
Soybeans	37.0-44.0	—	37.0-44.0
Potatoes	—	0.8-0.9	0.8-0.9
Vegetables[b]	—	Neg	Neg
Subtotal	61.9-77.6	24.8-30.9	86.7-108.5

	2005		
	Herbicide-Tolerant Plants	Insect-Resistant Plants	Total
Corn	48.0-57.0	35.0-40.0	83.0-97.0
Cotton	2.1-2.7	5.0-6.0	7.1-8.7
Soybeans	45.0-53.0	—	45.0-53.0
Potatoes	—	1.4	1.4
Vegetables[b]	—	0.3-0.4	0.3-0.4
Subtotal	95.1-112.7	41.7-47.8	136.8-160.5

[a] Includes traditionally bred and transgenic varieties. Projections for 2000 and 2005 include stacked trait varieties.

[b] Includes tomatoes and sweet corn.

Source: SRI Consulting.

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Table 7 summarizes SRIC's estimates and projections for the end-user value of the North American market for transgenic herbicide-tolerant and insect-resistant crop plants. Overall, for both product categories, the market is expected to grow at an average annual rate of about 23% between 1997 and 2005.

Table 7
NORTH AMERICAN MARKET FOR GENETICALLY MODIFIED HERBICIDE-TOLERANT AND INSECT-RESISTANT CROP PLANTS, 1995-2005

	Millions of Dollars, End-User Value					
Trait/Crop	**1995**	**1996**	**1997**	**1998**	**2000**	**2005**
Herbicide Tolerance						
Corn	3.6	4.4	10.5	19.4	48	150
Cotton	—	—	5	105	140	175
Soybeans	—	13.5	56	152	216	225
Subtotal	3.6	17.9	71.5	276.4	404	550
Insect Resistance						
Corn	—	4	40	50	100-125	175-200
Cotton	—	65	70	115	130-140	165-190
Potatoes	<0.1	0.4	2.8	5	33	40
Vegetables	—	—	—	—	5	20
Subtotal	<0.1	69.4	112.8	170	268-303	400-450
Total	3.7	87.3	184.3	446.4	672-707	950-1,000

Source: SRI Consulting.

SRIC has not estimated or projected the future size of the market for other categories of transgenic plant products, including those with disease-resistance traits, traits that enhance agronomic performance or product quality, or other potentially useful traits for this report. However, by 2005, we expect the end-user value of the total world market for all categories of transgenic plant products to be 5 to 6 times the value projected in Table 7 for herbicide-tolerant and insect-resistant plants.

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GENETICALLY MODIFIED CROP PLANT PRODUCTS

CORN

Table 8 summarizes the traits that are being genetically engineered into corn hybrids and identifies the companies that are developing and/or marketing the genetically modified corn products. By 2000, enhanced quality corn hybrids may account for as much as 20% of the U.S. corn seed market. "Designer" corn products such as high-oil, white, high-starch, high-oleic acid, high-lysine, and low-phytic acid hybrids are already on the market or expected to be commercialized within the next few years. Du Pont Quality Grains, Cargill Hybrid Seeds, and Pioneer Hi-Bred are the major suppliers of specialty corn seed products currently on the market. Most of the current output-specific-trait corn hybrids were developed using traditional plant breeding techniques, but as Table 8 indicates, products with genetically engineered traits are under development.

Table 8
GENETICALLY MODIFIED CORN PLANT PRODUCTS ON THE MARKET OR UNDER DEVELOPMENT

Trait/Resistance and/or Tolerance[a]	Developing Organization	Remarks
Fungal Resistance	AgrEvo	Field trials of leafblight-resistant hybrids
	Holdens Foundation Seeds	Field trials of leafblight-resistant hybrids and of hybrids with multiple resistance to Anthracnose + *Cercospora* + *Helmintho-sporium*. and Anthracnose + *Cercospora* + eyespot + *Helminthosporium*
	Novartis (Ciba)	Field trials of hybrids resistant to *Helminthosporium* and other fungal diseases
	Novartis (Northrup King)	Field trials of eyespot-resistant and Northern corn leafblight-resistant hybrids
	Pioneer Hi-Bred	Field trials of hybrids resistant to ear mold, gray leaf spot, ear mold + gray leafspot, and *Fusarium* + gray leafspot, smut, and postharvest fungal diseases

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Table 8 (Continued)

Trait/Resistance[a] and/or Tolerance	Developing Organization	Remarks
Fungal Resistance + Herbicide Tolerance		
	Novartis Seeds (Ciba)	Field trials of hybrids with frogeye leaf spot resistance + glufosinate tolerance
	Holdens Foundation Seeds	Field trials of hybrids with fungal resistance and glufosinate tolerance
Herbicide Tolerance		
Chloroacetanilide herbicides	Zeneca	1997 U.S. field trials
Chlorsulfuron	Monsanto	1995 field trials
Glufosinate	AgrEvo	Liberty Link™ Corn commercialized in the United States in 1997 and marketed through more than 100 seed companies; approved in Canada in April 1997
Glyphosate	Monsanto	Market launch of Roundup Ready® Corn planned for 1998
Imazethapyr	Zeneca Seeds	Approved in Canada July 1997
Sulfonylurea tolerance	Pioneer Hi-Bred	1991 field trials
Herbicide Tolerance + Agronomic Properties		
Glufosinate + Altered carbohydrate metabolism	DeKalb Genetics	1995 field trials
Glufosinate + Male sterile	Asgrow Seeds	1995 field trials
	Holdens Foundation Seeds	Field trials since 1993
	Novartis Seeds (Ciba)	1994 and 1996 field trials
	Novartis (Northrup King)	1995-1996 field trials
	Pioneer Hi-Bred	Field trials since 1993
	Other seed companies	1995 field trials
	Plant Genetic Systems	Approved in the United States in February 1996

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Table 8 (Continued)

Trait/Resistance and/or Tolerance[a]	Developing Organization	Remarks
Herbicide Tolerance + Product Quality		
Glufosinate tolerance + Increased lysine level	DeKalb Genetics	Field trials since 1994
Glufosinate tolerance + Increased methionine level	DeKalb Genetics	Field trials since 1994
Insect Resistance		
ECB	AgrEvo/Plant Genetic Systems	Market launch scheduled for 1998
	DeKalb Genetics	DeKalb® on the market in 1997
	Monsanto	Yield Gard™ launched in 1997
	Mycogen Seeds	NatureGard™ insect-resistant corn launched in 1996
	Novartis Seeds (Ciba)	Maximizer™ Bt corn hybrids launched in 1996
	Novartis Seeds (Northrup King)	NK™ launched in 1997
	Pioneer Hi-Bred	Pioneer® on the market in 1997
ECB + other Lepidopteran sp.	Mycogen	1995 field trials
	Novartis Seeds (Ciba)	1995-1996 field trials
BCW and/or CRW	Mycogen Seeds	Expected on the market in 2000-2001
CRW	AgrEvo/Plant Genetic Systems	Expected on the market in 2000-2001
	DeKalb Genetics	1996 field trials
	Novartis Seeds (Ciba)	1995-1996 field trials
	Pioneer Hi-Bred	1996 field trials
CRW + ECB	Pioneer Hi-Bred	Pioneer® expected on the market in 2000-2001
	Monsanto	Expected on the market in 2000-2002

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Table 8 (Continued)

Trait/Resistance and/or Tolerance[a]	Developing Organization	Remarks
Insect Resistance (Continued)		
Lepidopteran pests, including Fall armyworm and southwestern corn borer	Mississippi State University and USDA/ARS	Scientists have patented a gene (Mir 1), and enzyme (33 kd cysteine proteinase) that can be genetically engineered in corn plants to impart insect resistance.
Storage grain pests	Mycogen Seeds	Expected on the market in 2000-2001
	Pioneer Hi-Bred	Expected on the market in 2000-2001
Insect Resistance + Herbicide Tolerance		
ECB + glufosinate	AgrEvo/PGS	Pending regulatory approval, seed for the first Cry9C Bt/Liberty Link™ corn hybrids will be launched in 1998 and marketed by Garst Seed. The Cry9C Bt gene was developed by AgrEvo's subsidiary, Plant Genetic Systems (PGS).
	Novartis Seeds	Market launch planed for 1998
ECB + glyphosate-	Monsanto	YieldGard® + Roundup Ready® Corn expected to be commercialized in 1999-2002
ECB + glyphosate + glufosinate	DeKalb Genetics	1995 field trials
ECB + glufosinate + imidazolinone	Garst Seed	IMI™-Bt-Liberty™ Corn expected to be available in 1998
Nematode Resistance + Herbicide Tolerance	Novartis Seeds (Northrup King)	Commercialization expected after 2000
Nematode Tolerance + Insect Resistance	Novartis Seeds (Northrup King)	Commercialization expected after 2000
Virus Resistance	Novartis Seeds (Northrup King)	1992 field trials
	Pioneer Hi-Bred	1992-1993 field trials

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Table 8 (Concluded)

Trait/Resistance and/or Tolerance[a]	Developing Organization	Remarks
Agronomic Properties		
Altered fertility	Pioneer Hi-Bred	1996 field trials
Altered fruit ripening	Pioneer Hi-Bred	1995 field trials
Male sterile	AgrEvo	Seed Link™ Corn
	Cargill Hybrid Seeds	Field trials since 1992
	Holdens Foundation Seeds	Field trials since 1992
	Novartis Seeds (Ciba)	1995 field trials
	Pioneer Hi-Bred	Field trials since 1992
	Plant Genetic Systems	1996 U.S. approval
Stress tolerant	DeKalb Genetics	1996 field trials
Product Quality		
Altered carbohydrate metabolism	Du Pont	Field trials since 1994
	Monsanto	Field trials since 1995
Altered nitrogen metabolism	Monsanto	Field trials since 1995
Altered nutritional quality	Pioneer Hi-Bred	Field trials since 1995
Altered oil profile	Du Pont	Field trials since 1996
	Pioneer Hi-Bred	Field trials since 1996
Altered pigment metabolism	Pioneer Hi-Bred	
Altered protein quality	Du Pont	Field trials since 1994
	Pioneer Hi-Bred	Field trials since 1995
Other		
Cre recombinase produced	Du Pont	Field trials since 1995
Antibodies produced	Agracetus	Field trials since 1995
Novel protein produced	ProdiGene (College Station, TX)	1997 field trials. ProdiGene is developing transgenic plants that contain oral vaccines.
Starch produced	Du Pont	Two patented novel genetically engineered maize plants produce starch with improved functional properties for food uses and as a base starch for chemical modification

[a] BCW = black cutworm; CRW = corn rootworm; ECB = European corn borer.

