Plant Biotechnology: Current and Potential Impact For Improving Pest Management In U.S. Agriculture

An Analysis of 40 Case Studies

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1.0 INTRODUCTION

Advances in genetics and molecular biology have made it possible to identify genes coding for specific traits in one organism, isolate and clone them, and incorporate them into the genome of another organism, regardless of relatedness of the source and donor species. Myriad crop species are being experimentally transformed for protection against insects, pathogens, and herbicides, for improved management of pests that plague modern agriculture.

Several transgenic cultivars have full regulatory approval and are commercially available for planting by U.S. growers. Adoption of these transgenic cultivars has been rapid in some cases. In other cases, adoption has been minimal. The limited adoption of some transgenic varieties stems from growers' uncertainty of finding a market for their harvested product rather than from poor agronomic or pest management performance. Despite inconsistent adoption, however, research continues to improve and expand the application of biotechnology in agriculture.

An understanding of the contributions, both realized and potentially forthcoming, of agricultural biotechnology for crop pest management is critical to the unfolding public discussion that surrounds it and, ultimately, will determine its future. This report provides descriptions of traits transferred to crop plants for resistance to insects, pathogens and herbicides, and discusses current adoption levels and farm level impacts of available transgenic cultivars. Also reviewed are several transgenic crops under development, the agronomic pests they target, and projected farm level impacts of their commercialization and adoption.

2.0 Case Study Type

This report is organized around 40 case studies for which quantification is provided of the potential or realized impacts of biotech crop adoption by US growers. The 40 case studies are classified by six types of transgenic cultivars: insect resistant (IR)-11 case studies; herbicide tolerant (HT)-14 case studies; and four types of pathogen resistant cultivars, nematode resistant (NR)-1 case study; bacterial resistant (BR)-3 case studies; viral resistant (VR)-9 case studies; and fungal resistant (FR)-3 case studies. (1 case study includes cultivars with both insect and viral resistance).

(A) Insect Resistant (IR)

Insect resistant plants produced through biotechnology express traits derived from *Bacillus thuringiensis* (*Bt*), a species of soil-borne bacteria. Enclosed with the spores of *Bt* are protein crystals [1]. When spores are ingested by an insect, the alkaline conditions in the insect gut dissolve the protein crystal, releasing protoxins which are then activated by specific enzymes in the gut. Activated toxins bind to cells lining the insect gut and disrupt the ionic balance within the cells by creating membranous pores. When the cells rupture, a hole is produced in the gut lining. The infected insect may suffer from paralysis of the gut or entire body, cease to feed, and starve to death. If paralysis does not occur, the insect will be killed by systemic infection after the *Bt* spore germinates and begins vegetative growth within its body.

There are several varieties of *Bt*, and each produces one or more crystalline (Cry) proteins and protoxins. Each *Bt* toxin has specific insecticidal activity against certain groups of insects. This specificity is based on characteristics of the *Bt* toxin itself, such as its chemical structure, and of the affected insect, such as the presence of toxin binding sites in the gut, as well as pH level and the digestive enzymes present. *Bt* varieties include *Bt* var. *kurstaki* and var. *morrisoni*, with activity against lepidopteran larvae; *Bt* var. *israelensis*, specific to larvae of mosquitoes and blackflies; *Bt* var. *aizawai*, with activity against wax moth larvae; and *Bt* var. *tenebrionis*, specific against coleopteran larvae [2].

Toxins isolated from *Bt* varieties have been commercialized and applied as foliar insecticides for more than 40 years. They dominate the biopesticides market and are widely used throughout the U.S., particularly in organic production. In 1981, a *Bt* gene encoding a Cry protein was cloned and successfully transferred to and expressed in another organism, the bacterium *Escherichia coli* [3]. Within ten years, tomato, tobacco and cotton plants had been transformed to express *Bt* Cry proteins [4] [5] [6], and *Bt* corn and potato plants were developed soon thereafter [7] [8].

When a susceptible insect takes a bite of a transgenic crop cultivar expressing the *Bt* protein, it stops feeding and soon thereafter dies as a result of the binding of the *Bt* toxin to its gut wall.

(B) Herbicide Tolerant (HT)

A consistent limitation in crop weed management is the lack of cost effective herbicides with broad-spectrum activity and no crop injury. Consequently, multiple applications of numerous herbicides are routinely used to control a wide range of weed species infesting agronomic crops. Weed management tends to rely on preemergence (PRE) herbicide applications made in response to expected weed infestations rather than postemergence (POST) in response to actual weeds present, or on a combination of POST herbicides carefully mixed, timed, and directed to avoid damage to the growing crop. Mechanical cultivation and hand weeding are often necessary supplements for controlling weeds not controlled by herbicide applications, especially in high value crops that can sustain high labor costs.

Crops transformed with tolerance to a broad-spectrum, POST herbicide provide the basis for a simplified weed management program centering on one herbicide to control a wide spectrum of weeds with minimal crop damage. Qualitatively, ease of weed management is potentially increased because decisions about which herbicide active ingredients to apply, optimal timing, and placement of applications are reduced. Potential quantifiable impacts include a reduction in the number of herbicide active ingredients used for weed management, a reduction in the number of herbicide applications made during a season, yield increases due to improved weed management and less crop injury, and, presumably, a resultant increase in grower returns. Transgenic crops have been developed that express tolerance to one of three postemergence herbicides: glyphosate, glufosinate and bromoxynil. Because of the genetic transformations, these herbicides can be sprayed on transgenic crops without damage while nearby weeds are killed. The herbicides are toxic to untransformed conventional crop cultivars

Glyphosate is a contact, non-selective, non-residual, systemic herbicide. It is effective against both annual and perennial weeds. The phytotoxic activity of glyphosate is due to its inhibitory effect on the enzyme 5-enolpyruvyl-shikimate-3-phosphate synthase (EPSPS), the key enzyme in synthesis of aromatic amino acids, which in turn are essential for several critical processes, such as cell wall formation, hormone production, and energy transduction. Inhibition of EPSPS by glyphosate creates a lethal chemical imbalance within the plant, by which the plant starves for the products of EPSPS and accumulates toxic levels of compounds normally metabolized by EPSPS.

There are several organisms with natural resistance to glyphosate that can serve as sources for transgenic glyphosate resistance traits. The gene for one such trait, a form of EPSPS that is not susceptible to glyphosate inhibition, was isolated from the soil bacterium *Agrobacterium* sp. strain CP4 and used to produce glyphosate-tolerant crops.

Glufosinate is a broad-spectrum herbicide that inhibits glutamine synthetase, a plant enzyme essential to the processing of accumulated ammonia into a form of nitrogen usable by plants. Interfering with the activity of glutamine synthetase leads to toxic cellular accumulation of ammonia. But glufosinate’s most phytotoxic effects are less direct. The inhibition of glutamine synthetase indirectly inhibits carbon fixation, with cascading destructive effects that quickly kill the plant.

Glufosinate is a modified, synthetic version of a naturally occurring compound, bialaphos, which is produced by the soil bacterium *Streptomyces*. To avoid being poisoned by their own bialaphos production, *Streptomyces* species also produce an enzyme that detoxifies bialaphos. The detoxifying enzyme, phosphinothricin acetyl transferase (PAT), detoxifies glufosinate as well. In *Streptomyces hygroscopicus,* PAT is encoded by the *bar* gene. The *bar* gene has been isolated and used to produce glufosinate-tolerant crops. [10]

Bromoxynil, a benzonitrile compound with herbicide activity against broadleaf plants, binds to a protein on the thylakoid membrane of plant chloroplasts, where energy transfers take place that drive carbon fixation in photosynthesis. By binding to the thylakoid membrane protein, bromoxynil disrupts its functioning and prevents photosynthesis from continuing. In soil contaminated with bromoxynil, a bacterium, *Klebsiella ozaenae*, was found that uses bromoxynil as its only nitrogen source. The bacterium produces a nitrilase enzyme that specifically breaks down bromoxynil. The gene encoding the bromoxynil-specific nitrilase was isolated from *Klebsiella ozaenae* and used to develop bromoxynil-tolerant cotton. [11]

(C) Pathogen Resistant

The greatest advances in pathogen-resistant plants developed through biotechnology have been in the area of pathogen-derived resistance to plant viruses (VR). Pathogen-derived resistance in general plays on the assumption that there are certain biochemical functions associated exclusively with the pathogen and upon which survival of the pathogen, but not the host, depends [12]. By transforming the host plant with a gene integral to one of the pathogen's essential and exclusive functions, the expression of that gene by the host plant will interfere with the pathogen's essential process by upsetting the balance of related components. As a result, the virus does not spread in the plant.

The most common application of pathogen-derived resistance in commercial crop plants so far has been the use of viral coat protein genes, although use of truncated or entire viral replicase genes is increasing in the development of new pathogen-resistant crop plants [13]. The specific mechanism for coat protein mediated resistance is not yet known, but experimental evidence suggests there may be several which involve interference with critical viral processes, including viron coating and uncoating, replication, post-transcriptional gene expression, and intercellular transport [14] [15].

Genetic transformation is being used to develop plants with resistance to bacteria (BR), although none have reached the commercialization stage yet. A variety of antimicrobial and antitoxin defensive proteins have been identified in plants, animals, and microorganisms themselves. Advances in genetics and transformation techniques make it possible to harness some of these natural defense mechanisms and incorporate them into crop plants that lack them. For example, two classes of antimicrobial proteins, one derived from insects and one from chicken egg-white, have been successfully expressed in apple trees with potential to provide protection against bacterial infections [16]. The introduced antimicrobial protein in the plant sticks to invading bacterial cells and causes their death.

Biotechnology is also being applied to develop cultivars with resistance to fungal pathogens (FR), with the expected consequence of improved production and significantly lower use of soil fumigation and foliar fungicides. For example, an alfalfa gene encoding for an antifungal protein has been used to transform potatoes for resistance to verticillium wilt (*Verticillium dahliae*), a primary cause of yield losses in U.S. potato production [17]. Wheat genes encoding the antitoxin enzyme oxalate oxidase have been transferred to sunflower for resistance to the economic pest *Sclerotinia sclerotiorum* [18].

In an effort to combat scab in wheat and barley, resistant varieties are being developed by transforming the grains with antitoxin genes from another *Fusarium* species and from a species of yeast, *Saccharomyces cerevisiae* [19]. The fungal antitoxins (plant defensins) are highly stable molecules that are produced by plant cells either constantly or only when induced by invasion of the plant cell by a pathogen. Plant defensins bind to fungal cells and inhibit fungal growth by permeating fungal cell membranes.

Lastly, transgenic technology is being used to develop nematode resistance (NR) in crop plants. Wild rice naturally produces cystatin, a proteinase inhibitor that interferes with nematode feeding and digestion [20]. A commercial pineapple variety has been transformed with a wild rice-derived cystatin transgene for resistance to the reniform nematode (*Rotylenchulus reniformis*), a primary pest of pineapple which is currently controlled with soil fumigants [21]. When feeding on a transformed plant's root, the nematode ingests a small amount of the cystatin, stops feeding and dies.

3.0 Case Study Methodology

The case studies were selected and impact estimates were calculated using the following six methodological steps.

Research projects in the US (both public and private commercial) focussed on the development of transgenic plants for pest management purposes were identified. Pest management scientific journals were reviewed as were commodity publications and conference proceedings to locate articles describing research into developing transgenic plants for pest management purposes [22], [23], [24], [25], [26], [27]. USDA’s Current Research Information System (CRIS) was searched to identify federally funded genetic-engineering projects at federal research facilities and universities [30]. Some of the federally funded projects have been described in articles in *Agricultural Research*. [19], [28], [29].

Researchers developing transgenic plants for pest management purposes were interviewed. Researchers were contacted by phone, email and letters to verify research success in genetic transformation of plants with transgenes and subsequent pest resistance or herbicide tolerance. Research summaries were solicited, as were specific information on the transformation process and mechanism of pest resistance or herbicide tolerance.

States for which the transformed crop would provide pest management benefits were identified. In most cases, research projects were logically linked to the states in which they were being developed. However, many of the transformed cultivars could have a potential role in pest management in many states. For the purpose of this study, only certain states were selected for the purpose of analyzing the potential role of the technology. These states were generally those with the largest acreage of the crop or states where the pest problem was most significant. For each state an estimate has been made of the acreage likely to be planted with the transgenic cultivar.

The current status of the pest problem and its current management in the selected states were quantified in terms of pesticide use, crop losses and costs of management practices.

Pesticide use surveys and pest loss reports were examined to determine the extent of the pest problem in the selected states. The extent of the problem and its management with pesticides was quantified in terms of annual production losses, pesticide use, and costs of control.

The potential impacts that would likely result from the introduction of the transgenic cultivar were quantified. Four aggregate measures were quantified in all the case studies. Changes in production costs were calculated by determining which current practices would be affected resulting in savings and by projecting an assumed cost of the transgenic technology. Changes in quantities of crop production and value of production were estimated if the transgenic technology was determined to be more effective in preventing pest losses than the technology it would likely replace. Changes in pesticide use amounts were quantified if the transgenic cultivar was likely to replace current use for the target pest.

A case study writeup was prepared and sent to outside reviewers for comment. The writeups were sent to the public and private researchers developing the technology as well as Extension Service and commodity pest management specialists in the state. Commodity groups representing the crop were also sent these writeups . Review comments were integrated into revised versions of the writeups.

4.0 Case Study Adoption Status

The 40 case studies are classified according to their adoption status into four categories.

Adopted (A): Eight case studies quantify the impacts that have occurred as a result of current (2001) adoption of transgenic crops for pest management in the US. The case studies estimate the changes in pesticide use, crop production, and costs of production that occurred in 2001 as a result of adoption. Three approaches were used depending on the case study. For certain case studies, the impacts were estimated in terms of comparison with a year before adoption; in some cases, the estimates were based on a comparison of adopters and nonadopters in 2001;in other cases, the impacts are based on a simulation of likely substitutes for the transgenic technology if it had not been used in 2001.

Approved but not adopted (AA): Four case studies quantify the impacts that would have occurred in 2001 had US growers planted transgenic cultivars which have been registered and commercialized for planting in the US but which are not being planted. The impact estimates quantify foregone benefits in terms of production volume, production costs, and pesticide use impacts that are as yet unrealized.

Under development for current pest problems (UDCP): Twenty-four case studies quantify the impacts that would have occurred in 2001 had US farmers planted transgenic cultivars currently under development to manage a current pest problem. The impact estimates quantify potential gain in terms of current problem conditions. The impact estimates quantify the potential production volume and cost changes and impacts on pesticide use that would likely occur if the transgenic plants were developed and planted by US farmers. These impact estimates represent gains measured from the baseline.

Under development for future pest problems (UDFP): Four case studies quantify the potential impacts of the introduction of transgenic cultivars to manage pest problems that are expected to occur in the near future. The case studies simulate the likely worsening of certain pest control problems in the US in terms of production losses and increases in cost of production and pesticide use. The impact analysis simulates the impacts of the introduced transgenic plant in terms of preventing these developments from occurring by quantifying what impact costs and yield reductions would have been incurred in 2001 if the pests were present.

5.0 Limitations

The report is limited to the US. Many transgenic crop cultivars are being developed to manage pests in other parts of the world. Some of these research projects are being conducted in the US. Many of the case studies included in this report have great potential for managing pests in other parts of the world as well.

The report is limited to the development of transgenic plants for pest management purposes. Other uses of biotechnology to improve pest management (such as the use of selectable markers) are excluded. Also excluded are transgenic plants being developed for purposes other than pest management—such as reductions in allergenic content.

The report is limited to cases for which successful transformation has occurred and for which there are at least preliminary results on performance for pest management. As a result, there are many transgenic plant projects excluded from the study because research had not proceeded far enough at the time the case studies were selected.

The report projects adoption of the transgenic crop to only certain states. There are numerous states for which certain transgenics would potentially have a beneficial role which are not included in the study.

The study is limited to adoption of transgenic cultivars at 2001 levels of adoption. There has been a projected increase in herbicide tolerant cotton for 2002 which is not accounted for in the case study. Herbicide tolerant corn may also increase significantly in the near future following expected regulatory approval by the European Union.

6.0 Case Study Summaries

Table 1 lists the 40 case studies included in the report. Table 1 identifies the type of case study (IR, HT, BR, FR, NR, VR), its adoption status (Adopted, Approved but not adopted, Under development for current pest problems, Under development for future pests problems) and identifies the states for which impact estimates are calculated.

Each of the 40 case studies is the subject of a short (5-40 page) writeup which summarizes the pest problem being addressed, the development and testing of the transgenic, and the methodology and data used to calculate the projected impacts of adoption. These case study writeups include a listing of all the references that were consulted. These 40 case study writeups are included in Appendix A of this report.

Each of the 40 case studies has been summarized in a one-page case study summary sheet which provides a more concise description of the pest problem and development of the transgenic cultivar. Key findings are presented, as are the names of independent outside experts who are knowledgeable regarding the pest problem and research into and adoption of the transgenic cultivars. The 40 summary sheets are included as Appendix B of this report

Table 1: The 40 Biotech Crop Case Studies

#	Crop	Type	Geographic Region	Status
1	Papaya	Viral Resistant	Hawaii	A
2	Squash	Viral Resistant	Florida/Georgia	A
3	Peanut	Viral Resistant	Georgia	UDCP
4	Peanut	Insect Resistant	Georgia	UDCP
5	Tomato	Viral Resistant	Florida	UDCP
6	Tomato	Herbicide Tolerant	California	UDCP
7	Lettuce	Herbicide Tolerant	California	UDCP
8	Strawberry	Herbicide Tolerant	Northeast (19 States)	UDCP
9	Pineapple	Nematode Resistant	Hawaii	UDCP
10	Broccoli	Insect Resistant	California	UDCP
11	Citrus	Viral Resistant	Texas	UDFP
12	Citrus	Bacterial Resistant	Florida	UDFP
13	Sweet Corn	Insect Resistant	Florida	AA
14	Sweet Corn	Herbicide Tolerant	Wisconsin	AA
15	Stone Fruit	Viral Resistant	Pennsylvania	UDFP
16	Raspberry	Viral Resistant	OR/WA	UDCP
17	Potato	Insect/Viral Resistant	OR/WA/ID	AA
18	Potato	Fungal Resistant	OR/WA/ID	UDCP
19	Potato	Herbicide Tolerant	OR/WA/ID	UDCP
20	Sugarbeet	Herbicide Tolerant	US (11 States)	AA
21	Grape	Bacterial Resistant	California	UDFP
22	Apple	Bacterial Resistant	US (15 States)	UDCP
23	Sunflower	Fungal Resistant	ND/KS/MN/SD	UDCP
24	Canola	Herbicide Tolerant	North Dakota	A
25	Soybean	Insect Resistant	GA/AL/MS/LA/SC	UDCP
26	Soybean	Herbicide Tolerant	US (31 States)	A
27	Rice	Herbicide Tolerant	US (6 States)	UDCP
28	Field Corn	Insect Resistant (1)	US (36 States)	A
29	Field Corn	Insect Resistant (2)	US (10 States)	UDCP
30	Field Corn	Insect Resistant (3)	US (18 States)	UDCP
31	Field Corn	Herbicide Tolerant	US (33 States)	A
32	Cotton	Insect Resistant (1)	US (16 States)	A
33	Cotton	Insect Resistant (2)	US (16 States)	UDCP
34	Cotton	Herbicide Tolerant	US (15 States)	A
35	Alfalfa	Herbicide Tolerant	California	UDCP
36	Barley	Fungal Resistant	North Dakota	UDCP
37	Wheat	Herbicide Tolerant	ND/SD/MN/MT	UDCP
38	Wheat	Viral Resistant	OR/WA/ID	UDCP
39	Eggplant	Insect Resistant	New Jersey	UDCP
40	Sugarcane	Herbicide Tolerant	Louisiana	UDCP

A: Approved
AA: Approved but not adopted
UDCP: Under development for current pest problems
UDFP: Under development for future pest problems

The 40 case studies are summarized below.

1. Papaya (Viral Resistant)

The development and adoption of transgenic papaya in Hawaii provides one of the most dramatic illustrations of the potential for crop improvement through biotechnology. Papaya ringspot virus (PRSV) is a limiting factor in papaya production worldwide, including in Hawaii. In the 1990s, Hawaiian papaya production was significantly declining due to a severe PRSV epidemic. Transformation of papaya with a PRSV coat protein gene produced successful protection against Hawaiian strains of the virus. Adoption of PRSV-resistant papaya varieties in Hawaii was rapid. In 2000, two years after their introduction, approximately 40% of total papaya acreage and 53% of bearing acreage in Hawaii was planted with one of the two PRSV-resistant cultivars. Statewide production, which had fallen 45% from 1992 to 1998, rebounded by 35% from 1998 to 2000.

2. Squash (Viral Resistant)

Four mosaic viruses are of particular concern to U.S. summer squash production: cucumber mosaic virus, watermelon mosaic virus, zucchini yellow mosaic virus and papaya ringspot virus type W. Generally growers can expect to lose about 20% of their summer squash crop to viruses. The first line of summer squash with transgenic resistance to viruses was deregulated by EPA in 1994 and made available commercially in 1995. It carried coat protein mediated resistance to two viruses, ZYMV and WMV2. In 1996, EPA deregulated another line that carried resistance to these two viruses as well as to CMV. It is estimated that transgenic squash with virus protection has been planted on 5,000 acres – mostly in Georgia and Florida. Planting transgenic squash increases the length of the marketing season and increases the number of harvests per acre.

3. Peanut (Viral Resistant)

Since the late 1980s, tomato spotted wilt virus (TSWV) has been a limiting factor in Georgia peanut production. Surveys have found 100% of peanut fields in Georgia are infected with TSWV, with as many as 60% of plants in some fields showing symptoms. A field with 50% incidence will lose an estimated 1,000 to 2,000 pounds in yields. Tomato spotted wilt virus is only transmitted by thrips, tiny winged insects which feed on plants. One insecticide, phorate, while not showing greater efficacy against thrips, does provide added protection against TSWV through some unknown mechanism, reducing incidence by 20-25%. In addition to phorate use, growers are planting varieties with moderate resistance to TSWV. With management techniques such as planting moderately resistant varieties and applying phorate, annual losses to TSWV are generally not significant, averaging around 5% ($17 million/yr.). Researchers at the University of Georgia have transformed a peanut variety with the coat protein gene from TSWV to give it resistance to the virus. The transgenic peanut shows TSWV resistance comparable to that of the moderately resistant cultivars. Work continues to increase the expression of resistance and to introduce it into commercial peanut varieties which already have some natural resistance so as to create a variety with complete resistance to TSWV.

4. Peanut (Insect Resistant)

Bt peanut lines have been developed, expressing a *CryIA(c)* gene with efficacy against lesser cornstalk borer (LCB). Larval LCB cause serious economic damage by feeding on parts of the plant at or just below the soil surface. In addition to direct damage, LCB feeding scars and wounds facilitate infestations of soilborne plant pathogens such as *Aspergillus* fungi. *Aspergillus* fungi are of major concern to the peanut industry because of aflatoxin production, especially in drought conditions, which favor their growth. Peanut lots that are contaminated with *Aspergillus* are downgraded at a significant loss to the grower. An economic analysis, based on the non-drought years 1993 – 1996, estimated the average net cost to Georgia growers of downgrading due to *Aspergillus* contamination to be $1.7 million. Experimental *Bt* peanut lines demonstrated high control of LCB and moderate to high control of two other peanut lepidopteran pests. If they prove to reduce *Aspergillus* and aflatoxin levels as well, they could prevent significant economic losses to contamination.

5. Tomato (Viral Resistant)

Reduction in crop value of 1990-91 Florida tomatoes due to tomato mosaic virus (ToMoV), was conservatively estimated to be 20%, or $140 million. A second geminivirus, tomato yellow leaf curl virus (TYLCV), may also reduce a tomato plant's production severely, or even eliminate it. There are no commercially available cultivars with immunity or significant tolerance to geminiviruses. Geminivirus management therefore has been based on whitefly management. Currently, growers use one soil application of imidacloprid at planting, followed eight weeks later by a rotation of foliar insecticides. Whitefly treatment programs are expensive, but losses due to ToMoV and TYLCV remain low as a result. Research on transgenic, virus resistant tomatoes began at the University of Florida in the early 1990's. The procedure for pathogen-derived resistance has been used to produce tomato lines with resistance to ToMoV and lines with resistance to TYLCV. In the presence of virus pressure, transgenic plants remain symptom free with yields 1.7 times greater than the non-transformed commercial hybrid.

6. Tomato (Herbicide Tolerant)

Weed control costs are a major part of the operating costs for processing tomatoes. Ninety nine percent of California’s tomatoes are treated with herbicides for weed control. Some weed species found on California processing tomato acreage, however, are not adequately controlled by registered herbicides. Nightshade species and nutsedge are widespread and competitive weeds in California processing tomatoes, causing substantial yield reductions, and bindweed interferes with mechanical harvests. Handweeding and cultivation are used on all of California’s tomato acreage to manage these problem weeds not controlled by herbicides. Tomato plants have been transformed via microprojectile bombardment with a gene that makes them tolerant to direct broadcast application of glufosinate, a nonselective herbicide with efficacy against a wide range of grass and broadleaf weeds. The gene originates from a bacterium and codes for an enzyme called phosphinothricin acetyl transferase (PAT). Transformed tomato plants were backcrossed with elite cultivars and the resulting hybrids have been field tested. The genetically engineered tomatoes show tolerance to glufosinate at all developmental stages, allowing its use for control of problem weeds.

7. Lettuce (Herbicide Tolerant)

Before the development of effective herbicides, severe weed infestations sometimes resulted in complete lettuce crop losses. The herbicides used in California lettuce have changed little in more than 30 years. No individual herbicide, or combination of herbicides, control all weed species under all production conditions and soil types in California lettuce. Cultivation and handweeding are used extensively to control weeds after lettuce seedlings have emerged. An estimated $166 per acre per year is spent on weed control in a typical California lettuce field. As a result of this combination of herbicide applications, cultivation and handweeding, California lettuce fields are largely free of weeds, and aggregate yield losses related to weed infestations are estimated to be less than 2% annually.Lettuce has been transformed with a gene from a soil microorganism for resistance to the nonselective herbicide glyphosate, allowing glyphosate to be applied to emerging and established fields without causing crop damage. California field trials determined that a glyphosate-based weed management system, consisting of transformed lettuce plants treated with two glyphosate applications, provided adequate control of the key weed species and has the potential to reduce handweeding costs without causing crop damage.

8. Strawberry (Herbicide Tolerant)

Strawberries are grown for direct fresh market (u pick) throughout the Northeastern U. S., including in the states of Connecticut, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, and Vermont. Weeds are the biggest management problem for Northeast strawberry production, causing greater economic losses than insect and disease pests combined. Strawberry acreage in Northeastern states has been declining since 1982, due in part to increasing weed pressure. Herbicides are applied to approximately 95% of Northeast strawberry acreage. But the herbicides currently registered for use in strawberries do not effectively control the full range of weeds invading Northeastern fields. Consequently, use of cultivation and hand weeding has increased to almost 100% of the acreage, accounting for 75% of the labor hours per year. Altogether, weed control costs for Northeast strawberry production is estimated to be

$500 per acre. Multiple strawberry varieties have been transformed with a bacterial gene for resistance to the nonselective herbicide glyphosate. Glyphosate effectively controls all the common troublesome weed species in Northeastern strawberry fields. Transformed plants are being screened for vegetative and floral tolerance to commercial application rates of glyphosate. If Northeast strawberry production shifts to a glyphosate-based system for weed control, approximately three applications of glyphosate per acre would replace the combination of three herbicide applications, three hand weedings and two cultivations currently used on average per acre at a savings of $242/A.

9. Pineapple (Nematode Resistant)

U.S. commercial pineapple production for both fresh market and processing is centered in Hawaii, with annual production of more than 352,000 tons. The reniform nematode is the primary nematode pest for Hawaiian pineapple and is present in most fields. Reduction is marketable yields due to uncontrolled nematode populations have been reported to be as high as 38% in the first harvest and 60% in the second. Nematode management in Hawaiian pineapples currently includes a six to twelve month fallow period followed by preplant soil fumigation with methyl bromide or 1,3-D to reduce losses in the first crop. In order to ensure a marketable second and possible third crop, postplant applications of nematicides such as fenamiphos are used. Pineapple plants of the commercially common variety ‘Smooth Cayenne’ have been transformed with a wild rice gene modified for more efficient expression in pineapple tissue. The wild rice gene codes for cystatin, a naturally occurring proteinase inhibitor that interferes with nematode feeding and digestion, thereby reducing root damage and nematode populations. Transformed pineapple plants have tested successfully for cystatin expression in the roots. Future tests will evaluate their resistance to reniform nematodes.

10. Broccoli (Insect Resistant)

In broccoli, preventing contamination of heads by insects and their frass is as essential for the production of a marketable crop as is protection from feeding damage. Feeding by larvae of the diamondback moth (DBM) causes both significant damage as well as larval and frass contamination. The biology of DBM and its history of developing resistance to multiple classes of insecticides make its economic control a dynamic challenge. In 1997, an outbreak of DBM in California broccoli overwhelmed standard insecticide-based control and resulted in crop losses estimated at more than $6 million. In laboratory assays, an experimental line of *Bt* broccoli producing a CryIC protein was protected against *Bt*-susceptible DBM, CryIA-resistant DBM, and DBM with moderate resistance to CryIC, as well as newly hatched cabbage looper and imported cabbage worm larvae. Broccoli varieties with CryIC have the potential to prevent the severe economic damages incurred during periodic DBM outbreaks such as the one seen in 1997, as well as reduce background annual losses to lepidopteran feeding and contamination.