Sources: Communications with industry, trade literature, and electronic field trials data bases.

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COTTON

Table 9 lists transgenic cotton plant products currently on the market or under development and identifies the developing organizations.

Table 9
GENETICALLY MODIFIED COTTON PLANT PRODUCTS ON THE MARKET OR UNDER DEVELOPMENT

Trait/Resistance and/or Tolerance	Developing Organization	Remarks
Herbicide Tolerance		
Bromoxynil	Calgene	BXN® Cotton launched in 1995
2,4-D	All-Tex Seed	1994 field trials
	United Agri Products	1994 and 1995 field trials
	USDA/ARS	1996 field trials
	Other seed companies	1994 field trials
Glyphosate	Monsanto	Roundup Ready® Cotton launched in 1997
Imidazolinone	American Cyanamid	1995 field trials by American Cyanamid, Boswell, Calgene, and Phytogen
Glufosinate	AgrEvo	1995-1996 field trials by Calgene, Delta and Pine Land, and Mycogen; commercialization expected after 2000
Sulfonylurea	Du Pont	Approved for marketing, but not commercialized; field trials by Calgene, Monsanto, and Delta and Pine Land
Insect Resistance		
Boll weevil	Monsanto	Expected on the market in 2000-2002
Lepidopteran pests	Monsanto	Bollgard® Cotton launched in the United States in 1996 and marketed in Australia as Ingard®; developed in cooperation with Delta and Pine Land. A second-generation Bollgard® with a different mode of action is under development.
	Mycogen	Expected on the market in 2000-2002

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Table 9 (Concluded)

Trait/Resistance and/or Tolerance	Developing Organization	Remarks
Insect Resistance + Herbicide Tolerance		
Lepidopteran pests + Bromoxynil	American Cyanamid	1993 field trials
	Monsanto/Calgene	Bollgard® + BXN® Cotton scheduled for launch in 1998
Lepidopteran pests + Glyphosate	Monsanto	Bollgard® + Roundup Ready® Cotton expected on the market in 1998-1999
Lepidopteran pests + Sulfonylurea	Calgene	1993 field trials
Agronomic Properties		
Cold tolerance	All-Tex Seed	1995 field trials
Male sterile	Delta and Pine Land	1994 field trials
Increased yield	Calgene	1995 field trials
Product Quality		
Cationic peroxidase level decreased	USDA/ARS	1993 field trials
Melanin production and altered fiber pigment	Calgene/Monsanto	Calgene patent covers a gene construct for expression of melanin in cotton fiber. Naturally colored fiber will reduce handling and disposal of dyes in textile manufacture.
Fiber strength altered	Agracetus	Field trials since 1996; commercialization expected by 2003

Sources: Communications with industry, trade literature, and electronic field trial data bases.

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POTATOES

Table 10 lists traits that are being genetically engineered in potatoes and identifies the companies that are marketing and/or developing new potato varieties containing each trait.

Table 10
GENETICALLY MODIFIED POTATO PLANT PRODUCTS ON THE MARKET OR UNDER DEVELOPMENT

Trait/Resistance and/or Tolerance[a]	Developing Organization	Remarks
Bacterial Resistance	Frito Lay	1994 field trials
	Montana State University	1992 field trials
	USDA/ARS	Field trials since 1991
	Washington State University	1995 field trials
	Bundesanstalt für Zuchtugforschung und Kulturplanzen (Quedlinburg, Germany)	German field trials approved for 1996-2002
Bacterial Resistance + Fungal Resistance	Washington State University	1991 field trials
Bacterial Resistance + Fungal Resistance + Virus Resistance	Frito Lay	1993 field trials
Fungal Resistance		
Phytophthora	Boyce Thompson Institute	1996-1997 field trials
	Frito Lay	Field trials since 1994
	Illinois University	1995 field trials
	Monsanto	Field trials since 1993
	Purdue University	1994-1995 field trials
Rhizoctonia solani	Frito Lay	Field trials since 1993
Verticillium dahlae	Frito Lay	Field trials since 1995
	Washington State University	Field trials since 1991
Unspecified fungus	Max Planck-Institut (Cologne, Germany)	German field trials approved for 1996-1999
Herbicide Tolerance		
Bromoxynil	University of Idaho	Field trials since 1992
	USDA/ARS	1991 field trials
2,4-D	USDA/ARS	1991 field trials
Glyphosate	Monsanto	Field trials since 1996

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Table 10 (Continued)

Trait/Resistance and/or Tolerance[a]	Developing Organization	Remarks
Herbicide Tolerance (Continued)		
Imidazolinone	American Cyanamid	Field trials since 1994
Sulfonylurea	Frito Lay	Field trials since 1993
Herbicide Tolerance + Insect Resistance		
Glyphosate + CPB	Monsanto	1993 field trials
Herbicide Tolerance + Insect Resistance + Product Quality		
Glyphosate + CPB + Altered auxin metabolism	Monsanto	1993 field trials
Insect Resistance		
CPB	Frito Lay	Field trials since 1992
	Monsanto	NewLeaf® Insect resistant potatoes commercialized in 1995
	Michigan State University	Field trials since 1994
	Nickerson Biocem (United Kingdom)	Pea-derived insect resistance; 1991-1994 UK field trials
	Plant Genetics	1996 field trials
	USDA/ARS	1992 field trials
CPB + Lepidopteran pests	USDA/ARS	1990 field trials
Lepidopteran pests	Michigan State University	1993-1996 field trials
	USDA/ARS	1996 field trials
Unspecified pests	Axis Genetics (United Kingdom)	Snowdrop lectin gene; 1995 UK field trials
Insect Resistance + Product Quality		
CPB + Increased tuber solids	Monsanto	1992-1995 U.S. field trials
CPB + Increased auxin metabolism	Monsanto	1993 U.S. field trials
Insect Resistance + Virus Resistance	Calgene	1992 U.S. field trials

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Table 10 (Continued)

Trait/Resistance and/or Tolerance[a]	Developing Organization	Remarks
Insect Resistance + Virus Resistance (Continued)	Frito Lay	1993 U.S. field trials
	Monsanto	1990-1996 U.S. field trials; NewLeaf® Y potato varieties with stacked resistance to CPB and potato virus Y expected to be commercialized in 1998 by Monsanto's NatureMark™ subsidiary
Insect Resistance + Virus Resistance + Product Quality (Increased tuber solids)	Monsanto	1992-1993 U.S. field trials
Nematode Resistance	KARNA (the Netherlands)	1994 Dutch field trials
	Monsanto	1993 U.S. field trials
Potato cyst nematode + kanamycin resistance	Plant Breeding International	1995 UK field trials
Virus Resistance	Bundesanstalt für Zuchtugforschung und Kulturplanzen (Quedlinburg, Germany)	German field trials approved for 1997-2005
	CSIRO Division of Plant Industry (Australia)	Field trials in Australia since 1991
	Frito Lay	1992 and 1994 field trials
	Hokkaido Green-Bio Institute	Confining field trials conducted in Japan since 1994
	Kemira Agro (Finland)	1996 field trials
	Max Planck-Institut (Cologne, Germany)	German field trials approved for 1994 and 1997-2000
	Michigan State University	1992 field trials
	Monsanto	U.S. field trials since 1989
	Oregon State University	Field trials since 1994
	Plant Breeding International	1993 UK field trials
	Scottish Crop Research Institute	1996 UK field trials
	USDA/ARS	Field trials since 1994

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Table 10 (Continued)