11. Citrus (Viral Resistant)

Approximately 98% of citrus grown in Texas is planted on sour orange rootstock because sour orange is tolerant of the adverse soil conditions of that area. Sour orange rootstock, however, is susceptible to citrus tristeza virus (CTV). There is no remedy for an infected tree other than to remove it. Both grapefruit and sweet orange cultivars are susceptible to CTV if planted on sour orange rootstock. Severe strains of CTV are present in Texas already, but not in areas of commercial citrus production. Spread of CTV has not reached commercial citrus production in Texas largely because an efficient vector of CTV is not yet present in Texas. The brown citrus aphid is the most efficient vector of CTV. Currently the brown citrus aphid is found in Mexico and Florida, and is expected to reach Texas. When the brown citrus aphid arrives in Texas, it will likely move severe strains of CTV from symptomless dooryard trees in the east to susceptible commercial orchards, potentially destroying the Texas citrus industry. Researchers at Texas A&M University are using biotechnology to insert CTV coat protein genes into commercial citrus varieties to produce pathogen-derived resistance. In 2000, transformed grapefruit shoots grafted onto sour orange rootstock were planted in a field trial, and preliminary data indicate they have CTV resistance. The field trials are expected to bear fruit in a few years, at which point fruit quality will be tested. With development of CTV resistant citrus fruit cultivars, Texas growers will be able to continue using sour orange rootstock in the presence of brown citrus aphid without risking devastation from severe strains of CTV.

12. Citrus (Bacterial Resistant)

In Florida citrus, significant economic losses to citrus canker include yield reductions and the downgrading of fresh market fruits to juice markets. The most recent efforts to eradicate citrus canker in Florida have led to the destruction of more than 1.5 million trees since 1995. Biotechnology is being used to investigate several mechanisms for citrus canker resistance, including expression of antimicrobial peptides and interference with pathogenic proteins produced by the canker bacterium.

13. Sweet Corn (Insect Resistant)

Florida ranks number one in the U. S. for production and value of fresh market sweet corn. Two of the most important insect pests of Florida sweet corn are fall armyworm and corn earworm. A commercialized field corn variety transformed with a Bt gene was bred with sweet corn cultivars to produce transgenic Bt sweet corn. Novartis (now Syngenta) Seeds registered the Bt sweet corn cultivars with EPA in 1998 and marketed them under the trade name Attribute. In field trials, the season-long insect protection of Bt sweet corn cultivars consistently produced more marketable yield than non-Bt cultivars, and required between 42% and 84% fewer insecticide applications. Because Bt sweet corn does not provide protection against the corn silk fly, its adoption in Florida is not expected to eliminate insecticide applications altogether, but rather is expected to drop average per season applications from 12 to 2 on 80% of the acreage. Despite the potential beneficial impacts of planting Bt sweet corn, Florida sweet corn growers are not planting the transgenic cultivars.

14. Sweet Corn (Herbicide Tolerant)

In the last decade, sweet corn production in Wisconsin has declined by 45%. Groundwater protection regulations limiting or prohibiting use of the herbicide atrazine, the susceptibility of sweet corn to injury from some herbicides, and the appearance in sweet corn fields of weeds with resistance to other herbicides have resulted in a limited number of herbicides, with limited efficacy, registered for use on sweet corn in Wisconsin. Production has become less stable and food-processing companies in the state have closed or now purchase sweet corn from states which do not restrict atrazine use. Glufosinate is a nonselective herbicide effective against a wide range of broadleaf and grass weeds. A gene for glufosinate resistance, originally obtained from a bacterium, was used to transform corn cells, and the resultant plants withstood treatments with glufosinate. Research has demonstrated that two applications of glufosinate would provide effective control of the troublesome weed species in Wisconsin sweet corn. Glufosinate is not currently registered for use on sweet corn, although Wisconsin was granted use on transgenic sweet corn through an emergency registration granted by EPA in 1999. Based on the transgenic cultivars currently available, a glufosinate-based weed management program could be implemented on approximately 30,000 acres of sweet corn in the state, preventing the current 20% yield loss to weed competition on those acres.

15. Stone Fruit (Viral Resistant)

Plum pox virus is an aphid-borne virus that causes significant economic losses in stone fruits such as peaches, nectarines and plums. The most significant losses are due to premature fruit drop, which may lead to loss of the entire crop. There is no treatment or cure for plum pox, only methods to manage its spread and incidence. A major plum pox management strategy is to immediately remove trees that show symptoms. In 1999, plum pox virus was detected in Pennsylvania, where more than 6,000 acres of stone fruit were in production. The state established a quarantine of the affected areas in order to prevent further spread to other stone fruit production areas within the state, in other states, and in Canada. The state of Pennsylvania has spent $5.1 million in eradication, which has included the destruction of approximately 900 commercial acres of infected and exposed trees. Through biotechnology, a transgenic plum variety has been developed with pathogen-derived plum pox resistance. Resistance in the transgenic cultivar is controlled by a single gene, potentially lending itself to incorporation into other stone fruit varieties through classical breeding techniques. In trials in Europe, the transgenic plum trees have remained virus free while all of the nontransgenic controls have developed plum pox symptoms.

16. Raspberry (Viral Resistant)

In the US, red raspberries are grown primarily in Oregon and Washington. In the 1980's, the most commonly planted raspberry cultivar in the Pacific Northwest changed to Meeker. Meeker plants are susceptible to raspberry bushy dwarf virus (RBDV). The virus reduces plant productivity and reduces fruit quality, making it crumbly. Fruit produced by RBDV-infected plants is unsalable in the fresh and individually quick frozen (IQF) markets and will only sell in the juice or jam market. In 1996, 84% of the raspberry fields in northern Washington were infected with RBDV. There is no treatment for RBDV, which is spread in the pollen of infected plants, so growers remove infected plants and replant with virus-free plants. Because of RBDV, the productive life of the average raspberry planting has been reduced from approximately 15 years to approximately 5 years. The process of replanting a raspberry field includes removing old plants and their trellises, fumigating the soil, replanting and retrellising. A collaborative effort in Oregon between USDA-ARS researchers and Exelixis, Inc. has resulted in the successful transformation of raspberry plants with RBDV resistant properties. Three different pathogen-derived mechanisms for RBDV resistance are being tested in field trials. Preliminary data from the first year of field trials indicate that 80% of the transgenic raspberry plants remained virus free. Fruit quality is being assessed.

17. Potato (Insect Resistant/Viral Resistant)

Two of the most damaging pests in Northwest potato production are the Colorado Potato Beetle (CPB) and the green peach aphid. Uncontrolled CPB populations can defoliate an entire field by mid-season, severely lowering plant yields and tuber quality. The green peach aphid are considered primary pests because of their ability to spread potato leaf roll virus. Potato leaf roll virus severely reduces marketable yields by reducing plant production and causing net necrosis in tubers, making them unsalable.

CPB and aphid management in potatoes has been based on significant insecticide use, progressing from lead arsenate use in the early part of the century to DDT and parathion use in the 1940s and 1950s, numerous organophosphates in the 1960s, and pyrethroids and carbamates in the 1970s. However, because insecticide applications do not kill all aphids or prevent all aphid feeding, and because of aphids migrating into fields from other areas, virus infections and associated losses still occur. Russet Burbank potatoes have been transformed to express the Cry3A Bt protein, which is toxic to CPB, and to express a potato leaf roll virus coat protein, which provides resistance to the virus. Field trials indicate protection against CPB provided by the Bt gene is equivalent to that provided by current insecticide usage, and the pathogen-derived protection against potato leaf roll virus is close to 100%. Planting of CPB and virus resistant potatoes could therefore potentially replace current insecticide applications targeting CPB and aphids, as well as prevent current losses to potato leaf roll virus.

18. Potato (Fungal Resistant)

Verticillium wilt is a major limiting factor in potato production throughout the U. S. The fungal pathogen enters root tissue and infects the water conducting system of the plant, causing symptoms of severe drought. Size and quality of potatoes are decreased and yields decline 20% to 40%. The fumigant metam sodium applied to soil through sprinkler irrigation prior to planting is the most common control of Verticillium due to its efficacy and ease of application. In continuous potato plantings, metam sodium increases yields by 23-33%. It must be reapplied each season, and it is expensive. An antifungal gene from alfalfa has been isolated and transferred to Russet Burbank potato plants. The protein encoded by the gene, alfAFP, can inhibit Verticillium growth completely. In laboratory studies, transgenic potato plants producing alfAFP exhibited enhanced resistance to Verticillium wilt as compared to non-transgenic plants. In the field, fungal levels in transgenic potato plants were six-fold lower than those in non-transgenic plants. If commercialized, transgenic potato plants with Verticillium wilt resistance could significantly reduce metam sodium use and lower growers production costs.

19. Potato (Herbicide Tolerant)

Potato is a slow growing crop that offers little competition for weeds. The primary weed control practice in Northwest potato fields is a combination of cultivations and timely hilling plus one or more herbicide applications. Over 90% of Pacific Northwest potato acreage is treated with herbicides, and typically two active ingredients are applied per acre. Post-emergence use of herbicides in potatoes is limited because of risk of phytotoxicity to the crop. In addition, available post-emergence herbicides are ineffective against many weeds which are troublesome, particularly nightshade species and perennials such as Russian thistle. As a result, approximately 2% of Northwest potato production is lost annually to uncontrolled weeds. Glyphosate tolerant potato varieties have been developed through the insertion of genetic material from a soil bacterium into the potato genome and have been field-tested. Preliminary data show the potential for providing Northwest growers an effective tool for post-emergence weed management without risk of crop damage. In a glyphosate resistant potato system, growers could continue with current practices for pre-emergence weed management, and supplement them with a post-emergence glyphosate application for more complete weed suppression.

20. Sugarbeet (Herbicide Tolerant)

In sugarbeet, competition from uncontrolled weeds can severely reduce production. Growers in the U.S. typically make three to four herbicide applications each year, with each application consisting of multiple active ingredients. Mechanical cultivation and hand weeding are employed for control of weeds, such as kochia, which are not adequately controlled by available herbicides. Glyphosate-resistant sugarbeet varieties were granted regulatory approval in 1999. Experimental data show weed suppression and subsequent yields in glyphosate-resistant sugarbeet, treated with two glyphosate applications, were equivalent to or better than those in plots treated with standard herbicides. Weeds controlled included species most troublesome in conventional sugarbeet fields, such as kochia, pigweed, lambsquarters, foxtail, and wild oat. Adoption of sugarbeet varieties with glyphosate resistance is expected to lead to a reduction in the number of herbicide applications applied per acre. In addition, reductions are expected in the cultivation and hand weeding practiced in sugarbeet for weed control. With fewer herbicide applications, fewer cultivation passes, and fewer hours of hand weeding, a significant reduction in weed control costs is expected. To date, however, herbicide-resistant sugarbeet varieties have not been marketed or planted.

21. Grape (Bacterial Resistant)

Pierce's disease is a bacterial plant disease that clogs water-conducting arteries of grapevines. It is spread by plant-feeding insects called sharpshooters, which feed on the fluid in the water-conducting vessels of plants. Plants infected with Pierce's disease are starved of water and nutrients, so they wilt and dry up. In the 1990s, a new species of Pierce's disease-spreading sharpshooter, the glassy-winged sharpshooter (GWSS) arrived in California. It is bigger and a more voracious feeder than the other sharpshooters in the state. The GWSS is a stronger and longer flier than the other sharpshooters in the state, easily moving beyond vineyard borders. The GWSS also has a much wider host range, making its presence more widespread more quickly. Since the arrival of the GWSS in California, in Riverside County alone, more than 300 acres have been killed, 25% of the acreage removed. The GWSS/Pierce's disease combination seriously threatens all of California's $2.7 billion grape production, and it's associated $33 billion wine industry. Biotechnology offers a way to introduce Pierce's disease resistance into current elite grapevine varieties without changing the distinctive qualities of the fruit or wine they would produce. Already several potential sources of Pierce's disease resistance have been identified, transferred to commercial grape varieties, and are being tested for performance and quality. These include genes from giant silkworm moth pupae that produce the antibacterial protein cecropin.

22. Apple (Bacterial Resistant)

Outbreaks of fire blight in apples, each causing millions of dollars in damages, are increasing in frequency as fire blight populations develop resistance to the foliar antibiotics currently applied for their management. A variety of transgenic traits are being tested as sources of fire blight resistance, including antimicrobial proteins and pathogen-derived genes that may elicit systemic acquired resistance to the disease. If successful, transgenic fire blight resistance could eliminate antibiotic use in orchards and reduce economic losses to the disease.

23. Sunflower (Fungal Resistant)

In North Dakota, South Dakota, Kansas and Minnesota, states whose combined sunflower production constitutes approximately 85% of U.S. production, Sclerotinia is the number one disease problem in sunflower. An estimated 8% of sunflower production, on average, is lost to Sclerotinia diseases annually, although losses in individual fields with high incidence may be as much as 80% in epidemic years. There are no fungicides registered for control of Sclerotinia in sunflower and there are no sunflower cultivars with resistance to the fungus. Crops with natural Sclerotinia resistance, such as wheat and barley, produce an enzyme, oxalate oxidase, which breaks down and detoxifies the phytotoxins produced by Sclerotinia. A wheat gene for oxalate oxidase has been transferred to sunflower and the resulting transgenic sunflower plants show resistance to Sclerotinia wilt, head and stalk rot.

24. Canola (Herbicide Tolerant)

Canola, a member of the mustard family, is not competitive in the seedling stage, but once established, is a good competitor with most weeds. In addition to potentially causing significant yield reductions in establishing canola plantings, weed infestations can lead to seed contamination and problems in processing. Weeds in the mustard family tend to have high levels of erucic acid and glucosinolate, two undesirable compounds which reduce the consumer quality of canola oil and feed quality of canola meal, respectively, leading to price discounts or rejection in the market. Canada thistle, for which there are no economical herbicides available, is also troublesome in canola. The cornerstone of weed management in canola is herbicide use, as the narrow row planting of canola inhibits use of cultivation. Glyphosate provides a wider spectrum of control than other herbicides currently available for use in canola, including management of Canada thistle, mustard species, and ALS-resistant kochia. With glyphosate-resistant canola varieties, growers can use one or two well timed glyphosate applications for effective weed control with no crop injury. Estimated savings to growers include a reduction in herbicide use of approximately 0.7 pounds per acre with a $15 per acre reduction in herbicide costs.

25. Soybean (Insect Resistant)

In southern soybean production, the most damaging defoliating insects are velvetbean caterpillar and soybean looper. Other foliage feeders of economic significance include lesser cornstalk borer and corn earworm. Losses from velvetbean caterpillar alone in Georgia soybean may be as high as $2 million in combined damage and cost of control. Researchers at the University of Georgia have transformed soybean with a synthetic *cryIAc Bt* gene for protection against velvetbean caterpillar and lesser cornstalk borer. In addition to the transgene-induced insect resistance, natural lepidopteran-resistance traits from Japanese soybean varieties were bred into the *Bt* soybean for increased protection against corn earworm and soybean looper. Several lines with different combinations of *Bt* and natural resistance genes are being tested in the laboratory and in the field for a wide range of lepidopteran protection. If commercialized, southern soybean growers, who spend an estimated $100 million per year on insecticide use, are expected to benefit most through insecticide use reduction.

26. Soybean (Herbicide Tolerant)

Soybeans have been transformed with a bacterial gene for resistance to the non-selective herbicide glyphosate. The Roundup Ready technology was planted on two-thirds of the nations soybean acres in 2001. Postemergence glyphosate applications largely replaced the previous herbicides. In addition to changing herbicide use patterns, US soybean growers have also changed tillage practices following the introduction of Roundup Ready soybeans. A recent survey indicated that 53% of US soybean growers reported making fewer tillage passes through their fields since 1995 with the average reduction reported as 1.8 tillages/acre. Several new herbicide active ingredients and combination products were introduced to the US soybean market 1997-2001. Generally these active ingredients have been shown to work best in combination with other products which extend the period or spectrum of control. Recent tests with newly-registered active ingredients indicate that combinations of 4-5 active ingredients could provide effective weed control of common grasses and broadleaves approximately equal to those provided by glyphosate. A survey of Extension Service weed scientists solicited herbicide replacement scenarios for

Roundup. For most states, the specialists indicated that at least 3 products would have to be used to effectively replace Roundup. Most Roundup programs use approximately 1 lb/AI and cost $15-16/A. Most alternative programs cost $30-40/A and utilize more than one pound of active ingredient per acre.

27. Rice (Herbicide Tolerant)

There are currently two varieties of transgenic herbicide tolerant rice being developed. Liberty Link rice withstands the applications of glufosinate while Roundup Ready rice can tolerate the applications of glyphosate. Research suggested that single or sequential applications of glufosinate provided excellent control of red rice, barnyardgrass and broadleaf signalgrass. The main benefit offered by transgenic rice would be greater control of red rice which is a major problem in the Delta and Gulf Coast producing areas. In California, where red rice is not a severe threat, production losses due to other weeds that are resistant to common herbicides are a problem. Use of transgenic rice would allow the postemergence applications of non-selective herbicides, glufosinate and glyphosate, for the effective control of the resistant weeds. With an effective herbicide for controlling red rice and resistant grasses, rice growers would no longer need to practice waterseeding, which is more costly than dryseeded rice due to additional costs for water, tillage and seed.

28. Field Corn (Insect Resistant) (1)

Beginning in 1996, several seed companies commercially introduced new corn hybrids that had been altered genetically to produce a Bt protein toxic to corn borers. Research has demonstrated that the SWCB is as susceptible to Bt corn as the ECB. Larvae survival is very low on all transgenic hybrids. Numerous studies have estimated the increases in corn yields due to Bt corn adoption since 1997. These studies' results have been largely determined by the extremely low population of the ECB in Midwestern states (1998 – 2000). However, many entomologists regard the years 1998 – 2000 as extremely unusual and not typical of long-term normal ECB populations which began to increase in 2001. A survey of extension service entomologists was undertaken for information on corn yield impacts due to ECB/SWCB infestations during a 'low' and a 'high' infestation year. In order to estimate the Bt corn price premium paid by US farmers, two companies supplying Bt corn seed were contacted. The cost of the Bt technology is estimated at $6.50/A. The use of insecticides is simulated on Bt corn acreage for a high infestation year. Of the 36 main corn-producing states, there are only three states (AL, IN, MS) for which an insecticide application during a high year would not cover the cost of the insecticide treatment. In a high year, growers only gain from Bt corn the extra 20% yield improvement that they would not gain from using insecticides. Bt corn is credited with lowering production costs during a high infestation year because Bt corn costs less than insecticides. In a low infestation year, Bt corn is credited with stopping yield losses to borers.

29. Field Corn (Insect Resistant) (2)

Cutworms are among the major soil insects of field cron. On younger, small-stemmed corn plants, larvae cut the plant off at or near soil level. Large populations can decimate an entire field of corn seedlings. Fall armyworm (FAW) is native to the tropics. Southeastern states experience annual FAW infestations. In high infestations, FAW larvae may eat all available food and crawl en masse in “armies” to adjoining fields. Field corn genetically engineered to express the Cry1F Bt protein controls the European Corn Borer (ECB) and Southwestern Corn Borer (SWCB), and provides intermediate suppression of corn earworm, similar to the Cry1Ab Bt field corn varieties currently marketed. In addition Cry1F provides protection against black cutworm (BCW) and fall armyworm (FAW). Cry1F field corn is most appropriate in corn growing areas where black cutworm, fall armyworm, European corn borer and southwestern corn borer are consistently problematic.

30. Field Corn (Insect Resistant) (3)

Corn rootworms (CRW) are the most serious insect pests in field corn in the US. Approximately 12 million pounds of soil-applied insecticides were used in 1997 to control rootworms on 18 million acres in 18 major corn acreage states. Soil insecticides applied for corn rootworm larvae control also help control other soil-borne insect pests in corn, such as wireworms, black cutworms, and white grubs. Crop rotation has failed to control CRW damage in some areas, resulting in economic losses in first year corn. A new biotype of beetles appearing in eastern Illinois, northern Indiana and parts of Michigan will lay eggs in soybean fields rather than corn, so that egg hatch the next season coincides with a corn rotation. A trend towards increasing insecticide use in corn, where rotation-resistant rootworm is the most widespread, is becoming discernable. Two new transgenic corn varieties have been developed which produce Bt proteins toxic to corn rootworm beetles. One potential benefit Bt corn for rootworm protection may offer is more consistent and reliable protection than that provided by soil insecticides. The efficacy of soil-applied insecticides is dependent on proper timing and placement, and the environmental conditions that affect insecticide duration in the soil and rootworm larval emergence. In terms of level of root damage and consistency of protection, the transgenic varieties performed equally well or better than the soil insecticide treatments used for comparisons. It is estimated that acreage likely to be planted to rootworm-protected corn includes corn acreage that is treated with soil insecticides at planting. In addition, corn acreage that is at risk ofinfestation with rotation-resistant rootworm would also be planted to rootworm-protected corn.

31. Field Corn (Herbicide Tolerant)

Roundup Ready corn has a single added protein: the enzyme mEPSPS, which is resistant to the effects of glyphosate. For corn, the source of mEPSPS was its own cloned gene that had been mutagenized in vitro. Liberty Link corn varieties were developed to withstand application of the herbicide glufosinate (Liberty). Resistance to glufosinate was obtained originally from a gene found in a bacterial species. It is estimated that national adoption of the herbicide tolerant cultivars represents 5.8 million acres or 8% of corn acreage. University weed scientists report that adoption has been largely driven by improved control of troublesome weed species for which there are weaknesses in conventional programs; wild proso millet, burcucumber, wirestem muhly, sandbur, hemp dogbane, bermudagrass and perennials in general. The university specialists reported that the adoption of the herbicide tolerant corn varieties has replaced previously-used herbicide programs in two ways: (1) growers have reduced the rates of soil-applied preemergence treatments and used glyphosate or glufosinate to effectively control weeds that emerge and (2) growers have substituted glyphosate or glufosinate for their previously-used postemergence applications. These substitutions are estimated to save corn growers approximately $10/A. It is estimated that replacing the currently used herbicide programs results in an average reduction in herbicide use of 1 lb/A and costs of $10/A.

32. Cotton (Insect Resistant) (1)

Bt cotton varieties were introduced in 1996, providing control of three major cotton insect pests: tobacco budworm, cotton bollworm and pink bollworm. These varieties offer an alternative to conventional insect spray programs. The adoption of Bt varieties was extremely rapid in states that experienced resistance problems (Arizona, Alabama, Georgia, Florida). After the year of very high budworm populations and damage in 1995, growers in Alabama adopted the new technology at an extremely rapid rate, planting over 60% of total acreage to Bt varieties in 1996. Bt cotton is credited with saving the cotton industry in Alabama. Adoption was accelerated in certain states (Mississippi, Louisiana, Texas, Oklahoma, Arkansas, and Tennessee) due to implementation of Boll Weevil Eradication Programs (BWEP) and resistance problems experienced in 1995. Growers in BWEP areas are advised to plant Bt cotton due to the effects of the weevil sprays on predators of bollworms/budworms. Numerous surveys have found that growers are achieving higher yields and attaining higher profits by planting Bt varieties, due to better pest control and decreased insect control costs. The average increase in net income in 2000, comparing Bt to conventional varieties, was $20/ acre, taking into account the technology fee. On average, per acre insect control costs were $2 higher. This increased cost was outweighed by a yield increase of 36 lbs/ acre.

33. Cotton (Insect Resistant) (2)

The fall armyworm, soybean looper and the beet armyworm are destructive migratory pests of cotton in the southeastern US. Transgenic Bt cotton has been commercially available in the United States since 1996. Bt cotton has demonstrated remarkable control of some lepidopteran pests, particularly the tobacco budworm and the pink bollworm. Control of the bollworm has been less dependable. Common lepidopteran pests such as fall armyworms, beet armyworms and soybean loopers are even more tolerant than bollworms. Approximately 36% of current Bt cotton acreage is treated for bollworms. For beet armyworm/fall armyworm/soybean looper control, approximately 21% of current Bt cotton acreage is treated. Unacceptable control of bollworms and other lepidopteran pests such as beet armyworms, fall armyworms and soybean loopers, prompted the development of a new genetically modified cotton that contains two separate crystalline proteins. The addition of a second Bt protein provides satisfactory control of beet armyworms, fall armyworms, and soybean loopers. Efficacy is improved against bollworms. Bt cotton I will likely be phased out and completely replaced with Bt cotton II. It is estimated that Bt cotton II will be adopted on the same acreage that is currently planted with Bt cotton I. The major impact of Bt cotton II would be an elimination of current losses and spraying costs due to bollworms/loopers/armyworms on Bt cotton acreage.

34. Cotton (Herbicide Tolerant)

In 1995, the typical US cotton acre was treated with an average of nearly three active ingredients in nearly three treatments. There were also three cultivations made on the typical acre. Extensive use of hand-weeding crews has been utilized. In the early 1990s, 21% of US cotton acreage was handweeded annually with the highest use in California where 75% of the acreage was handweeded. US cotton growers applied nearly 32 million pounds of active ingredients at an annual cost of $302 million just prior to introduction of transgenic herbicide tolerant cotton varieties. The total cost of weed control including herbicide, handweeding, cultivation and application costs was $797 million/yr.

US cotton acreage planted with Roundup Ready varieties increased steadily following its introduction in 1997 reaching 70% of planted acreage in 2001. Numerous press articles have reported that cotton growers have adopted the transgenic cultivars as a way to significantly reduce their production costs. Growers have reported making fewer trips across fields applying herbicides, making fewer cultivation trips, and making fewer applications of herbicides. USDA surveys of herbicide usage by cotton growers show a general decline in overall herbicide active ingredient used per acre for most states since 1996/1997 to 2000. Extension Service cotton weed control specialists were surveyed to estimate the changes in tillage, herbicide application trips and handweeding that has occurred on the acreage planted to transgenic cotton. All states reported fewer tillage trips and less handweeding, while herbicide application trips were either reported as unchanged or reduced.

35. Alfalfa (Herbicide Tolerant)

It is estimated that approximately 20% of California's alfalfa hay acreage does not receive adequate herbicide treatments currently and, as a result, weedy bales are produced during one half of the cuttings annually on 200,000 acres. It is estimated that a $30/ton discount occurs due to weediness on half of the annual production (3.5 tons) on these acres. The total discount due to weediness is estimated at $21 million/year. Weedy bales result when herbicides are not used or when they are applied and do not perform effectively. Weed control in seedling alfalfa is often unattainable with available herbicides.

Through genetic engineering, researchers have transformed alfalfa varieties through the insertion of a gene from a soil bacterium. This transformation confers glyphosate tolerance to the alfalfa. Research has demonstrated that the glyphosate tolerant alfalfa has excellent tolerance to glyphosate at all stages of plant development. Field tests with the glyphosate tolerant alfalfa are underway in California and several other states.

36. Barley (Fungal Resistant)

Since 1993, Fusarium head blight, or scab, has become the most serious fungal disease in North Dakota small grain. As a result of recent scab epidemics, North Dakota barley acreage has declined by one third, production has declined by 25%, and value by 40%. Losses to scab infection include reduced yields, reduced seed weight and quality, but severe economic losses from scab result from contamination by a mycotoxin it produces. Two anti-toxin genes, one from a fungus closely related to scab and the other from yeast, have been transferred to barley and are being tested for expression and performance. Both genes code for proteins that deactivate the mycotoxin. Barley is also being transformed to produce proteins that will attack the scab fungus itself when it first tries to infect kernels. Maltsters only accept certain elite barley cultivars based on enzymatic and other properties that affect brewing performance. Future goals include endowing the elite commercial cultivars accepted by maltsters with scab resistance by crossing them with transgenic barley varieties.

37. Wheat (Herbicide Tolerant)

Four states account for 92% of US spring wheat acreage: Montana, Minnesota, North Dakota, and South Dakota. The types of spring wheat grown in these four states are classified as hard red spring wheat and durum wheat. Hard red spring wheat has the highest protein content of all US wheats, usually 13 to 16%. Durum is the hardest of all wheats. Its density, combined with its high protein content and gluten strength, make durum the wheat of choice for producing premium pasta products. It has recently been estimated that approximately 33% of the spring wheat acreage is untreated for Canada thistle and is incurring a 4-bushel per acre loss as a result. Beginning in 1994, Monsanto has conducted field trials with wheat cultivars that have been transformed through the insertion of a gene from a soil microorganism. This transformation makes it possible to spray wheat with glyphosate herbicide (Roundup) without crop injury. Research in North Dakota has shown that two applications of 12 oz/A of Roundup provide season long control of wild oats, Canada thistle and wild mustard. Extension Service weed control guides for the Northern Plains states rate the effectiveness of glyphosate as good to excellent on all the key weeds in spring wheat, which is equivalent to the standard herbicides. The projected cost of the glyphosate tolerant spring wheat weed control program ($20/A) would be equivalent to the current cost for combinations of broadleaf plus grass or Canada thistle herbicides. On acreage where Canada thistle is currently uncontrolled because of the additional costs, the glyphosate system would offer a potential yield increase of 4 bushels an acre or $12/A in additional income. It is estimated that the glyphosate weed control system would be adopted on one-third of the spring wheat acres in MN, ND, SD, and MT (5.8 million acres) at no additional production cost but with an increase in income of $12/A.

38. Wheat (Viral Resistant)

Two of the most serious viruses affecting wheat in the Pacific Northwest are barley yellow dwarf virus (BYDV), vectored by aphids, and wheat streak mosaic virus (WSMV), vectored by mites. Both viruses stunt plant growth and reduce yields. Yield losses to these diseases can vary greatly from year to year, reaching as high as 70% to 90% in an infected field, but average losses are estimated at 1% to 3% across the region. Management of BYDV and WSMV in wheat depends on avoiding exposure to the aphids and mites that vector them. Delaying planting is a major technique for avoiding peak aphid and mite populations, but too great of a delay risks missing the period when soil and moisture conditions are best for wheat establishment. Yield losses to delayed planting may average as much as 10 bushels per acre, or 13%. For BYDV management, insecticides are applied to 2% of Northwest wheat acreage for aphid suppression. Commercial soft winter wheat varieties have been transformed with three different genes for protection against viruses. Two genes are coat protein genes, one from BYDV and one from WSMV. Each gene is expected to provide resistance specific to the virus from which it was isolated. The third gene being tested is derived from yeast. Its products interfere with a key enzyme needed for viral replication, thus providing more general virus resistance than the pathogen-derived genes. Field tests are underway to evaluate these three potential sources of virus resistance in transgenic wheat.