Trait/Resistance and/or Tolerance[a]	Developing Organization	Remarks
Virus Resistance (Continued)		
Virus Resistance, Multiple	Frito Lay	U.S. field trials since 1992
	Monsanto	U.S. field trials since 1991
	University of Idaho	Field trials since 1992
Agronomic Properties		
Calmodulin level altered	Washington State University	1994 field trials
Cold tolerance	Frito Lay	U.S. field trials in 1991-1993
Improved agronomic performance and storage quality	Advanced Technologies (Cambridge)	1993 UK field trials
Reduced growth rate	University of Wisconsin	1993 field trials
Stress tolerance	Frito Lay	1992-1993 U.S. field trials
Product Quality		
Altered carbohydrate composition	Nickerson Biocem	1996 UK field trials
Altered carbohydrate metabolism	Advanced Technologies (Cambridge)	1996 UK field trials
	AgrEvo (Berlin, Germany)	German field trials approved for 1997-2000
	Plant Breeding International	1996 UK field trials
	Scottish Crop Research Institute	1996 UK field trials
	Bioplant (Ebstorf, Germany)	Company has applied for approval to conduct field trials during 1998-2006.
	Frito Lay	1993-1996 field trials
	Institut für Genbiologische Forschung (Berlin, Germany)	1993-1994 field trials
	Institut für Pflanzengenetik und Kulturpflanzenforschung (Gatersleben, Germany)	Company has applied for approval to conduct field trials during 1998-1999.
	Max Planck-Institut (Koln, Germany)	German field trials approved for 1996-2000
	North Dakota State University	1994-1996 field trials
	University of Wisconsin	1993-1995 field trials

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Table 10 (Concluded)

Trait/Resistance and/or Tolerance[a]	Developing Organization	Remarks
Product Quality (Continued)		
Altered fruit ripening	North Dakota State University	1993 field trials
Altered starch composition	Verkoop-en Productie Vereniging van Coöperatieve aardappelmeelen derivaten "AVEBE" (Netherlands)	Approval for marketing in the EU pending
Altered starch metabolism	AgrEvo UK Crop Protection	1996 UK field trials
	Applied Starch Technology	1992 field trials
Bruising resistance	Monsanto	Notification of intent to conduct field trials acknowledged by USDA/ARS in November 1997
	USDA/ARS	1992-1995 field trials
Increased carbohydrate level/Increased tuber solids	Calgene	1991 U.S. field trials
	Frito Lay	1992 field trials
	Monsanto	Field trials of higher solids potatoes since 1993
Increased seed number	Monsanto	1991 field trials
Increased tyrosine level	USDA/ARS	1991 field trials
Reduced sugar content and kanamycin resistance	Axis Genetics	1994 UK field trials
Starch synthesis	AgrEvo	1996 field trials in Spain
Other		
Decreased epoxide hydrolase level	USDA/ARS	1994 field trials
Edible vaccines	Mycogen	Mycogen has obtained a license for exclusive commercial rights to human and animal health applications of technology developed by Washington University (St. Louis, MO) to genetically alter potato and other plants to produce and deliver edible vaccines.

[a] CPB = Colorado potato beetle.

Sources: Communications with industry, trade literature, and electronic field trials data bases.

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RAPESEED AND CANOLA

Table 11 lists transgenic rapeseed or canola plant products that are already commercialized or under development, and identifies the companies and other organizations that are developing each product.

Table 11
GENETICALLY MODIFIED RAPESEED AND CANOLA PLANT PRODUCTS ON THE MARKET OR UNDER DEVELOPMENT

Trait(s)/Resistance and/or Tolerance	Developing Organization	Remarks
Fungal Resistance	Planta (Einbeck, Germany)	German field trials approved for 1998-2000
	Zeneca	1993 UK field trials
Postharvest fungal resistance	Cargill Hybrid Seeds	1997 U.S. Field trials
Fungal Resistance + Marker Gene	Pioneer Hi-Bred	1996 Canadian field trials
	University of Manitoba (Canada)	1996 field trials
	Zeneca Seeds (Canada)	1996 Canadian field trials
Fungal Resistance + Herbicide Tolerance	Plant Genetic Systems	1996 Canadian field trials; 1997 UK field trials
Fungal Resistance + Herbicide Tolerance + Agronomic Properties	Plant Genetic Systems	1997 UK field trials
Herbicide Tolerance		
Bromoxynil tolerance	AgrEvo	1996 Canadian field trials
	Canola Council of Canada	1996 field trials
	Rhône-Poulenc	Approved in Canada in July 1997; field trials in Europe
	University of Manitoba (Canada)	Field trials since 1992

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Table 11 (Continued)

Trait(s)/Resistance and/or Tolerance	Developing Organization	Remarks
Herbicide Tolerance (Continued)		
Glufosinate	AgrEvo	Liberty Link™ Canola was commercialized in Canada in 1995, and a second line was approved for marketing in 1997. Approved in Japan in 1996; approval pending in the EU; currently in field trials in the United States.
	Canola Council of Canada	1996 field trials
	National Institute for Agricultural Botany (United Kingdom)	UK field trial permit obtained in 1994
	Perryfields Holdings	1996 UK field trials
	Pioneer Hi-Bred	1996 Canadian field trials
Glufosinate + Male Sterile	Plant Genetic Systems	Approved in the EU in 1997; approved in Japan 1996; field trials in the United States
	University of Idaho	1993-1995 field trials
Glyphosate	Monsanto	Roundup Ready® Canola commercialized in Canada in 1996 and approved in Japan in 1996. Roundup Ready® Rapeseed expected to be launched in the United States and Europe after 2000. Field trials in the UK by Monsanto, and several seed companies; field trials conducted in Argentina and Chile
Imidazolinone	Pioneer Hi-Bred International	Approved in Canada in 1995
Sulfonylurea	University of Chicago	1996 field trials
Herbicide Tolerance + Insect Resistance		
Glufosinate + Unspecified insect pest(s)	Cargill Hybrid Seeds	1995 Canadian field trials

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Table 11 (Continued)

Trait(s)/Resistance and/or Tolerance	Developing Organization	Remarks
Herbicide Tolerance + Male Sterile		
Glufosinate	Plant Genetic Systems	Approved in the EU and Japan in 1996
	University of Idaho	1996 U.S. Field trials
Herbicide Tolerance + Product Quality		
Glufosinate + higher protein product	Pioneer Hi-Bred	1996 Canadian field trials
Insect Resistance		
Lepidopteran	Mycogen	Bt canola expected on the market after 2000
	University of Chicago	1995-1996 field trials
	University of Georgia	1995 field trials
Agronomic Properties		
Male sterile + fertility restorer	AgrEvo	Approved by the U.S FDA in 1996
	Plant Genetic Systems	New hybridization system; approved in Canada in 1994 and in the EU in 1997
Stress Tolerance/Marker Gene	National Research Council, Plant Biotechnology Institute (Canada)	1996 Canadian field trials
Increased yield	Calgene	Notification of field trials acknowledged by USDA/ARS November 1997
Extended flower life	Monsanto	Application for field trials acknowledged by USDA/ARS November 1997
Product Quality		
Altered fatty acid metabolism	Cargill Hybrid Seeds	U.S. field trials since 1995
	Du Pont	1994 U.S. field trials

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Table 11 (Continued)

Trait(s)/Resistance and/or Tolerance	Developing Organization	Remarks
Product Quality (Continued)		
Altered oil composition/quality	Cargill Hybrid Seeds	1996-1997 Canadian field trials; 1997 U.S. trials
	Du Pont	1993-1994 U.S. field trials
High-laurate	Calgene	High-lauric acid (laurate) canola (Laurical®) commercialized in 1995; a less expensive source of high-quality raw materials for soaps, detergents, and cocoa butter replacements for food products. Planted on more than 70,000 acres in the United States in 1997. Under evaluation in field trials by the Scottish Agricultural College and several UK seed companies
High myristate	Calgene	High-myristate canola under development; a less expensive and more abundant source of raw materials for soaps and detergents.
High-stearate	Calgene/Monsanto	For improved oils for margarines and shortenings; no hydrogenation required; expected on the market in 1998 or 1999; under evaluation in field trials by the Scottish Agricultural College and several UK seed companies
	Mildola (Finland)	Rapeseed with increased stearic acid field tested in Finland in 1996
High oleic acid/low linolenic acid	Pioneer Hi-Bred International	Approved in Canada in 1996

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Table 11 (Continued)

Trait(s)/Resistance and/or Tolerance	Developing Organization	Remarks
Product Quality (Continued)		
Medium-chain fatty acid/medium chain triglyceride	Calgene	Medium-chain fatty acid/medium-chain triglyceride canola will be a less expensive source of raw material for high-performance lubricants, nutritional formulas, and high-energy foods.
Increased protein lysine level	Cargill Hybrid Seeds	1997 U.S. field trials
Lipid metabolism	Bundesanstalt für Zuchtugforschung and Kulturplanzen (Quedlinburg, Germany)	German field trials approved for 1996-2002
	Deutsche Saatveredelung (Salzkotten, Germany)	German field trials approved for 1997-2001
	Norddeutsche Pflanzenzucht, Hans George Lemke KG (Holtsee, Germany)	German field trials approved for 1997-2002
	Planta (Einbeck, Germany)	German field trials approved for 1997-2001
Phytase production	Nickerson Biocem	1996-1997 UK field trials
Nutritional Change + Marker Gene	University of Calgary	1996 Canadian field trials
Other		
Anticoagulant production	University of Calgary	1996 Canadian field trials
Enzyme production	University of Calgary	1996 Canadian field trials
Industrial enzymes production	Cargill Hybrid Seeds	1993 U.S. field trials
Pharmaceutical Proteins Production	Pioneer Hi-Bred	1996 UK field trials
Polymer Production	Monsanto	U.S. field trials since 1996

Sources: Communications with industry and trade literature.

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RICE

Table 12 summarizes world transgenic rice plant research and identifies the organizations that are developing genetically modified rice plant products.

Table 12
GENETICALLY MODIFIED RICE PLANT PRODUCTS UNDER DEVELOPMENT

Trait/Resistance and/or Tolerance	Developing Organization	Remarks
Bacteria Resistance	University of California, Davis	U.S. field trials of leaf blight-resistant rice since 1996
Fungal Resistance		
Rhizoctonia solani	Louisiana State University	Field trials since 1995
Herbicide Tolerance		
Glufosinate	AgrEvo	Field trials since 1996
	Louisiana State University	Field trials since 1993
Glyphosate	Monsanto	Roundup Ready® rice expected on the market after 2000
Imidazolinone	American Cyanamid	IMI™ rice under development in cooperation with universities and seed companies
Insect Resistance		
Coleopteran	Louisiana State University	1993 field trial
Lepidopteran	Louisiana State University	1991 field trial
Unspecified insect pests	Chinese Academy of Agricultural Science (Beijing, China)	Chinese scientists are attempting to insert a scorpion toxin gene into rice.
	Swiss Federal Institute of Technology (Zürich, Switzerland)	Bt rice, with the Bt gene provided by Novartis (Ciba-Geigy)
	Cornell University and Washington University	Developed under a grant from the Rockefeller Foundation's International Rice Biotechnology Program; large field trials in China in 1996

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Table 12 (Continued)

Trait/Resistance and/or Tolerance	Developing Organization	Remarks
Insect Resistance + Nematode Resistance	Leeds University, Centre for Plant Biocemistry and Biotechnology (UK)	Development of the technology was funded by the seed companies Hilleshog NK and Nickerson Biocem; they donated their royalty rights to the genetically engineered rice and certain other plants to the Plant Sciences Programme of the UK's Overseas Development Administration (ODA) to enable the technology to be adapted for free use in developing countries.
Insect Resistance + Product Quality		
Coleopteran Insect + Storage protein altered	Louisiana State University	1993 field trial
Lepidopteran pest(s) + Altered storage protein	Louisiana State University	1992 field trial
Lepidopteran + altered seed composition	Louisiana State University	1992 field trial
Virus Resistance	Mitsubishi Chemical Corporation Plantech Research Institute (Japan)	Nonconfined field trials of rice varieties resistant to rice stem virus in Japan since 1994
	Ministry of Agriculture, Forestry, and Fisheries (Japan)	Several rice lines resistant to rice stem virus in field trials
Agronomic Properties		
Male sterile	Plant Genetic Systems	Male sterility gene for production of hybrid rice licensed to Japan Tobacco, to develop a better variety of hybrid rice

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Table 12 (Concluded)

Trait/Resistance and/or Tolerance	Developing Organization	Remarks
Agronomic Properties (Continued)		
Salt and drought tolerance	Cornell University and Washington University	Developed with support from the Rockefeller Foundation's International Rice Biotechnology Program; large field trials in China in 1996; patents applied for by Cornell Research Foundation
Product Quality		
Increased yield and/or better taste	Japan Tobacco (Japan) and Monsanto	The two companies entered an agreement in December 1995 to collaborate to develop higher-yielding, better tasting rice varieties.
Increased yield	Monsanto	Notified USDA of intent to conduct field trials in three states in 1998
Low Protein	Japan Tobacco Kakomai Breeding Institute (Japan)	Confined field trials in 1997; improved product for sake brewing
Other		
Low Allergen	Mitsui Toatsu (Japan)	Ordinary field trials since 1995
	China	Chinese scientists have genetically engineered rice to remove the major allergen causing food allergies.
Pharmaceutical Proteins Produced	Applied Phytologics (Davis, CA)	

Sources: Communications with industry, trade literature, and electronic field trials data bases.

Provisions of the Rockefeller Foundation grant stipulate that the new insect-resistant and salt- and drought-tolerant rice plant technology developed by Cornell University and Washington University scientists be given to developing countries, but the technology will be sold in developed countries such as the United States and Japan.

The Cornell Research Foundation has applied for patents on the technology. Several companies have signed licensing agreements to use the insect-resistant gene technology in other crops, including corn and wheat. The genetically engineered insect-resistant and salt- and drought-tolerant rice plants are expected to be available to farmers by about 2001.

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SOYBEANS

Table 13 summarizes the transgenic soybean plant products commercialized or under development worldwide and identifies the developing organizations. In 1997, approximately 9 million acres of herbicide-tolerant soybeans (Roundup Ready® Soybeans from Monsanto) were planted in the United States, and another 3.5 million acres were planted in Argentina. AgrEvo's glufosinate-resistant (Liberty™ Link) soybeans are expected to be launched in the United States in time for the 1998 planting season.

Specialty soybean varieties with many unique traits are on the market, but most have been developed by traditional breeding methods. However, new genetically modified lines with low-linoleic, high-oleic, and lower palmitic acid traits, and other lines with other enhanced quality traits are under development and expected to be commercialized within the next few years.

Table 13
GENETICALLY MODIFIED SOYBEAN PLANT PRODUCTS ON THE MARKET OR UNDER DEVELOPMENT

Trait/Resistance and/or Tolerance	Developing Organization	Remarks
Herbicide Tolerance		
Glufosinate	AgrEvo	Liberty Link™ soybeans; scheduled for commercialization in North America in 1998; field trials since 1995
Glyphosate	Monsanto	Roundup Ready® soybeans, developed in cooperation with numerous seed companies, were launched in North America in 1996. EU approval for importation, storage, and processing was granted in 1997. Cultivation is not yet approved in the EU.
Herbicide Tolerance + Product Quality		
Glufosinate tolerance + Increased lysine level	DeKalb Genetics	1996 field trials
Glyphosate tolerance + Increased seed methionine storage	Pioneer Hi-Bred	1992-1993 field trials

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Table 13 (Continued)

Trait/Resistance and/or Tolerance	Developing Organization	Remarks
Insect resistance		
Lepidopteran insect pests	Monsanto	Notified USDA/ARS in October 1997 of intent to conduct field trials
Bt Soybeans	Mycogen	Bt soybeans under development for protection against various caterpillars and beetle pests
Nematode Resistance		
Root-knot	Monsanto	
Soybean cyst	Mycogen and Pioneer Hi-Bred	Mycogen and Pioneer Hi-bred collaborating to develop transgenic nematode-resistant soybeans; commercialization expected in 2001-2002
Virus resistance	Pioneer Hi-Bred	Soybean mosaic virus
	University of Kentucky	1995 field trials
Agronomic Properties		
Altered plant development	Monsanto	Notified USDA/ARS in December 1997 of intent to conduct field trials
Product Quality		
Altered oil profile	Du Pont	High-oleic acid soybeans approved in the United States in May 1997; commercialization in small quantities planned for 1998. Oil contains 80% or more oleic versus 24% in currently available soybean oil.
	Monsanto	High stearate soybeans for production of oil with healthier properties for margarines and shortenings. High-stearate oil requires no hydrogenation and contains no trans-fatty acids (which increase cholesterol).
Altered oil quality	Du Pont	Field trials since 1995

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Table 13 (Concluded)

Trait/Resistance and/or Tolerance	Developing Organization	Remarks
Product Quality (Continued)		
Altered oil quality + altered protein quality	Du Pont	1997 field trials
Altered protein quality	Du Pont	Field trials since 1995
Altered seed composition	Agracetus	Field trials since 1995
Altered storage protein	Du Pont	1993-1994 field trials
	Pioneer Hi-Bred	1992-1995 field trials
High methionine	Du Pont	Commercialization expected after 2002
	Pioneer Hi-Bred	Field trials since 1992
Other		
Production of antibody	Agracetus	Field trials since 1996
Production of industrial enzyme	Agracetus	Field trials since 1996
Production of polymer	Monsanto	Field trials since 1996

Sources: Communications with industry, trade literature, and electronic field trials data bases.

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SUGAR BEETS

Table 14 summarizes the traits that are being genetically engineered into sugar beets and identifies the companies that are developing transgenic sugar beet plant product in Western Europe and North America.