39. Eggplant (Insect Resistant)

In eggplant, insecticide use is dominated by the systemic imidacloprid. A primary pest in eggplant and a primary target of insecticide use is Colorado potato beetle (CPB). Transgenic eggplants expressing a synthetic *cryIIIA Bt* gene have been developed and field-tested. Presence of and feeding damage by CPB on *Bt* eggplants were significantly lower than on nontransgenic, untreated eggplants, and comparable to nontransgenic plants treated with imidacloprid. In varietal field trials, *Bt* cultivars met commercial standards for preferred plant and fruit qualities.

40. Sugarcane (Herbicide Tolerant)

Weed management is an essential component of sugarcane production in Louisiana. Both broadleaf and grass weeds reduce sugarcane yields and interfere with harvest, contributing to overall loss in production. Perennial grass weeds, such as johnsongrass and bermudagrass, are particularly troublesome because sugarcane itself is a grass and conditions suitable to its development are also conducive to grass weed growth. In addition, there is no single herbicide which effectively controls all perennial grass weeds in sugarcane. If uncontrolled, they may potentially reduce sugarcane yields by as much as 50%. Weed management in Louisiana sugarcane relies heavily on herbicide use, but also includes cultivation, both for incorporation of applied herbicides and as a supplementary technique for weed suppression. Three to four cultivations are usually interspersed with herbicide applications. Certain herbicides used with sugarcane are injurious to the crop as is tillage; overall, sugarcane yields are estimated reduced by 5% due to cultivation and phytotoxicity of herbicides. Transgenic sugarcane with glyphosate resistance has been developed and is currently being evaluated in field trials. Glyphosate usage would replace the herbicides in sugarcane for control of grass weeds. Glyphosate provides more effective control than the only postemergence grass control herbicide and equivalent control to herbicides used preemergence. Glyphosate would also substitute for two of the cultivations. Overall, sugarcane yields are estimated to increase by 5%.

7.0 Results

The impact of biotech crops was calculated for each of the four impact categories: adopted, approved but not adopted, under development for current pest problems and under development for future pest problems. Each of the 40 cultivars provides value equal to or greater than the pest-control practice it would replace. Value was calculated by determining any expected yield change plus or minus any change in growers' costs.

Table 2 displays impact estimates for the eight case studies where adoption has occurred. Four of the adopted cultivars resulted in increased yield because they provided more effective control of pests than the control methods they replaced. The other four show a decrease in grower costs, which is represented by a minus sign in the column. When a minus sign is used to indicate reduced costs, the reduction amount is added to the value of the yield to determine net value. Likewise, if grower costs increase, the increase is subtracted to determine net value.

The largest increases in production in 2001 occurred from planting insect resistant corn (3.5 billion pounds) and insect resistant cotton (185 million pounds). Before insect protected crops were developed, cotton growers relied on chemical sprays to control bollworms and budworms. The sprays, which were not as effective as in-plant protection, allowed a sizeable percentage of insects to survive, thereby reducing yield. In corn, the European corn borer and Southwestern corn borer are major pests not controlled readily because the pest tunnels into the stalk. Corn with in-plant protection provides nearly 100 percent season-long control of corn borers, resulting in increased yields.

The greatest economic impact of adopted crops was lower production costs for growers. Herbicide tolerant soybeans provided the greatest savings ($ 1 billion), followed by herbicide tolerant cotton ($ 133 million), and herbicide tolerant corn ($ 58 million). Overall, the adoption of the transgenic cultivars improved growers' bottom lines by $1.5 billion in 2001. The development of herbicide tolerant crops enabled growers to use one herbicide rather than three or four to control weeds. Growers were also able to make fewer trips across their fields, reducing production costs. The introduction of herbicide tolerant crops also resulted in lower overall herbicide costs and savings in hand-weeding costs.

In two instances, pesticide use remained unchanged compared with previous practices. In six of the cases, pesticide use declined. The largest decline was a result of herbicide tolerant soybean (28.7 million pounds) and herbicide tolerant cotton (6.2 million pounds). Overall, U. S. pesticide use was 45.6 million pounds lower in 2001 than it would have been without biotech crops.

Table 3 displays the foregone impact estimates for the four case studies representing biotech cultivars that have been approved for use by the federal government but were not adopted by growers in 2001.

The most significant foregone yield improvement was seen in potato production, where 1 billion pounds of yield loss could have been prevented in 2001 if growers had planted a cultivar that is resistant to insects and viral disease. The potato plants control the Colorado potato beetle, which defoliates potatoes. It also prevents the deadly potato leaf roll virus.

It is anticipated that if these four approved crops had been planted in 2001, U. S. growers would have improved their bottom line by $158 million. The greatest impact would have been in sugarbeet production, where growers must apply three or four different herbicides three to four times per season to kill different weed species.

The four approved but not adopted crops could have lowered pesticide use by 582,800 pounds in 2001 had they been planted. A 1.4 million pound reduction in potato insecticide use would have been somewhat offset by increases in sugarbeet and sweet corn herbicide use. Herbicide tolerant crops almost always reduce the number of herbicide active ingredients that must be applied and the number of applications that must be made. In some cases, the herbicides that are replaced are applied at a lower use rate than herbicides to which the crops have been made resistant.

Table 4 displays the estimates for the impact that could have been realized if 24 cultivars being developed to address current pest problems had been available in 2001. The 24 cultivars combined could have reduced growers' costs by $121 million. Based on data available, there does not appear to be a change in net value for three cultivars, insect resistant eggplant, herbicide resistant lettuce and rootworm resistant corn. However, if growers were to adopt those three cultivars, there would be a pesticide reduction of more than 14 million pounds per year.

Potential increases in production were quantified for fungus resistant barley (1.4 billion pounds), herbicide tolerant wheat (1.4 billion pounds), and herbicide tolerant sugarcane (1.4 billion pounds) because the transgenic cultivars are expected to provide more effective control of pests, which are currently reducing yields. Biotech barley, for example, could control fusarium head blight, which reduces yield by about 25 percent and produces fungal toxins, which decrease the grain value by about 40 percent. Herbicide tolerant wheat could control weeds that decrease yields by about four bushels per acre.

The largest decreases in cost could have resulted from herbicide tolerant rice adoption ($ 49 million) and herbicide tolerant tomato adoption ($ 30 million). Current herbicide options do not control all weeds in rice and tomato fields. As a result, extensive hand weeding, field flooding, tillage and fumigation are required.

The 24 products in development to address current pest issues could have reduced pesticide use in 2001 by a combined 56 million pounds. Significant potential reductions were quantified for fungus resistant potatoes (28 million pounds), herbicide tolerant tomatoes (4.2 million pounds) and nematode resistant pineapples (1.4 million pounds).

In each of those cases, biotech cultivars would enable growers to reduce their use of gas fumigants, which are injected into the soil to control soil-borne diseases, weed seeds and nematodes (microscopic, root-eating organisms). The adoption of rootworm resistant corn would substitute for 14 million pounds of insecticide, while herbicide tolerant rice would lower herbicide use by 3.8 million pounds.

Table 5 displays the potential economic impact estimates for the four cultivars that are under development that have the potential to manage developing or worsening pest problems in the United States. These cultivars have the potential to prevent the spread of crop diseases, which are not yet a serious problem but likely will be in the near future. To quantify their potential impact, it was assumed that expected pests were in fact present in 2001 and had to be managed with existing technology and practices. Projected yields, cost savings and pesticide reduction were calculated.

The impact estimates indicate that the transgenic cultivars could prevent the loss of 2.5 billion pounds of production – mainly citrus crops, which are at risk from viral and bacterial diseases. One such disease, citrus tristeza virus, is spread by an aphid, which has just recently spread from South America to Florida and northern Mexico. It is expected to affect susceptible citrus in Texas soon. Other diseases threaten grapes, plums, peaches and nectarines.

The anticipated lost production from future diseases is valued at $162 million per year. Without the transgenic cultivars, it is expected that growers would spend $161 million per year to manage the pest problems, costs that would be saved with the transgenic cultivars. In total, transgenic crops would prevent anticipated grower losses of approximately $324 million per year.

Without the adoption of the transgenic crops, growers would use an additional 60 million pounds of pesticides per year to manage these pest problems. Costly applications of insecticides and copper bactericides account for nearly all of this.

Table 6 summarizes the economic and pesticide-use impacts according to the status of the transgenic cultivar. The table shows that eight biotech products adopted by growers increased yields by 3.8 billion pounds in 2001, reduced growers' cost by $1.2 billion and cut pesticide use by 45.6 million pounds. Products in development or not yet adopted have potential to add another $1 billion in value to U. S. farmers.

These 40 examples are estimated to have the potential for generating 14 billion more pounds of food and fiber than would otherwise be produced.

The value of the increased production is estimated at $890 million per year with an additional economic benefit based on reduced grower costs. The 40 biotech cultivars could reduce production costs by $1.6 billion annually. On the whole, U. S. growers' bottom lines would increase by $2.5 billion per year with the adoption of these transgenic cultivars.

Pesticide use would be reduced by 163 million pounds with the adoption of these transgenics.

Table 7 shows aggregate impact estimates by type of biotech crop. With the exception of the nematode resistance case study, all of the cultivars have the potential for increasing crop production volume and value as a result of more effective pest control. Estimates of reduced grower costs ($ 1.6 billion) and positive impacts on growers’ net income ($ 2.5 billion) are dominated by savings as a result of herbicide tolerant crops, the bulk of which is due to the adoption of herbicide tolerant soybeans ($ 1 billion). Savings result from the large number of acres where the soybean technology has been adopted (50 million acres). Reduction in the use of pesticides is expected as a result of adoption of all types of biotech cultivars.

Table 8 displays the economic and pesticide use impact estimates by state. Impact estimates have been calculated for 47 states. The states with the highest potential economic impacts as a result of adoption are California and North Dakota. California represents 42 percent of the total potential impact of reduced pesticide use: 66 million pounds. Figures 1-5 display the impacts by state.

8.0 Comparison With Other Studies

Numerous studies of the impacts of biotechnology have been conducted by government agencies, university scientists and advocacy groups. These studies have primarily considered the impacts of currently commercialized traits: Bt field corn, herbicide tolerant soybeans, Bt cotton, and herbicide tolerant corn. The following section of this report compares the impact estimates presented in this report (referred to as the "NCFAP 2002 Study") with impact estimates made in other reports which are significantly different. Reference is also made to earlier impact estimates made by authors of the NCFAP 2002 Study.

Herbicide Tolerant Corn

NCFAP has not previously made estimates for herbicide tolerant corn. The NCFAP 2002 Study estimates the impact of herbicide tolerant corn to be a reduction in herbicide use of 1 lb/A and a reduction in cost of $10/A.

Benbrook calculates an increase in herbicide use of 0.6 million pounds and 1.9 million pounds as a result of planting Roundup Ready corn in 1999 and 2000 respectively [32] [33]. In the NCFAP 2002 Study, a reduction of 5.8 million pounds in herbicide use is attributed to the planting of herbicide tolerant corn in 2001. The primary reason the estimates disagree is due to the calculation of average per acre use rates. Benbrook specifies average herbicide use rates on the Roundup Ready corn acre of 2.47 and 2.73 lbs AI/A in 1999 and 2000 respectively and compares these rates to the average national use rate for corn in 1999 and 2000 of 2.25 and 2.08 lbs AI/A respectively.

The NCFAP 2002 Study estimates the average use rate on an herbicide tolerant corn acre at 2.36 lb AI/A, which is relatively close to Benbrook's assumptions. The NCFAP 2002 Report, however, estimates that the average alternative use rate would be 3.37 lbs AI/A which is considerably higher than the national average rates used by Benbrook. The reason for the higher alternative use rate in the NCFAP 2002 Study is due to the determination that the adopters of the herbicide tolerant technology have particularly tough to control weed problems which require higher use rates in comparison to the national average. Thus, the NCFAP 2002 Study indicates that herbicide tolerant corn growers would need to substitute herbicides that total 1.01 lbs/A more than the herbicide tolerant program to achieve equivalent control of the tough weeds. Benbrook's assumption that they could simply choose herbicide programs equal to the national average is not reasonable.

Herbicide Tolerant Soybean

Previous studies of the impacts of Roundup Ready soybean adoption in the US conducted by authors of the NCFAP 2002 Study estimated aggregate savings to US soybean growers in 1998-2000 of $216 - 307 million /yr. [37] [38]. The NCFAP 2002 Study estimates the economic impact of Roundup Ready soybeans to be $1.0 billion/yr. The earlier studies included only one component of cost savings that could be attributed to the adoption of Roundup Ready soybeans—reduced herbicide costs as measured from expenditures in a year prior to adoption. Recent surveys have indicated that Roundup Ready soybean growers are making fewer herbicide application trips and cultivating fewer times. A conservative accounting of the savings from making fewer trips ($385 million/yr) is presented in detail in Section 26 of this report, the herbicide tolerant soybean case study.

The methodology for estimating the impacts of Roundup Ready soybean adoption has changed in the NCFAP 2002 Study. NCFAP is no longer estimating changes from a year prior to their introduction because the effectiveness of previously-used herbicides has deteriorated in the past few years due to increasing problems of weed resistance and because of the introduction of herbicide products equally effective as Roundup. Thus, the premise of the NCFAP 2002 Study is that the value of Roundup Ready soybeans is most fairly assessed by simulating what replacements would have been used in 2001, and not by simply looking at what products were used before.

The NCFAP 2002 Study estimates that the primary impact of the Roundup Ready herbicide tolerant soybean in the US is a reduction of $20/A in weed control costs. Several other studies have estimated the difference in weed control costs between Roundup Ready and non-Roundup Ready acres to be $0/A, $3.50/A, and $6-11/A [39], [43], [42]. These other studies are based on surveys of farmers in particular years and compare the weed control costs as reported and do not capture differences in weed presence or account for the ease of weed management.

The surveys do not collect any information on weed infestations. As a result, no inference can be made that the Roundup Ready acre could simply be switched to the treatment used on the non-Roundup Ready acre with no loss in weed control effectiveness. It may be that the non-Roundup Ready acre has relatively mild weed infestation problems that can be managed with inexpensive alternative programs. The Roundup Ready soybean acre may be infested with weed species that are resistant to conventional herbicides and, as a result, could not simply be treated with the same herbicides as the non-Roundup Ready acre for equivalent control. Benbrook does note that Roundup Ready soybeans have been especially popular on problem fields where weeds have proven tough to manage [32].

The surveys indicate that the non-Roundup Ready acres receive more herbicide treatment trips and cultivation trips than the Roundup Ready acres [39]. One of the advantages of the Roundup Ready program is its simplicity and the reduction in herbicide application and cultivation trips. Several of these studies acknowledge that their methodology does not capture the value that soybean farmers assign to the Roundup Ready technology due to ease of weed management [48] [39]. The NCFAP 2002 Study simulates alternative herbicide programs for the Roundup Ready acreage that are as effective as Roundup on all troublesome weeds and which would not require additional herbicide or cultivation trips. The average cost increase associated with these alternative programs is $20/A. This estimate is a fairer measure of the value of the Roundup Ready program because it preserves the simplicity and ease of management characteristics of the Roundup Ready program as well as maintaining effective control of all troublesome weed species. Studies that suggest that Roundup Ready acres could simply be switched to the weed control programs used on non-Roundup Ready acres at a minimal cost increase with no loss in yields have not preserved the management advantages of the Roundup Ready system nor do they assure equivalent weed control.

Previous NCFAP studies concluded that the Roundup Ready technology had not resulted in a reduction in pounds of herbicides applied based on an analysis of pesticide use surveys. NCFAP has changed its methodology in the NCFAP 2002 Study because the comparison of herbicide use rates does not compensate for other changes that soybean growers have made – particularly in reduced tillage operations for weed control. The NCFAP 2002 Study simulates the likely rate of herbicide use without Roundup Ready soybean and without a return to cultivation which would require an increase of .57 lbs/A of herbicide use.

Benbrook reports that an analysis of 1998 pesticide use survey data indicates that Roundup Ready soybean acreage received 1.22 lbs AI/A in comparison to 1.08 lbs AI/A for conventional acreage [35]. Benbrook indicates that conventional growers are relying on low-rate herbicides and concludes that farmers could "easily" reduce herbicide application by .5lb AI/A by moving away from Roundup Ready soybeans to use of low rate herbicides. In contrast, the NCFAP 2002 Study indicates that the Roundup Ready acre is treated on average with .57 lbs less than an acre treated with an equally-effective herbicide program. The NCFAP 2002 Study indicates that the low rate herbicides cannot be relied on by themselves for effective control of the commonly troublesome weeds in most states because of the widespread extent of resistant weed populations including kochia, waterhemp, Russian thistle, common cocklebur, shattercane, and giant ragweed. Although Benbrook acknowledges this weakness with the low rate herbicides, he still suggests that they could be replacements for Roundup [32].

Most of the weed scientists who specified alternative weed control programs used in the NCFAP 2002 Study included a combination of 3-4 active ingredients including low rate herbicides in addition to higher rate herbicides with alternative modes of action for management of resistant weed species. (See section 26 of this report). Benbrook provides no analysis of the effectiveness ratings of the herbicide programs that he specifies as low rate alternatives. It may be that growers who are not utilizing the Roundup Ready program do not have resistant weed populations and can still use the low rate compounds or they may be compensating by making additional cultivation trips or repeated herbicide applications—practices that have been reduced on the Roundup Ready acres.

Bt Field Corn

Earlier reports by authors of the NCFAP 2002 Study estimated aggregate economic and pesticide use impacts of Bt corn adoption in the US 1997-1999 [37] [44]. The earlier studies estimated positive economic impacts in 1997 (+ $89 million) and losses in 1998-1999 (-$26, - $35 million) based on populations of the European corn borer in the Midwest. Those studies estimated that a reduction in insecticide use from prior years occurred as a result of growers planting Bt corn. The earlier studies estimated the cost premium of Bt corn to be $10/A (97) and $8/A (98/99).

The NCFAP 2002 Study differs from the earlier studies in several ways. The NCFAP 2002 Study estimates the value of Bt corn for a “typical” year which is based on a frequency distribution of low and high infestation years for corn borer infestations. Positive economic impacts are calculated for all states for the “typical” year. The NCFAP 2002 Study moves away from estimating the impacts in the specific years 1997-2001 because very unusual changes in the populations of the European corn borer (ECB) in the Midwest in those years distort the evaluation. Specifically, ECB populations were extremely low in the years 1998-2000 due to unusual environmental conditions. (A detailed analysis of these environmental conditions is provided in Section 28 of this report – the case study on insect resistant field corn).

A simulation of the impacts of Bt corn in a “typical” year is a fairer assessment of the value of the technology. NCFAP’s 2002 Study also includes an explicit consideration of the value of Bt corn in managing the southwestern corn borer (SWCB), which was not included in its earlier reports. The SWCB is not subject to the same population shifts as the ECB and also is much more damaging to corn than the ECB. The NCFAP 2002 Study uses a lower cost premium for the Bt corn technology than previously assumed: $6.50/A.

The insecticide use impacts in the 2002 NCFAP Study are based on a simulation of the rates that would be used in a typical year instead of attempting to measure changes from insecticide use patterns before the technology was introduced. This methodological change was made for two reasons; (1) the survey data quantifying insecticide use for corn borer control prior to and following the introduction of Bt corn are imprecise and incomplete, requiring numerous assumptions for evaluation purposes (the survey data do not identify target pests); and (2) in the absence of Bt corn, farmers are unlikely to return to the application levels prior to its introduction because they have seen the yield impacts that result from controlling corn borers and would be likely to take the pest more seriously and apply insecticides more frequently than in prior years. Thus, the NCFAP 2002 Study is based on the premise that a fairer indication of the likely impacts of Bt corn on insecticide use amounts is to simulate the likely insecticide use patterns that would occur in its absence. The NCFAP 2002 Study indicates that insecticide use would deliver positive economic value in years of high infestation. By simulating insecticide use in high infestation years, the NCFAP 2002 Study actually reduces the magnitude of the positive impact of Bt corn on corn yields in comparison to other studies which simply estimate the yield value of Bt corn in comparison to an untreated condition. NCFAP's 2002 Study estimates the value of Bt corn in a typical year to be $125 million with an associated reduction of 2.6 million pounds in insecticide use.

The NCFAP 2002 Study can be directly compared to a recent EPA analysis which estimated the net value of Bt corn in a low infestation year ($38 million) and a high infestation year ($219 million) [41]. (EPA does not weight the estimates to arrive at an estimate for a typical year). EPA uses a higher Bt corn price premium in its calculations ($8/A) and does not explicitly account for the impacts of SWCB. The EPA estimates compare the value of Bt corn to an untreated condition and no adjustment is made to account for likely insecticide use by farmers, which would result in lower value for Bt corn in high infestation years. Thus, the EPA value for Bt corn in a 'high' infestation year is greater than what the NCFAP 2002 Study estimates ($219 vs $183million) because NCFAP accounts for the yield loss prevented by insecticide use.

Benbrook has presented an analysis of the impacts of Bt corn for the years 1996-2001 [34]. Benbrook projects the cost premium for Bt corn at $9 – 10/A, which is higher than the premium used in the NCFAP 2002 Study ($6.50/A) or the EPA analysis ($8). As a result, Benbrook overstates the cost of the technology which, in turn, reduces the net benefit estimate. The methodologies used by Benbrook and NCFAP in arriving at these Bt corn price premiums are discussed in the case study on insect resistant field corn. (See Table 28-APP-01). As a result of the unusually low ECB population levels in 1998-2000, Benbrook calculates negative aggregate values for those years (-$76, -$67, and -$68 million respectively). For 1996, 1997 and 2001 Benbrook calculates positive aggregate values for Bt corn ($19, $7, and $93 million respectively). The NCFAP 2002 Study, similar to EPA's analysis, does not rely on specific yearly data as Benbrook does since the unusually low years 1998-2000 distort the assessment.

While Benbrook acknowledges that one reason that farmers prefer Bt corn is that the alternative is insecticide use, he does not simulate the use of insecticides as an alternative, preferring to compare Bt corn to an untreated condition and preferring to try and measure changes in pesticide use from the years prior to Bt corn's introduction. Benbrook claims that insecticide use for ECB control actually increased following the introduction of Bt corn – a finding that has been challenged by University scientists. This "finding" illustrates the pitfall of trying to use available use surveys that do not identify target pests. The increase in certain insecticides in corn in recent years is attributable to other pests, not ECB. The NCFAP 2002 Study makes clear that in high infestation years that the alternative to Bt corn is insecticide use.

Duffy has reported on survey results regarding Bt corn impacts in Iowa in 1998 and 2000 [39] [40]. Duffy concludes that Bt corn produced a return essentially equal to non-Bt corn. For 1998, Duffy reports that Bt corn resulted in a 13 bushel/A increase in corn yield resulting in an increase in income of $24.70/A. However, Duffy reduces this advantage by netting out higher seed costs for Bt corn ($9.66/A), and by subtracting other costs which were higher on the Bt corn acreage (fertilizer, weed control) and arrives at a per acre advantage of Bt corn of $3.97. Duffy follows the same methodology in reporting the results for 2000. The Bt corn yield advantage is calculated at 3 bushels/acre valued at $6/A, and the Bt price premium is estimated at $4.31/A. Higher costs for other inputs on the Bt corn acre (fertilizer) reduces the economic advantage of Bt corn to a negative $3.26/A.

By not controlling for factors unrelated to Bt corn, the Duffy analysis does not isolate the impacts of Bt corn. For example, higher fertilizer use on Bt corn acreage may account for higher yields as well as higher costs. As Duffy points out, there is no inherent production reason why fertilizer use should be higher on Bt corn acreage [39].

Purdue researchers have conducted analyses of Bt corn, for Indiana and other states. In an analysis of the benefits of Bt field corn for Indiana growers, they found that, on average, the expected value of yield increases resulting from the adoption of Bt field corn varieties was not sufficient to pay for the additional seed cost [31]. Indeed, the NCFAP 2002 Study also indicates low ECB pressure, and low predicted adoption of Bt corn in Indiana (6%). The NCFAP 2002 Study estimates positive benefits to Indiana growers in areas where pest pressure is highest.

In a later study by the same Purdue researchers, estimated benefits were calculated for growers in several states, including Indiana, Illinois, Iowa and Kansas. This study suggested that the value of Bt corn increases from east to west across the U.S. Corn Belt, due to generally higher infestations and the presence of the SWCB in the western states [36]. This finding is also in agreement with the NCFAP 2002 Study.

Bt Cotton

There is general agreement that cotton insecticide use has declined in the past 10 years. Previously-issued reports that have estimated the impact of Bt cotton on insecticide use amounts have relied on comparing the use levels of insecticides targeted at the bollworm/budworm complex in years before and after the adoption of Bt cotton. This methodology was used in previous studies by authors of the NCFAP 2002 study who estimated reductions in pesticide use amounts of 2.0 and 2.7 million pounds in 1998 and 1999 attributable to Bt cotton [44] [37].

Benbrook agrees that Bt cotton has contributed to the reduction in cotton insecticide use but argues that some of the reduction is due to the Boll Weevil Eradication Program (BWEP) [32].

The NCFAP 2002 Study uses a different methodology, which results in an estimated reduction of 1.87 million lbs of insecticide use in 2001 attributable to Bt cotton. The NCFAP 2002 Study methodology relies on data that compares insecticide use patterns of adopters vs. non-adopters of Bt cotton on a state-Bt-state basis in a current year. This methodology eliminates the lack of precision of comparing insecticide use patterns between two time periods during which time a key pest (the boll weevil) has been eliminated from several states. The elimination of the boll weevil means that even non-Bt cotton acres do not have to be sprayed as often as before for bollworms/budworms due to the elimination of boll weevil sprays which have negative effects on predators of the budworms/bollworms. On the other hand, the NCFAP 2002 Study estimates significant use reductions attributable to Bt cotton in states with ongoing BWEP due to the increase in sprays for the boll weevil, which in turn makes it more difficulty to control the bollworms/budworms. In these states, growers have been advised to plant Bt cotton (and they have done so) in order to reduce the need to spray for budworm/bollworm outbreaks caused by the increased boll weevil sprays.

By comparing adopters and non-adopters of Bt cotton in a current year, the NCFAP 2002 Study reflects not only current adoption levels, but also current pest infestation levels and eradication programs which have changed dramatically since the mid-1990’s.

EPA estimates that two fewer insecticide applications are being made per acre as a result of the adoption of Bt cotton. EPA estimates aggregate net benefits to growers of between $60 and $126 million per year [41]. The NCFAP 2002 study estimates the net benefits of Bt cotton at $103 million per year.

9.0 Conclusions

The examination of 40 case studies of biotechnology applied to pest management in agriculture demonstrates that biotechnology is having and can continue to have significant impact on improved yields, reduced grower costs and pesticide reduction.

If growers adopt all of the cultivars examined in this study, the total net economic impact would be $2.5 billion per year, an annual increase in production of 14 billion pounds and a pesticide reduction of 163 million pounds per year.

Eight currently adopted cultivars are having a significant impact, primarily in major commodity crops. Combined, they are reducing pesticide use by 46 million pounds per year, increasing yield by 4 billion pounds per year and providing a net economic impact of $1.5 billion per year.

Thirty-two additional cultivars, either not yet fully developed or not yet adopted, will extend similar impact to other crops. Their potential is as follows: increased production of 10 billion pounds per year, net economic impact of $1 billion per year and an annual pesticide-use reduction of 117 million pounds.

Current cultivars primarily address weed control and insect control. The next wave of cultivars will greatly extend biotechnology into the control and prevention of crop diseases.

Every cultivar examined for this report has potential to significantly impact pest control; either through pesticide reduction, increased yield or reduced cost. Each cultivar provides value equal to or greater than the pest-control practice it would replace.

Every state examined for this report would realize economic benefits from the adoption of one or more cultivars.