Table 14
GENETICALLY MODIFIED SUGAR BEET PLANT PRODUCTS UNDER DEVELOPMENT

Trait/Resistance and/or Tolerance[a]	Supplier or Developer	Remarks
Fungal Resistance	Novartis Seeds	1994 field trials by Hilleshög AB, now part of Novartis Seeds, Field Crops Europe
Herbicide Tolerance		
Glufosinate	AgrEvo	Liberty Link™ Sugar Beets expected on the market after 2000; U.S. field trials by AgrEvo and Betaseed; European field trials by AgrEvo, Zeneca, and several seed company cooperators
Glyphosate	Monsanto	Roundup Ready® Sugar Beets expected to be launched after 2000; European field trials by Monsanto and seed company cooperators
	Novartis Seeds	1997-1998 U.S. field trials; 1997 field trials in Spain; German field trials approved for 1998-2002
Imidazolinone	American Cyanamid	IMI™ Sugar Beets are being developed in cooperation with universities and seed companies and are expected to be commercialized after 2000.
Herbicide Tolerance + Antibiotic Resistance		
Glufosinate resistance + tetracycline resistance	KWS France	1995 field trials in France

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Table 14 (Continued)

Trait/Resistance and/or Tolerance[a]	Supplier or Developer	Remarks
Herbicide Tolerance + Fungus Resistance + Virus Resistance	Maribo Seed	1993 European field trials
Herbicide Tolerance + Insect Resistance		
Glufosinate + Lepidopteran Insects	Novartis Seeds	1996 European field trials by Hilleshög AB, now part of Novartis Seeds Field Crops Europe
Herbicide tolerance + Virus Resistance		
Glufosinate + BNYV	Planta GmbH (Einbeck, Germany)	Field trials since 1992. Planta is a subsidiary of KWS Kleinwanzlebener Saatzuch.
	Sharpes International Seeds (United Kingdom)	1994 UK field trials
Glufosinate + BNYV + BWY	Sharpes International Seeds	1992 UK field trials
Glyphosate + BNYV + BWY	VanderHave[b]	Field trials in the Netherlands since 1990 and in France since 1995
Glyphosate - glufosinate + BNYV + BWY-BMY	VanderHave[b]	1994 Dutch field trials
Herbicide Tolerance + Virus Resistance + Product quality		
Glyphosate + Glufosinate + BNYV + increased sugar content	VanderHave[b]	1996 field trials in France
Herbicide Tolerance + Product Quality		
Glyphosate + increased sugar production	VanderHave[b]	1994 Dutch field trials

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Table 14 (Continued)

Trait/Resistance and/or Tolerance[a]	Supplier or Developer	Remarks
Insect Resistance	Novartis Seeds	Bt sugar beets have been field tested in Europe since 1993 by Hilleshög AB, now part of Novartis Seeds, Field Crops Europe.
Nematode Resistance		
Sugar beet cyst	Novartis Seeds	A patent was obtained in 1993 by Sandoz Inventions, Austria.
	University of Kiel Institute of Crop Science and Plant Breeding (Germany)	University scientists have identified and cloned a nematode-resistance gene that originated in a wild beet plant. Their goal is to use the gene to create lines of resistant sugar beets and other crops.
Virus Resistance		
BNYV[c]	Betaseed	U.S. field trials since 1993. Betaseed is a subsidiary of KWS Kleinwanzlebener Saatzuch (Germany).
	Novartis Seeds	Field trials in Europe since 1992 by Hilleshög, now part of Novartis Seeds
	KWS Kleinwanzlebener Saatzuch (Einbeck, Germany)	KWS, Germany's largest seed company, has worked on BNYV/*Rhizomania*-resistant sugar beets since 1988. Extensive field trials were conducted in Europe and the United States in 1996 and 1997 by KWS and subsidiary companies. Registration and market launch are expected by 2001.

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Table 14 (Concluded)

Trait/Resistance and/or Tolerance[a]	Supplier or Developer	Remarks
Virus Resistance (Continued)		
BNYV[c]	Planta GmbH (Einbeck, Germany)	Planta is a subsidiary of KWS Kleinwanzlebener Saatzuch. and has conducted German field trials of BNYV-resistant sugar beets since 1992. Additional trials have been approved through 2003.
	RWTH Aachen (Germany)	1994 German field trials
	VanderHave[b] (The Netherlands)	1990 Dutch field trials
Agronomic Properties		
Drought resistance	VanderHave[b]	1996 field trials
Product Quality		
Altered carbohydrate metabolism	VanderHave[b]	1993 Dutch field trials
Fructan production	Sharpes International Seeds	1995 UK field trials
	VanderHave[b]	1994 Dutch field trials
Trehalose production	VanderHave[b]	1994 Dutch field trials

[a] BMY = beet mosaic virus; BNYV = beet necrotic yellow vein virus; BWY = beet western yellow virus.

[b] Now part of Advanta. In 1996, Zeneca Seeds and the Royal VanderHave Group (the seed division of the Dutch sugar cooperative, Suiker Unie) merged to form a new company, Zeneca VanderHave, owned 50% by each company. The company's name was changed to Advanta at the end of 1996.

[c] BNYV is the causal agent of *Rhizomania*, one of the most destructive diseases of sugar beets.

Sources: Communications with industry, trade literature, and electronic field trials data bases.

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TOBACCO

Tobacco is considered one of the easiest plants to manipulate genetically, and during the past 15-20 years, many organizations have conducted field trials of transgenic and other genetically modified tobacco varieties. As of year end 1997, two transgenic tobacco products have been approved and/or commercialized. Bromoxynil-tolerant tobacco developed by the French tobacco company Seita, was approved in the EU in 1994. Transgenic high-nicotine tobacco developed in the United States by Brown & Williamson Tobacco Corporation, has been grown commercially in Brazil since 1983. Table 15 identifies the traits that are being genetically engineered in tobacco and the companies and other organizations worldwide that are developing them.

Table 15
GENETICALLY MODIFIED TOBACCO PLANT PRODUCTS UNDER DEVELOPMENT

Trait(s)/Resistance and/or Tolerance	Developing Organization	Remarks
Bacterial Resistance	USDA/ARS	1993 field trials of tobacco with bacterial soft rot resistance trait
	Institute of Genetic Engineering, Tobacco Experiment Station (Bulgaria)	1995 field trials; unspecified bacterial disease
Fungal Resistance		
Black shank	University of Kentucky	1997 field trial
Botrytis cinerea	Bayer	1993 U.S. field trials
Frogeye leaf spot	U.S. EPA	1996 field trials
	Kansas State University	1994 field trials
Phytophthora	Novartis Seeds	1993 U.S. field trials by Ciba-Geigy
Phytophthora + Rhizoctonia	DNA Plant Technology	1992 field trials
Rhizoctonia + Thelaviopsis	DNA Plant Technology	1991 field trials
Fungal diseases, genera/unspecified	Agriculture Canada, Research Branch	1993 field trials of plants with root rot resistance gene
	Du Pont	1988 field trials

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Table 15 (Continued)

Trait(s)/Resistance and/or Tolerance	Developing Organization	Remarks
Fungal Resistance (Continued)		
Fungal diseases, genera/unspecified (Continued)	Novartis Seeds	1993-1994 U.S. field trials by Ciba-Geigy
	Rutgers University, Waksman Institute	1994 field trials
	University of Kentucky	1994 field trials
Fungal Resistance + Virus Resistance		
Black shank + tobacco etch virus (TEV)	University of Kentucky	1996 field trials
Herbicide Tolerance		
Bromoxynil	Calgene	1987 field trials
	Seita (France)	EU approval for marketing in 1994. Seita is France's leading tobacco producer.
Chlorsulfuron	University of Chicago	1996 field trials
Glufosinate	Mycogen	1984 field trials
	Plant Genetic Systems	1986 field trials in Belgium
	Seita	1992 field trials in France
	Southern Illinois University	1995-1996 field trials
	University of Kentucky	1994 field trials
Glyphosate	Calgene	Late 1980s field trials
	R J Reynolds	1993 field trials
Imidazolinone	American Cyanamid	1992 field trials
Isoxazole herbicides	Rhône-Poulenc	1997 field trials in Spain
Oxynil herbicides + asulam	Rhône-Poulenc	Early 1990s field trials in France
Shikimate herbicide	Rhône-Poulenc	1997 field trials in Spain
Sulfonylurea	American Cyanamid	1993 field trials
	University of Chicago	1996 field trials
	Novartis Seeds	1988 U.S. field trials by Sandoz

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Table 15 (Continued)

Trait(s)/Resistance and/or Tolerance	Developing Organization	Remarks
Herbicide Tolerance (Continued)		
Unspecified herbicide	Agriculture Canada, Research Branch	1991-1993 field trials
	Rhône-Poulenc	1997 U.S. field trials
Herbicide Tolerance + Male Sterility		
Glufosinate + Male sterility	Plant Genetic Systems	1990 field trials in Belgium
Insect Resistance		
Lepidopteran insects	Auburn University	1994 field trials
	Calgene	1993 field trials
	CSIRO	Australian field trials approved in 1995
	Mycogen	1996 and 1997 U.S. field trials
	North Carolina State University	1991-1993 field trials
	Novartis Seeds	U.S. field trials since 1990, originally by Ciba-Geigy; 1988 U.S. field trials of Lepidopteran insect-resistant tobacco by Sandoz
	Rohm and Haas	1989-1991 field trials
	U.S. EPA	1993 field trials
Unspecified insects	Agriculture Canada Research Branch	1994-1996 field trial
	Chinese Academy of Agricultural Science (Beijing, China)	Scorpion toxin gene inserted into tobacco plants
Nematode Resistance	Advanced Technologies (Cambridge) (United Kingdom)	1997 UK field trials
	Mogen International (the Netherlands)	
	Monsanto	1993-1994 field trials
	North Carolina State University	1993-1995 field trials

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Table 15 (Continued)