Table 2: Impact of Biotech Crops Adopted and Planted in 2001

Case Study	Crop	Type	**Production** (per year)			Total Net Value (000$/yr)	Pesticide Use (lbs AI/yr.)	Acreage
			Volume (000lb.)	**Value (000$)**	**Costs (000$)**			
1	Papaya	VR	+53,000	+17,000	0	+17,000	0	1,600
2	Squash	VR	+6,000	+2,000	+375	+1,625	0	5,000
24	Canola	HT	0	0	-11,000	+11,000	-531,000	871,000
26	Soybean	HT	0	0	-1,010,765	+1,010,765	-28,703,001	50,016,000
28	Field Corn	IR (1)	+3,540,992	+126,466	+1,110	+125,356	-2,603,456	14,927,000
31	Field Corn	HT	0	0	-58,050	+58,050	-5,805,000	5,805,000
32	Cotton	IR (1)	+185,373	+115,002	+12,034	+102,968	-1,870,100	5,144,000
34	Cotton	HT	0	0	-132,676	+132,676	-6,169,000	9,301,000
Total			**+3,785,365**	**+260,468**	**-1,198,972**	**+1,459,440**	**-45,681,557**	

Table 3: Potential Impact of Biotech Crops Approved but Not Adopted in 2001

Case Study	Crop	Type	Production (per year)			Total (000$/yr)	Pesticide Use (lbs AI/yr.)	Acreage
			Volume (000lb.)	**Value (000$)**	**Costs (000$)**			
13	Sweet Corn	IR	+22,000	+3,900	-1,300	+5,200	-112,000	32,000
14	Sweet Corn	HT	+72,000	+2,400	+1,400	+1,000	+16,200	30,000
17	Potato	IR/VR	+1,000,000	+52,000	-6,700	+58,700	-1,450,000	621,000
20	Sugarbeet	HT	0	0	-93,300	+93,300	+963,000	1,500,000
Total			**+1,094,000**	**+58,300**	**-99,900**	**+158,200**	**-582,800**	

Table 4: Potential Impact of Biotech Crops Under Development for Current Pest Problems

Case Study	Crop	Type	Production (per year)			Total (000$/yr)	Pesticide Use (lbs AI/yr.)	Acreage
			Volume (000lb.)	**Value (000$)**	**Costs (000$)**			
3	Peanut	VR	+59,000	+17,000	0	+17,000	0	540,000
4	Peanut	IR	0	+900	-600	+1,500	-47,520	540,000
5	Tomato	VR	0	0	-4,200	+4,200	-64,600	42,000
6	Tomato	HT	0	0	-30,000	+30,000	-4,200,000	289,000
7	Lettuce	HT	0	0	0	0	-140,000	214,000
8	Strawberry	HT	0	0	-1,265	+1,265	-13,851	5,200
9	Pineapple	NR	0	0	-2,100	+2,100	-1,427,790	21,000
10	Broccoli	IR	+3,400	+1,200	-2,659	+3,859	-11,623	82,000
16	Raspberry	VR	+10,000	+11,200	-2,500	+13,700	-371,000	7,600
18	Potato	FR	0	0	-18,000	+18,000	-28,400,000	621,000
19	Potato	HT	+521,640	+26,000	+20,000	+6,000	+465,000	621,000
22	Apple	BR	+251,000	+35,600	-2,794	+38,394	-21,800	204,175
23	Sunflower	FR	+260,000	+17,200	+4,780	+12,420	0	2,390,000
25	Soybean	IR	+54,000	+4,400	-2,400	+6,800	-295,000	1,280,000
27	Rice	HT	0	0	-49,168	+49,168	-3,828,000	943,000
29	Field Corn	IR (2)	+725,648	+25,796	+6,323	+19,473	-237,435	2,575,000
30	Field Corn	IR (3)	0	0	0	0	-14,496,000	23,402,000
33	Cotton	IR (2)	+37,454	+22,468	-23,908	+46,376	-986,655	5,144,000
35	Alfalfa	HT	0	+21,000	+3,400	+17,600	+200,000	1,000,000
36	Barley	FR	+1,440,000	+100,000	-360	+100,360	-4,500	3,000,000
37	Wheat	HT	+1,416,000	+70,800	0	+70,800	0	5,900,000
38	Wheat	VR	+913,920	+38,895	-828	+39,723	-82,800	4,600,000
39	Eggplant	IR	0	0	0	0	-208	800
40	Sugarcane	HT	+1,400,000	+16,000	-15,200	+31,200	-1,800,000	460,000
Total			**+7,092,062**	**+408,459**	**-121,479**	**+529,938**	**-55,763,782**	

Table 5:	**Potential Impact of Biotech Crops Under Development for Future Pest Problems**							
Case Study	Crop	Type	**Production** (per year)			Total (000$/yr)	Pesticide Use (lbs AI/yr.)	Acreage
			Volume (000lb.)	**Value (000$)**	**Costs (000$)**			
11	Citrus	VR	+904,000	+48,000	0	+48,000	0	30,000
12	Citrus	BR	+1,560,000	+97,650	-56,700	+154,350	-1,638,000	762,000
15	Stone Fruit	VR	+60,000	+17,000	0	+17,000	0	7,200
21	Grape	BR	0	0	-105,000	+105,000	-59,000,000	790,000
Total			**+2,524,000**	**+162,650**	**-161,700**	**+324,350**	**-60,638,000**	

Table 6:	**Total Impact of Biotech Crops by Status**				
Status	**Production (per year)**			**Total Net Value (000 $)**	**Pesticide Use (lbs AI/yr.)**
	Volume (000 lbs.)	**Value (000 $)**	**Cost (000 $)**		
Adopted	+3,785,365	+260,468	-1,198,972	+1,459,440	-45,681,557
Approved but not adopted	+1,094,000	+58,300	-99,900	+158,200	-582,800
Under development for current pest problems	+7,092,062	+480,459	-121,479	+529,938	-55,763,782
Under development for future pest problems	+2,524,000	+162,650	-161,700	+324,350	-60,638,000
Total	**+14,495,427**	**+889,877**	**-1,582,051**	**+2,471,928**	**-162,666,139**

Table 7:	**Total Impact of Biotech Crops by Type**				
Type	**Production (per year)**			**Total (000 $)**	**Pesticide Use (lbs AI/yr.)**
	Volume (000 lbs.)	**Value (000 $)**	**Cost (000 $)**		
Insect Resistant	+5,568,867	+352,132	-18,100	+370,232	-22,109,997
Herbicide Tolerant	+3,409,640	+136,200	-1,376,624	+1,512,824	-49,545,652
Virus Resistant	+2,005,920	+151,095	-7,153	+158,248	-518,400
Fungus Resistant	+1,700,000	+117,200	-13,580	+130,780	-28,404,500
Bacteria Resistant	+1,811,000	+133,250	-164,494	+297,744	-60,659,800
Nematode Resistant	0	0	-2,100	+2,100	-1,427,790
Total	**+14,495,427**	**+889,877**	**-1,582,051**	**+2,471,928**	**-162,666,139**

Table 8: Total Impact of Biotech Crops by State

State	Volume (000lb)	Value (000$)	Costs (000$)	Total (000$/yr)	Pesticide Use (lbs AI/yr)
AL	10381	5120	-7155	12275	-736521
AR	31689	8583	-74670	83253	-2908744
AZ	19512	10222	-1024	11246	-64404
CA	29209	28076	-178454	206530	-65830119
CO	46144	1647	-2571	4218	-328980
CT	728	26	-100	126	-4687
DE	10640	381	-4860	5241	-199930
FL	1586486	103590	-63953	167543	-2040540
GA	85069	28652	-12375	41027	-1929948
HI	53000	17000	-2100	19100	-1427790
IA	628992	22464	-161233	183697	-8302180
ID	1099690	55587	-25152	80739	-18853784
IL	241248	8616	-126014	134630	-8898870
IN	85792	3064	-146660	149724	-8322368
KS	567456	20960	-31788	52748	-1878760
KY	41216	1471	-13179	14650	-559400
LA	1480783	21385	-75984	97369	-4741754
MA	2280	410	-198	608	-5906
MD	39920	1490	-12719	14209	-342995
ME	0	0	-103	103	-1126
MI	61752	3735	-31964	35699	-827940
MN	578848	23517	-132723	156240	-5145888
MO	209909	10121	-71787	81908	-3485579
MS	212930	39513	-46664	86177	-2559255
MT	312000	15600	-4900	20500	37000
NC	21680	7999	-34804	42803	-1881958
ND	2410920	150989	-33801	184790	-86732
NE	487592	17414	-36245	53659	-3020542
NH	0	0	-43	43	-466
NJ	6264	288	-1537	1825	-58770
NM	10397	1841	127	1714	-18906
NY	35200	3651	-3821	7471	-516074
OH	300536	11163	-93170	104333	-4379922
OK	41259	8689	672	8017	143605
OR	431547	24254	-3815	28069	-8035040
PA	109288	19696	-9509	29205	-591598
SC	16171	4642	-12995	17638	-133216
SD	518480	22560	-51667	74227	291444
TN	54768	14378	-23564	37942	-932898
TX	1427348	94367	-14820	109187	-761132
UT	0	0	-70	70	-7000
VA	13052	1934	-3644	5578	145020
VT	560	21	-83	104	-5210
WA	1045323	70154	-5969	76123	-2999276
WI	125200	4301	-21995	26296	-512106
WV	4168	306	-138	444	8106
WY	0	0	-2830	2830	47000

Table 9 Potential Impacts of Biotech Crops by State

Case #	*Crop*	*Type*	*State*	*Production (per year)*			*Total (000$/yr)*	*Pesticide Use (lbs AI/yr)*
				Volume (000lb)	*Value (000$)*	*Costs (000$)*		
33	Cotton	IR (2)	AL	1,833	1,099	540	559	-4,211
32	Cotton	IR (1)	AL	5,848	3,801	2,893	908	-43,000
34	Cotton	HT	AL	0	0	-7,740	7,740	-590,000
28	Field Corn	IR (1)	AL	0	0	0	0	0
25	Soybean	IR	AL	2,700	220	-120	340	-14,750
26	Soybean	HT	AL	0	0	-2,728	2,728	-84,560
33	Cotton	IR (2)	AR	4,323	2,594	-6,078	8,672	-164,354
34	Cotton	HT	AR	0	0	-18,422	18,422	-960,000
32	Cotton	IR (1)	AR	8,550	5,318	-1,682	7,000	-142,000
28	Field Corn	IR (1)	AR	18,816	671	-31	702	-11,590
31	Field Corn	HT	AR	0	0	-240	240	-24,000
27	Rice	HT	AR	0	0	-294	294	-42,000
26	Soybean	HT	AR	0	0	-47,923	47,923	-1,564,800
34	Cotton	HT	AZ	0	0	-2,437	2,437	29,000
32	Cotton	IR (1)	AZ	16,524	9,882	1,249	8,633	-81,000
33	Cotton	IR (2)	AZ	412	247	238	9	-3,884
28	Field Corn	IR (1)	AZ	2,576	93	-4	97	-1,520
31	Field Corn	HT	AZ	0	0	-70	70	-7,000
35	Alfalfa	HT	CA	0	21,000	3,400	17,600	200,000
22	Apple	BR	CA	21,000	3,000	-189	3,189	-1,400
10	Broccoli	IR	CA	3,400	1,200	-2,659	3,859	-11,623
32	Cotton	IR (1)	CA	4,692	2,806	355	2,451	-23,000
34	Cotton	HT	CA	0	0	-14,895	14,895	368,000
33	Cotton	IR (2)	CA	117	70	63	7	-1,096
31	Field Corn	HT	CA	0	0	-300	300	-30,000
21	Grape	BR	CA	0	0	-105,000	105,000	-59,000,000
07	Lettuce	HT	CA	0	0	0	0	-140,000

Case #	Crop	Type	State	Production (per year)			Total (000$/yr)	Pesticide Use (lbs AI/yr)
				Volume (000lb)	Value (000$)	Costs (000$)		
27	Rice	HT	CA	0	0	-25,529	25,529	-3,048,000
20	Sugarbeet	HT	CA	0	0	-3,700	3,700	57,000
06	Tomato	HT	CA	0	0	-30,000	30,000	-4,200,000
31	Field Corn	HT	CO	0	0	-1,300	1,300	-130,000
28	Field Corn	IR (1)	CO	46,144	1,647	-71	1,718	-26,980
30	Field Corn	IR (3)	CO	0	0	0	0	-239,000
20	Sugarbeet	HT	CO	0	0	-1,200	1,200	67,000
28	Field Corn	IR (1)	CT	728	26	-3	29	-950
31	Field Corn	HT	CT	0	0	-30	30	-3,000
08	Strawberry	HT	CT	0	0	-67	67	-737
28	Field Corn	IR (1)	DE	10,640	381	-31	412	-11,780
31	Field Corn	HT	DE	0	0	-190	190	-19,000
26	Soybean	HT	DE	0	0	-4,639	4,639	-169,150
12	Citrus	BR	FL	1,560,000	97,650	-56,700	154,350	-1,638,000
34	Cotton	HT	FL	0	0	-2,590	2,590	-208,000
33	Cotton	IR (2)	FL	426	256	142	114	-500
32	Cotton	IR (1)	FL	1,360	884	673	211	-10,000
26	Soybean	HT	FL	0	0	-147	147	-7,440
02	Squash	VR	FL	2,700	900	169	731	0
13	Sweet Corn	IR	FL	22,000	3,900	-1,300	5,200	-112,000
05	Tomato	VR	FL	0	0	-4,200	4,200	-64,600
32	Cotton	IR (1)	GA	11,016	7,160	5,449	1,711	-81,000
33	Cotton	IR (2)	GA	3,453	2,072	-635	2,707	-51,498
34	Cotton	HT	GA	0	0	-15,223	15,223	-1,650,000
28	Field Corn	IR (1)	GA	3,976	142	77	65	-570
29	Field Corn	IR (2)	GA	1,624	58	44	14	-5,250
03	Peanut	VR	GA	59,000	17,000	0	17,000	0
04	Peanut	IR	GA	0	900	-600	1,500	-47,520
25	Soybean	IR	GA	2,700	220	-120	340	-14,750

Case #	Crop	Type	State	Production (per year)			Total (000$/yr)	Pesticide Use (lbs AI/yr)
				Volume (000lb)	Value (000$)	Costs (000$)		
26	Soybean	HT	GA	0	0	-1,573	1,573	-79,360
02	Squash	VR	GA	3,300	1,100	206	894	0
01	Papaya	VR	HI	53,000	17,000	0	17,000	0
09	Pineapple	NR	HI	0	0	-2,100	2,100	-1,427,790
28	Field Corn	IR (1)	IA	628,992	22,464	-1,560	24,024	-592,800
31	Field Corn	HT	IA	0	0	-9,600	9,600	-960,000
30	Field Corn	IR (3)	IA	0	0	0	0	-1,643,000
26	Soybean	HT	IA	0	0	-150,073	150,073	-5,106,380
22	Apple	BR	ID	2,000	300	-22	322	-200
31	Field Corn	HT	ID	0	0	-90	90	-9,000
18	Potato	FR	ID	0	0	-11,520	11,520	-18,176,000
17	Potato	IR/VR	ID	640,000	33,280	-4,288	37,568	-928,000
19	Potato	HT	ID	333,850	16,640	12,800	3,840	297,600
20	Sugarbeet	HT	ID	0	0	-21,800	21,800	-15,000
38	Wheat	VR	ID	123,840	5,367	-232	5,599	-23,184
30	Field Corn	IR (3)	IL	0	0	0	0	-3,179,000
28	Field Corn	IR (1)	IL	241,248	8,616	-718	9,334	-272,840
29	Field Corn	IR (2)	IL	0	0	-332	332	-33,150
31	Field Corn	HT	IL	0	0	-3,310	3,310	-331,000
26	Soybean	HT	IL	0	0	-121,654	121,654	-5,082,880
28	Field Corn	IR (1)	IN	85,792	3,064	2,165	899	0
30	Field Corn	IR (3)	IN	0	0	0	0	-2,358,000
31	Field Corn	HT	IN	0	0	-3,330	3,330	-333,000
29	Field Corn	IR (2)	IN	0	0	-416	416	-41,625
26	Soybean	HT	IN	0	0	-145,079	145,079	-5,589,743
31	Field Corn	HT	KS	0	0	-3,840	3,840	-384,000
28	Field Corn	IR (1)	KS	314,496	11,232	-432	11,664	-164,160
30	Field Corn	IR (3)	KS	0	0	0	0	-339,000
29	Field Corn	IR (2)	KS	232,960	8,528	2,624	5,904	-9,600