Trait(s)/Resistance and/or Tolerance	Developing Organization	Remarks
Virus Resistance[a]	Agriculture Canada Research Station (Delhi, Ontario)	1996 field trials
	Agrigenetics	1988 field trials
	Cleveland Clinic Foundation	1994 field trials
	Japan Tobacco (Japan)	Confined field trials of CMV-resistant tobacco in Japan since 1994
	Monsanto	1995 field trials
	North Carolina Department of Agriculture	1997 field trials in Georgia
	North Carolina State University	Field trials since 1993
	Oklahoma State University	1994 field trials
	Pioneer	1993 field trials
	Purdue U	1993 field trials
	Ribozyme	1993 field trials
	Seita (France)	1995 field trials
	University of Arizona	1992 field trials
	University of Florida	Field trials since 1991
	University of Georgia	1996 field trials
	University of Kentucky	1990-1998 field trials
	USDA/ARS	1991 and 1996-1997 field trials
Agronomic Properties		
Abiotic stress tolerance	Agriculture Canada, Research Branch	Mammalian metallothionein production; 1990 field trials
		Fish antifreeze protein gene inserted; 1993-1994 field trials
	Seita (France)	Metallothionein production; 1995-1996 field trials
Altered CO_2 metabolism	Du Pont	1993 field trials
Altered growth rate	University of Hawaii, Manoa	1997-1998 field trials
Altered metabolism	Amoco	1990-1991 field trials
	R J Reynolds	1996 field trials
Altered nitrogen metabolism	Monsanto	1995 field trials
	Seita (France)	Field trials since 1993

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Table 15 (Continued)

Trait(s)/Resistance and/or Tolerance	Developing Organization	Remarks
Agronomic Properties (Continued)		
Altered pigments (phytochrome A&B; phytochrome A)	University of Leicester	1995-1996 UK field trials
Altered senescence	University of Wisconsin, Madison	1997 field trials
Disable shade avoidance response	University of Leicester	1994 UK field trials
Female sterile/Male sterile	Novartis Seeds	1993-1994 U.S. field trials by Ciba-Geigy
Increased ammonium assimilation	Southern Illinois University	1995-1997 U.S. field trials
Increased chlorophyll	Monsanto	1994 field trials
Increased flowering	Verneuil-Recherche (France)	1992 field trials in France
Male sterile	Nickerson Biocem (United Kingdom)	1994 UK field trials
	Pioneer Hi-Bred	1994 field trials
Photosynthetic efficiency + marker	Agriculture Canada Research Station (Delhi, Ontario)	1996 field trials
Reduced growth rate	Mississippi State University	1993 field trials
Reduced seed set	Harvard University	
Stress tolerance, unspecified	Plant Genetic Systems	1990 field trials in Belgium
	Texas A&M University	1993 field trials
Product Quality		
Altered carbohydrate metabolism	Biosource Technologies	1995 field trials
Altered carotenoid content	R J Reynolds	1994 field trials
Altered oil profile	Carnegie Institute	1993 field trials
Altered pigment metabolism	Biosource Technologies	1993 field trials
Altered seed quality	Carnegie Institute	1993 field trials
Altered storage protein	North Carolina State University	1995 field trials
Decreased flavinoid level	Noble Foundation	1993 field trials
Decreased flavinoid level + stunted growth	Noble Foundation	1993 field trials

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Table 15 (Continued)

Trait(s)/Resistance and/or Tolerance	Developing Organization	Remarks
Product Quality (Continued)		
Increased nicotine content	Brown & Williamson Tobacco	Cultivation of genetically engineered high-nicotine tobacco began in Brazil in 1993; about 20,000 acres planted in the state of Rio Grande do Sul in 1997. The high-nicotine tobacco is produced for export to cigarette manufacturers in the United States, Europe, and Japan, which blend it with cheaper tobaccos to achieve desired nicotine levels in cigarette products.
Increased protein lysine level	BioTechnica	1989 field trials; BioTechnica is 94% owned by Limagrain Genetics Corp., part of Groupe Limagrain.
Increased sterols	Amoco	1992 field trials
Other		
Antibody kappa chain produced	Scripps	1994 U.S. field trials
Antibody produced	Agracetus	U.S. field trials since 1994
	North Carolina State University	1993 field trials
Antibody produced + novel protein produced	Agracetus	1994 U.S. field trials
Antioxidant enzyme produced	Pennsylvania State University	1994 field trials
Betaine aldehyde resistance	University of Florida	1994 field trials
Collagen produced	Clause IB/Biogem	1997 field trials in Spain; part of Groupe Limagrain
Dog gastric lipase cDNA expressed	Tezier Ibérica (Spain)	1997 field trials in Spain; company owned by Groupe Limagrain
	Clause IB/Biogem	1997 field trials in Spain; part of Groupe Limagrain
Heavy metals sequestered	University of Kentucky	1989-1990 and 1993 field trials

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Table 15 (Concluded)

Trait(s)/Resistance and/or Tolerance	Developing Organization	Remarks
Other (Continued)		
Enzyme produced	Institut für Pflanzernenetik und Kulturpflanzenforschung (Gatersleben, Germany)	1995 German field trials
Loss of systemic resistance	Rutgers University, Waksman Institute	1994 field trials
Novel proteins produced	Biosource Technologies	Field trials in 1991, 1994-1997, and planned through 2001
Pharmaceutical proteins produced	Biosource Technologies	Permit for field trials issued November 1997
Reduced salicylic acid level	Novartis Seeds	1993 U.S. field trials by Ciba-Geigy
	Rutgers University	1993 field trials
	University of Wisconsin	1993 field trials
Undisclosed (confidential)	Biosource Technologies	Permit for field trial in Kentucky issued April 1997
	Biosource Technologies	Notified USDA/ARS in November 1997 of intent to conduct trials during 1997-2002

[a] Includes both single- and multiple-virus resistance traits.

Sources: Communications with industry, trade literature, and electronic field trials data bases.

According to a study released in March 1996 by the Southern Technology Council, considerable economic potential, ranging from commodity products to niche markets, exists for genetically engineered tobacco.

Biosource Technologies, Vacaville, California, is working with genetically modified tobacco varieties designed to produce pharmaceuticals such as malaria vaccines and other drugs that are not economically available today. Biosource contracts with farmers in Kentucky to grow the transgenic tobacco for its field trial evaluations.

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TOMATOES

Table 16 lists genetically modified tomato plant products that are under development or on the market in North America, Western Europe, and Japan, and identifies the organizations that are developing each product.

Table 16
GENETICALLY MODIFIED TOMATO PLANTS ON THE MARKET OR UNDER DEVELOPMENT

Trait/Resistance and/or Tolerance[a]	Developing Organization	Remarks
Bacterial Resistance		
Bacterial speck	Ohio State University	1997 field trials
	Purdue University	1996 field trials
	University of Wisconsin	1996-1997 field trials
Hordothionin produced	University of Florida	1995 field trials
Fungal Resistance		
Alternaria solani	Seminis Vegetable Seeds	1995 field trials
Alternaria + Botrytis	DNA Plant Technology	1993 field trials
Phytophthora	Monsanto	1996 field trials
Phytophthora + Rhizoctonia	DNA Plant Technology	1991 field trials
Powdery mildew	Seminis Vegetable Seeds	1997 field trials
Soft rot fungus	University of California	1995 field trials
Unspecified	Agriculture Canada, Research Branch	1996 field trials
	DNA Plant Technology	1995 field trials
	Mogen International (the Netherlands)	1994 field trials in the Netherlands
	Novartis Vegetable Seeds	1994 field trials in Italy by Ciba-Geigy
Herbicide Tolerance		
Bromoxynil	Calgene	1987 field trials
Glyphosate	Calgene	1987-1988 field trials
	Monsanto	Field trials since 1988
Glufosinate	AgrEvo	1989-1990 field trials in Canada by Hoechst and Agriculture Canada
	Canners Seed	1990 field trials

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Table 16 (Continued)

Trait/Resistance and/or Tolerance[a]	Developing Organization	Remarks
Herbicide Tolerance (Continued)		
Sulfonylurea	Du Pont	1987-1988 U.S. field trials; 1988 field trials in France
Insect Resistance		
Lepidopteran insects	Applied Horticultural Research (Australia)	1997 field trials
	BHN Research	1997-1998 Bt tomato field trials in CA, FL, GA, and PR
	Calgene	Expected on the market after 2000; field trials since 1996
	Campbell Soup	1991-1992 field trials
	Clause Semences (France)	1993 field trials of Bt tomatoes
	Monsanto	Commercialization expected in 1998-1999; field trials since 1988
	Mycogen	Expected on the market in 1998-1999; 1988 field trials by Agrigenetics and by Mycogen since 1996
	Novartis Vegetable Seeds	1991 field trials by Northrup King and by Rogers NK in 1992
	Texas Tech University	1996 field trials
	Organization unknown (France)	1994 field trials of Bt tomatoes in France
Insects, general/unspecified	Ohio State University	1995 field trials
	Seminis Vegetable Seeds	1997 field trials by Asgrow
	Seminis Vegetable Seeds	1995-1996 field trials by Petoseed

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Table 16 (Continued)

Trait/Resistance and/or Tolerance[a]	Developing Organization	Remarks
Insect Resistance + Product Quality		
Lepidopteran insects + Altered fruit ripening	Calgene	1989 field trials
Nematode Resistance	Mogen International[a]	Patented technology
	Plant Genetic Systems	Patented technology
Virus Resistance[b]	Agritope	1994 field trials
	Calgene	Field trials since 1996
	Centro de Investigación y Desarollo Hortícola de Almeria (Spain)	1994 field trials
	Harris Moran	1995 and 1997 field trials
	Instituto Sperimentale per la Vegetale à Roma (Italy)	1993-1996 field trials
	Ministry of Agriculture, Forestry and Fisheries (Japan)	Several virus-resistant tomato varieties evaluated in nonconfined field trials since 1992
	Monsanto	Field trials since 1988
	New York State Experiment Station	1992 and 1995 field trials
	Novartis Vegetable Seeds	1991 and 1997 field trials by Rogers NK
	Seminis Vegetable Seeds	U.S. field trials by Upjohn and Asgrow since 1990; by Petoseed in 1995-1996, and by Seminis in 1997-1998; 1994 field trials in Spain by Sluis and Groot (now part of Seminis Vegetable Seeds)
	University of Florida	1996 field trial
	USDA/ARS	1994 and 1996 field trials
Agronomic Properties		
Cold tolerant	DNA Plant Technology	1991 field trials

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Table 16 (Continued)

Trait/Resistance[a] and/or Tolerance	Developing Organization	Remarks
Agronomic Properties (Continued)		
Male sterility	Biocem (France)	1995 field trials; Biocem is part of Groupe Limagrain.
Reduced ethylene synthesis	Agritope	1994-1995 field trials
Reduced flower and fruit abscission	Campbell Soup	1995 field trials
Product Quality[c]		
Altered carbohydrate metabolism	Calgene	Field trials since 1993
	Harris-Moran	1997 field trials
	Nestle	1995 U.S. field trials
	Seminis Vegetable Seeds	1995-1996 field trials by Petoseed
	University of Wisconsin	1995 and 1997 field trials
Altered carotenoid content	Seminis Vegetable Seeds	1995 field trials by Petoseed
	Zeneca	1996 field trials
Altered/delayed fruit ripening	Agritope	Commercialized in 1996; field trials continue
	Calgene	FlavrSavr™ tomato was commercialized in 1994; field trials continue in the United States and other countries.
	Calgene/Kirin Brewery (Japan)	Calgene's FlavrSavr™ tomato was jointly developed for the Japanese market by Calgene and Kirin Brewery. The product was approved for marketing in Japan in December 1997.
	Campbell Soup	Field trials since 1991
	DNA Plant Technology	Endless Summer™ delayed ripening tomatoes commercialized in 1995; field trials continue

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Table 16 (Continued)

Trait/Resistance and/or Tolerance[a]	Developing Organization	Remarks
	Heinz	1992 field trials; 1993-1994 field trials in Portugal by Idal-Heinz
	Monsanto	Commercialization expected after 2000
	Seminis Vegetable Seeds	1995 field trials by Asgrow and by Petoseed since 1992
	Purdue University	Field trials since 1992
	Unifoods (Australia)	1992-1993 field trials
	University of Florida	1995-1997 field trials
	USDA/ARS	1995 field trials
	Zeneca	1996 field trials
	Zeneca Seeds/SES France/ Peto Europe/Royal Sluis France SARL	1995 field trials in France
Altered ethylene metabolism	Zeneca	1997 U.S. field trials
Altered fruit sugar profile	Calgene	High-sweetness tomatoes under development
	Campbell Soup	1995-1997 field trials
Altered pigment metabolism	Seminis Vegetable Seeds	1995-1996 field trials by Petoseed and by Seminis in 1997-1998
Altered polyamine metabolism	Purdue University	1995-1997 field trials
	USDA/ARS	1994-1997 field trials
Altered processing characteristics	Seminis Vegetable Seeds	1995-1996 field trials by Petoseed
	Zeneca	1995 field trials
Altered protein quality	Campbell Soup	1996-1997 field trials
	Zeneca Plant Science	1994-1995 field trials
Decreased fruit PG level	Hunt-Wesson	1995 field trials
Delayed fruit ripening + increased fruit solids	Zeneca Plant Science	1997 U.S. field trials
Enhanced Flavor, Color, and Increased Antioxidant Vitamin Content	Zeneca Plant Science	Expected on the market after 2000

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Table 16 (Continued)

Trait/Resistance and/or Tolerance[a]	Developing Organization	Remarks
Product Quality (Continued)		
High pectin	Zeneca Plant Science	Commercialized in 1995; tomatoes genetically modified to remain firm longer and retain pectin during processing into tomato paste; developed in the United States by Zeneca Plant Science (ZPS) and Petoseed; under development in Japan by ZPS and Kagome
Improved processing characteristics	Seminis Vegetable Seeds	1995 field trials in Spain by Petoseed Ibérica and in Italy by Peto Italiana
	SES Ibérica	1994 field trials in Spain
Increased fruit firmness/ decreased fruit poly-galacturonase level	Purdue University	1995 field trials
	Zeneca Plant Science	1994 field trials
Increased fruit solids	BHN Research	Field trials since 1996
	Heinz	1993 and 1995 field trials
	Campbell Soup	1995 field trials
	Gargiulo	1997-1998 Florida field trials. Gargiulo is a major fresh market tomato grower and packer/shipper owned by Calgene.
	Monsanto	Commercialization expected after 2000; field trials since 1993
	Purdue University	1995-1996 field trials
	Seminis Vegetable Seeds	Field trials by Petoseed since 1993
	Zeneca Plant Science	U.S. field trials since 1996
Increased fruit solids + reduced PG level		
	Hunt-Wesson	1995 field trials
Increased fruit solids + reduced seed set	University of Georgia	1997 field trials

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Table 16 (Continued)

Trait/Resistance and/or Tolerance[a]	Developing Organization	Remarks
Reduced PE level	Purdue University	1997 field trials
	Zeneca Plant Science	1996 field trials
Reduced PG activation	Seminis Vegetable Seeds	1994 field trials in Spain by Petoseed Ibérica
Reduced PG and/or pectin activation	Hispareco (Spain)	1992-1993 field trials
Reduced PG level	Hunt-Wesson	1995 field trials
Uniform Ripening	DNA Plant Technology	Cherry tomatoes.
Other		
Pharmaceutical proteins produced	ProdiGene	Permit for field trials in 1998 pending
Transposon inserted	University of California, Davis	1991-1992 field trials

[a] Mogen has worked with Asgrow Vegetable Seeds to transfer genes for nematode resistance to vegetable crops.

[b] Single and/or multiple virus-resistant varieties.

[c] PG = polygalacturonase; PE = pectin esterase. Both enzymes are involved in modifying pectins during normal tomato development.

Source: Communications with industry, trade literature, and electronic field trials data bases.

Since the mid-1970s, several research groups have worked to develop improved processing and fresh market tomato varieties through the use of DNA technology. The tomato is a relatively easy fruit on which to work, and researchers believe that the benefits gained from understanding the complexities of the tomato ripening process at the molecular level and methods devised for modifying tomato quality will be transferable to other fruit and vegetable crops. A large number of genes expressed either exclusively or preferentially in ripening and ripe tomatoes have been isolated. Some of the isolated genes affect fruit characteristics such as viscosity, handling characteristics, soluble solids, color, and taste.

Genetically modified processing tomatoes with reduced pectin degradation and decreased fruit polygalacturonase (PG) traits (high-pectin tomatoes) were developed by Zeneca Plant Science (ZPS). Field trials began in 1989 in Chile and California in a collaboration between ZPS and Petoseed (now part of Seminis Vegetable Seeds). The first genetically improved processing tomato hybrids were approved for marketing in the United States in June 1995, and the first commercial crop was harvested in California that fall and processed into tomato paste. The canned tomato paste product, clearly labeled as produced from genetically modified tomatoes, was launched in the United Kingdom in

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February 1996. The product gained rapid market acceptance and is sold throughout the United Kingdom by two supermarket chains, Safeway and Sainsbury. The product has not yet been approved for sale in other European countries.

Cost-benefits of high-pectin tomatoes include less waste during harvest and transport because the fruit is firmer, and reduced energy costs during processing, because the fruit contains less water at harvest. The tomato paste product also has improved flavor inasmuch as reduced heat treatment allows for better retention of natural flavor compounds.

Fresh market tomatoes with improved product characteristics have been commercialized by Calgene (FlavrSavr™). As indicated in Table 16, other companies and organizations are also developing new genetically modified tomato lines for the fresh market and/or for processing.

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OTHER VEGETABLES

Other commercial vegetable crops that have been genetically engineered or otherwise genetically modified for insect or disease resistance, herbicide tolerance, and/or enhanced agronomic or product quality traits include carrots, cole crops, sweet corn, cucurbits, eggplant, lettuce, onions, peas, and peppers. Table 17 lists genetically modified vegetable plant products under development and identifies the developing organizations.

Table 17
OTHER GENETICALLY MODIFIED VEGETABLES ON THE MARKET OR UNDER DEVELOPMENT

Trait/Resistance and/or Tolerance	Developing Organization	Remarks
Carrots		
Fungal Resistance		
Alternaria dauci	Seminis Vegetable Seeds	1995 field trials by Asgrow and by Seminis in 1997-1998
Product Quality		
Altered nutritional quality	Seminis Vegetable Seeds	1994 field trials by Petoseed
Unspecified/confidential	Amoco	1993-1994 field trials
	Seminis Vegetable Seeds	1997-1998 Florida field trials
Cole Crops		
Herbicide Tolerance		
Glufosinate	Takii (Japan)	1997 confined field trials in Japan of glufosinate-tolerant broccoli and cauliflower
	University of Saskatchewan (Canada)	1997 broccoli field trials
Herbicide Tolerance + Agronomic Properties		
Glufosinate + male sterile	American Takii	1996-1998 U.S. field trials
Insect Resistance		
Lepidopteran pests	Cornell University	1995-1997 field trials
Product Quality		
Prolonged shelf life	Seminis Vegetable Seeds	1997 field trials

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Table 17 (Continued)

Trait/Resistance and/or Tolerance	Developing Organization	Remarks
Corn, Sweet		
Fungal Resistance	Novartis Vegetable Seeds	1996-1997 field trials by Rogers Seed
Herbicide Tolerance		
Glufosinate	Novartis Vegetable Seeds	1994-1997 field trials by Rogers Seed
Insect Resistance		
Lepidopteran pests	Novartis Vegetable Seeds	Expected to be launched in 1998-2000
Insect Resistance + Herbicide Tolerance		
Lepidopteran insects + glufosinate	Seminis Vegetable Seeds	Field trials since 1996
Virus Resistance[a]	Novartis Vegetable Seeds	1994 field trials by Rogers Seed
Cucurbits		
Fungal Resistance	Seminis Vegetable Seeds	1993 field trials by Upjohn
Herbicide Tolerance		
Glufosinate	Harris Moran Seed	Melon field trials since 1991-1992; Harris Moran Seed owned by Groupe Limagrain, France
Glufosinate Tolerance + altered protein	Sunseeds (Morgan Hill, CA)	1997-1998 field trials. Sunseeds acquired Pioneer Hi-Bred's vegetable seeds program in 1995.
Virus Resistance[a]	Cornell University/ New York State Experiment Station	Field trials since 1989
	Harris Moran Seed	1991-1996 melon field trials
	Michigan State University	1992-1996 melon field trials

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Table 17 (Continued)

Trait/Resistance and/or Tolerance	Developing Organization	Remarks
Cucurbits (Continued)		
Virus Resistance[a] (Continued)	Novartis Vegetable Seeds	1995 melon field trials by Rogers Seed and by Sandoz in 1996
	Seminis Vegetable Seeds	Freedom® II virus-resistant squash was commercialized in 1995. U.S. field trials of virus-resistant cucurbit crops have been conducted since 1990—by Upjohn, 1990-1995; by Asgrow, 1995-1996; by Petoseed, 1994-1996; and by Seminis since 1997. 1995 field trials in Spain by Asgrow and Seminis in 1997
	Ministry of Agriculture, Forestry and Fisheries (Japan)	Nonconfined field trials of virus-resistant melon varieties since 1996
	S&G Semillas (Spain)	1996 melon field trials in Spain
Product Quality		
Altered/delayed Fruit Ripening	Agritope	Expected on the market in 1998-1989
	Seminis Vegetable Seeds	1995-1996 field trials by Asgrow
Eggplant		
Insect Resistance		
Coleopteran pests	Rutgers University	1994-1996 field trials
Lettuce		
Bacterial Resistance + Fungal Resistance	Harris Moran Seed	1997 field trials
Fungal Resistance		
Downy mildew	Seminis Vegetable Seeds	1993 field trials by Upjohn
Herbicide Tolerance		
Glyphosate	University of Florida	1994-1995 field trials

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Table 17 (Concluded)

Trait/Resistance and/or Tolerance	Developing Organization	Remarks
Lettuce (Continued)		
Virus Resistance[a]	Seminis Vegetable Seeds	1994-1995 field trials by Upjohn
	University of Hawaii, Manoa	1993 field trials
Onion		
Fungal Resistance		
Fusarium + *Phoma*	Texas Tech University	1996 field trials
Pea		
Enhanced Product Quality		
Reduced Starch	DNAP Plant Technology	Sugar snap peas modified for sweeter flavor and higher yield by conversion of sugar to starch using Transwitch® technology; currently in field evaluations
Pepper		
Virus Resistance[a]	Seminis Vegetable Seeds	Field trials by Petoseed since 1996
Product Quality		
Altered fruit ripening	DNAP Plant Technology	1994-1998 field trials
Increased firmness	DNAP Plant Technology	Sweet pepper genetically modified to remain firm after harvest; in field evaluations
Increased sweetness	DNAP Plant Technology	Seed increase and field evaluation

[a] Single and/or multiple virus-resistant varieties.

Source: Communications with industry, trade literature, and electronic field trials data bases.

Seminis Vegetable Seeds, the world's largest producer of vegetable seeds, is a relatively new company formed in 1995 when Empresas La Moderna (ELM) of Mexico acquired the Dutch seed company, Royal Sluis, and California-based Petoseed from

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George J. Ball and combined them with Asgrow Seed, which it had purchased from Upjohn in 1994.

In 1996, Seminis acquired DNA Plant Technology (DNAP) and sold Asgrow Seed's corn and soybean seed business to Monsanto. DNAP, with headquarters in Oakland, California, is a leading agricultural biotechnology company that uses advanced breeding, genetic engineering, and other biotechnologies to develop premium branded fresh and processed fruits and vegetables.

Harris Moran merged with Ferry Morse Seed June 1, 1997. The two companies are owned by Groupe Limagrain of France, one of the world's largest vegetable and flower seed companies.

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WHEAT

Wheat has been more difficult to modify genetically than other major grains, and a longer time has been required to perfect the gene transfer process. However, according to published reports, as of December 1997, 16 wheat hybrids with genetically modified traits were on the market with average yields 10-15% higher than average yields of standard wheat varieties.

By 2003, additional new genetically modified wheat varieties with herbicide tolerance and/or disease resistance traits are expected to be available. Table 18 lists genetically modified wheat plant products that are on the market or under development worldwide and identifies the developing organizations.

Table 18
GENETICALLY MODIFIED WHEAT PLANT PRODUCTS UNDER DEVELOPMENT

Trait(s)/Resistance and/or Tolerance	Developing Organization	Remarks
Fungal Resistance		
Fusarium	Monsanto	Expected to be commercialized by 2003; U.S. field trials since 1996
Head scab, other fungal diseases	Monsanto	Monsanto expects to commercialize fungal disease resistant wheat by 2003.
Septoria	Novartis Seeds	1997 U.S. field trials
Fungal Resistance + Herbicide Tolerance		
Unspecified fungus + glufosinate	New Farm Crops (United Kingdom)	Permit for UK field trials granted in December 1995
Unspecified fungus + glyphosate	Monsanto	Commercialization expected by 2003; U.S. field trials since 1995
Herbicide Tolerance		
Glufosinate	AgrEvo	1994 U.S. field trials; permits granted for UK field trials in 1994 and 1997
	CSIRO Division of Plant Industry (Australia)	1996-1997 Australia field trials
	Plant Genetic Systems	1997 UK field trials
	Sharpe International Seeds (United Kingdom)	1995-1997 UK field trials

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Table 18 (Continued)

Trait(s)/Resistance and/or Tolerance	Developing Organization	Remarks
Herbicide Tolerance (Continued)		
Glyphosate	Monsanto	Roundup Ready® Wheat expected on the market by 2003
Imidazolinone	American Cyanamid	IMI™ wheat, which is expected on the market after 2000, is under development in cooperation with universities, seed companies, and public and private laboratories. 1997 Canadian field trials
Herbicide Tolerance + Product Quality		
Glyphosate + altered color	Monsanto	1994 field trials
Unspecified herbicide + pollen disruption	Nickerson Biiocem (United Kingdom)	Company owned by Groupe Limagrain, France; a permit for UK field trials issued in August 1994
Insect Resistance	Mycogen	Bt wheat expressing a protein toxin effective against various caterpillar and beetle pests under development in collaboration with Pioneer Hi-Bred; expected on the market after 2000
Virus Resistance	Monsanto	Field trials since 1995
	University of Idaho	Field trials since 1996
Agronomic Properties		
Stress tolerance	National Research Council, Plant Biotechnology Institute (Canada)	1995 field trials
Increased yield	Monsanto	1997-1998 field trials

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Table 18 (Continued)

Trait(s)/Resistance and/or Tolerance	Developing Organization	Remarks
Agronomic Properties		
Enhanced photosynthesis	Monsanto	1997 field trials
Stress tolerance	National Research Council, Plant Biotechnology Institute (Canada)	1995 field trials
Male Sterile	National Research Council, Plant Biotechnology Institute (Canada)	1995 field trials
Product Quality		
Altered carbohydrate metabolism (altered/improved starch quality)	Monsanto	1997-1998 field trials
	Nickerson Biocem (United Kingdom)	Part of Groupe Limagrain, France; 1994 field trials
	Senasa (Spain)	Part of Groupe Limagrain, France; 1996 field trials in Spain
Altered carbohydrate metabolism + altered nitrogen metabolism	Monsanto	1996 U.S. field trials
Altered nitrogen metabolism	Monsanto	1997-1998 field trials
Altered seed composition	USDA/ARS	1996 field trials
Altered/increased storage protein	USDA/ARS	Field trials since 1995
Altered starch composition	CSIRO Division of Plant Industry (Australia)	1996-1997 Australia field trials
Improved baking quality	John Innes Centre (United Kingdom)	Permit issued in February 1997 for UK field trials.
Increased seed methionine storage	USDA/ARS	1996 field trials

Sources: Communications with industry, trade literature, and electronic field trials data bases.

In January 1997, Novartis Corporation, parent company of Novartis Seeds, received a U.S. patent for genetically modified wheat that covers technology used to insert new genetic traits such as disease and insect resistance into wheat. The patent (U.S. 5,596,131) is the first issued for transgenic wheat, and is based on biotechnology research conducted by the former Ciba Seeds, which merged with Northrup King January 1, 1997 to form Novartis Seeds. Novartis has announced that it will broadly license the intellectual property rights to its new wheat technology.

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