Case #	Crop	Type	State	Production (per year)			Total (000$/yr)	Pesticide Use (lbs AI/yr)
				Volume (000lb)	Value (000$)	Costs (000$)		
26	Soybean	HT	KS	0	0	-30,580	30,580	-982,000
23	Sunflower	FR	KS	20,000	1,200	440	760	0
31	Field Corn	HT	KY	0	0	-250	250	-25,000
29	Field Corn	IR (2)	KY	0	0	-369	369	-36,900
28	Field Corn	IR (1)	KY	41,216	1,471	-123	1,594	-46,740
26	Soybean	HT	KY	0	0	-12,437	12,437	-450,760
33	Cotton	IR (2)	LA	4,270	2,561	-5,655	8,216	-286,725
34	Cotton	HT	LA	0	0	-11,612	11,612	-1,065,000
32	Cotton	IR (1)	LA	-563	-338	-7,206	6,868	-478,000
28	Field Corn	IR (1)	LA	14,448	515	129	386	-6,384
29	Field Corn	IR (2)	LA	48,048	1,459	463	996	-16,650
27	Rice	HT	LA	0	0	-20,880	20,880	-583,000
25	Soybean	IR	LA	14,580	1,188	-648	1,836	-79,650
26	Soybean	HT	LA	0	0	-15,375	15,375	-426,345
40	Sugarcane	HT	LA	1,400,000	16,000	-15,200	31,200	-1,800,000
22	Apple	BR	MA	2,000	400	-54	454	-400
31	Field Corn	HT	MA	0	0	-40	40	-4,000
28	Field Corn	IR (1)	MA	280	10	-1	11	-380
08	Strawberry	HT	MA	0	0	-103	103	-1,126
22	Apple	BR	MD	1,000	100	-27	127	-200
31	Field Corn	HT	MD	0	0	-400	400	-40,000
30	Field Corn	IR (3)	MD	0	0	0	0	-59,000
28	Field Corn	IR (1)	MD	38,920	1,390	91	1,299	-15,352
26	Soybean	HT	MD	0	0	-12,294	12,294	-227,465
08	Strawberry	HT	MD	0	0	-89	89	-978
08	Strawberry	HT	ME	0	0	-103	103	-1,126
22	Apple	BR	MI	30,000	2,600	-827	3,427	-6,500
30	Field Corn	IR (3)	MI	0	0	0	0	-517,000
31	Field Corn	HT	MI	0	0	-1,580	1,580	-158,000

Case #	Crop	Type	State	Production (per year)			Total (000$/yr)	Pesticide Use (lbs AI/yr)
				Volume (000lb)	Value (000$)	Costs (000$)		
28	Field Corn	IR (1)	MI	31,752	1,135	-650	1,785	-52,402
26	Soybean	HT	MI	0	0	-21,607	21,607	-238,038
20	Sugarbeet	HT	MI	0	0	-7,300	7,300	144,000
28	Field Corn	IR (1)	MN	400,848	14,317	1,723	12,594	-290,928
30	Field Corn	IR (3)	MN	0	0	0	0	-609,000
31	Field Corn	HT	MN	0	0	-7,260	7,260	-726,000
26	Soybean	HT	MN	0	0	-97,466	97,466	-3,895,960
20	Sugarbeet	HT	MN	0	0	-29,900	29,900	376,000
23	Sunflower	FR	MN	10,000	800	180	620	0
37	Wheat	HT	MN	168,000	8,400	0	8,400	0
22	Apple	BR	MO	1,000	200	-108	308	-800
34	Cotton	HT	MO	0	0	-8,016	8,016	-200,000
33	Cotton	IR (2)	MO	661	396	129	267	-1,519
32	Cotton	IR (1)	MO	3,400	2,210	1,435	775	-8,500
29	Field Corn	IR (2)	MO	0	0	-914	914	-91,410
30	Field Corn	IR (3)	MO	0	0	0	0	-290,000
28	Field Corn	IR (1)	MO	204,848	7,315	-333	7,648	-126,350
31	Field Corn	HT	MO	0	0	-2,770	2,770	-277,000
27	Rice	HT	MO	0	0	-525	525	-75,000
26	Soybean	HT	MO	0	0	-60,685	60,685	-2,415,000
32	Cotton	IR (1)	MS	47,104	28,211	-1,546	29,757	-512,000
33	Cotton	IR (2)	MS	7,766	4,659	-5,782	10,441	-195,380
34	Cotton	HT	MS	0	0	-18,238	18,238	-1,170,000
28	Field Corn	IR (1)	MS	12,992	464	377	87	0
29	Field Corn	IR (2)	MS	118,608	4,023	1,800	2,223	0
27	Rice	HT	MS	0	0	-50	50	-5,000
26	Soybean	HT	MS	0	0	-22,049	22,049	-532,325
25	Soybean	IR	MS	26,460	2,156	-1,176	3,332	-144,550
20	Sugarbeet	HT	MT	0	0	-4,900	4,900	37,000

Case #	Crop	Type	State	Production (per year)			Total (000$/yr)	Pesticide Use (lbs AI/yr)
				Volume (000lb)	Value (000$)	Costs (000$)		
37	Wheat	HT	MT	312,000	15,600	0	15,600	0
22	Apple	BR	NC	5,000	600	-121	721	-900
34	Cotton	HT	NC	0	0	-11,157	11,157	-744,000
32	Cotton	IR (1)	NC	6,822	4,264	735	3,529	-170,000
33	Cotton	IR (2)	NC	4,930	2,958	-1,428	4,386	-66,250
31	Field Corn	HT	NC	0	0	-460	460	-46,000
28	Field Corn	IR (1)	NC	4,928	177	-150	327	-9,728
26	Soybean	HT	NC	0	0	-22,223	22,223	-845,080
36	Barley	FR	ND	1,440,000	100,000	-360	100,360	-4,500
24	Canola	HT	ND	0	0	-11,000	11,000	-531,000
30	Field Corn	IR (3)	ND	0	0	0	0	-154,000
31	Field Corn	HT	ND	0	0	-1,860	1,860	-186,000
28	Field Corn	IR (1)	ND	38,920	1,389	384	1,005	-19,038
26	Soybean	HT	ND	0	0	-10,645	10,645	589,806
20	Sugarbeet	HT	ND	0	0	-13,000	13,000	218,000
23	Sunflower	FR	ND	140,000	10,000	2,680	7,320	0
37	Wheat	HT	ND	792,000	39,600	0	39,600	0
28	Field Corn	IR (1)	NE	487,592	17,414	4,814	12,600	-238,602
31	Field Corn	HT	NE	0	0	-5,640	5,640	-564,000
30	Field Corn	IR (3)	NE	0	0	0	0	-1,502,000
26	Soybean	HT	NE	0	0	-31,119	31,119	-764,940
20	Sugarbeet	HT	NE	0	0	-4,300	4,300	49,000
08	Strawberry	HT	NH	0	0	-43	43	-466
22	Apple	BR	NJ	1,000	100	-27	127	-200
39	Eggplant	IR	NJ	0	0	0	0	-208
28	Field Corn	IR (1)	NJ	5,264	188	-112	300	-9,044
31	Field Corn	HT	NJ	0	0	-40	40	-4,000
26	Soybean	HT	NJ	0	0	-1,252	1,252	-44,160
08	Strawberry	HT	NJ	0	0	-106	106	-1,158

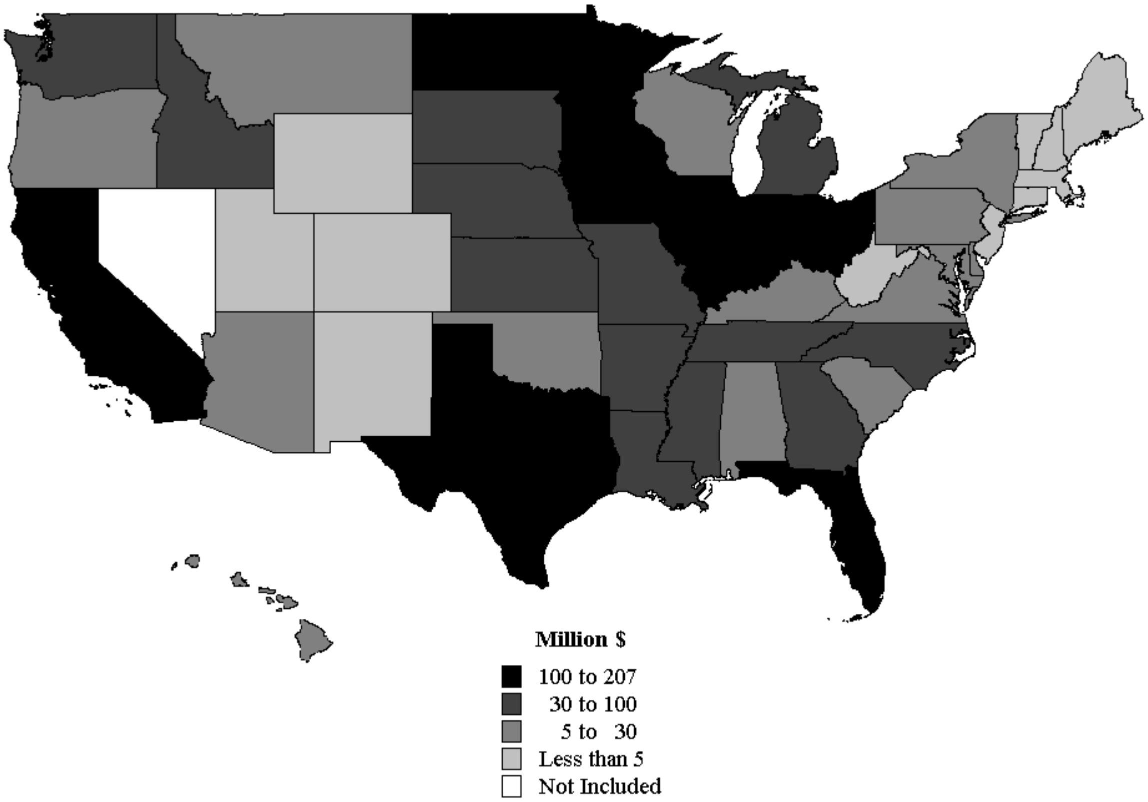
Case #	Crop	Type	State	Production (per year)			Total (000$/yr)	Pesticide Use (lbs AI/yr)
				Volume (000lb)	Value (000$)	Costs (000$)		
33	Cotton	IR (2)	NM	63	38	-54	92	-1,846
32	Cotton	IR (1)	NM	2,550	1,525	193	1,332	-12,500
28	Field Corn	IR (1)	NM	7,784	278	-12	290	-4,560
22	Apple	BR	NY	31,000	3,500	-486	3,986	-3,600
31	Field Corn	HT	NY	0	0	-720	720	-72,000
28	Field Corn	IR (1)	NY	4,200	151	-15	165	-5,510
30	Field Corn	IR (3)	NY	0	0	0	0	-375,000
26	Soybean	HT	NY	0	0	-2,228	2,228	-55,888
08	Strawberry	HT	NY	0	0	-372	372	-4,076
22	Apple	BR	OH	2,000	500	-189	689	-1,400
30	Field Corn	IR (3)	OH	0	0	0	0	-469,000
29	Field Corn	IR (2)	OH	271,656	9,702	2,805	6,897	0
28	Field Corn	IR (1)	OH	26,880	961	855	106	-17,556
31	Field Corn	HT	OH	0	0	-1,320	1,320	-132,000
26	Soybean	HT	OH	0	0	-95,321	95,321	-3,759,966
34	Cotton	HT	OK	0	0	-400	400	168,000
32	Cotton	IR (1)	OK	13,536	7,445	1,548	5,897	-9,400
33	Cotton	IR (2)	OK	451	270	72	198	-2,865
28	Field Corn	IR (1)	OK	27,272	974	-42	1,016	-15,960
31	Field Corn	HT	OK	0	0	-80	80	-8,000
30	Field Corn	IR (3)	OK	0	0	0	0	-17,000
26	Soybean	HT	OK	0	0	-426	426	28,830
22	Apple	BR	OR	4,000	400	-145	545	-1,200
17	Potato	IR/VR	OR	270,000	14,040	-1,809	15,849	-391,500
19	Potato	HT	OR	46,947	2,340	1,800	540	125,550
18	Potato	FR	OR	0	0	-1,620	1,620	-7,668,000
16	Raspberry	VR	OR	2,300	2,600	-575	3,175	-85,330
20	Sugarbeet	HT	OR	0	0	-1,300	1,300	2,000
38	Wheat	VR	OR	108,300	4,874	-166	5,040	-16,560

Case #	Crop	Type	State	Production (per year)			Total (000$/yr)	Pesticide Use (lbs AI/yr)
				Volume (000lb)	Value (000$)	Costs (000$)		
22	Apple	BR	PA	13,000	1,400	-54	1,454	-400
31	Field Corn	HT	PA	0	0	-1,300	1,300	-130,000
30	Field Corn	IR (3)	PA	0	0	0	0	-199,000
28	Field Corn	IR (1)	PA	36,288	1,296	497	799	-24,624
26	Soybean	HT	PA	0	0	-8,311	8,311	-233,840
15	Stone Fruit	VR	PA	60,000	17,000	0	17,000	0
08	Strawberry	HT	PA	0	0	-341	341	-3,734
32	Cotton	IR (1)	SC	3,708	2,317	400	1,917	-94,000
34	Cotton	HT	SC	0	0	-8,790	8,790	-240,000
33	Cotton	IR (2)	SC	2,719	1,631	-1,839	3,470	-64,500
28	Field Corn	IR (1)	SC	2,184	78	52	27	-1,064
26	Soybean	HT	SC	0	0	-2,482	2,482	307,648
25	Soybean	IR	SC	7,560	616	-336	952	-41,300
31	Field Corn	HT	SD	0	0	-6,540	6,540	-654,000
28	Field Corn	IR (1)	SD	284,480	10,160	-635	10,795	-241,300
30	Field Corn	IR (3)	SD	0	0	0	0	-1,222,000
26	Soybean	HT	SD	0	0	-45,972	45,972	2,408,744
23	Sunflower	FR	SD	90,000	5,200	1,480	3,720	0
37	Wheat	HT	SD	144,000	7,200	0	7,200	0
33	Cotton	IR (2)	TN	3,336	2,001	-579	2,580	-31,750
32	Cotton	IR (1)	TN	17,160	11,154	7,241	3,913	-42,900
34	Cotton	HT	TN	0	0	-9,160	9,160	-570,000
31	Field Corn	HT	TN	0	0	-710	710	-71,000
28	Field Corn	IR (1)	TN	34,272	1,223	338	885	-16,758
26	Soybean	HT	TN	0	0	-20,694	20,694	-200,490
11	Citrus	VR	TX	904,000	48,000	0	48,000	0
33	Cotton	IR (2)	TX	2,122	1,273	-2,576	3,849	-97,677
32	Cotton	IR (1)	TX	42,874	27,868	212	27,656	-143,000
34	Cotton	HT	TX	0	0	-3,675	3,675	641,000

Case #	Crop	Type	State	Production (per year)			Total (000$/yr)	Pesticide Use (lbs AI/yr)
				Volume (000lb)	Value (000$)	Costs (000$)		
30	Field Corn	IR (3)	TX	0	0	0	0	-555,000
28	Field Corn	IR (1)	TX	425,600	15,200	-4,465	19,665	-288,800
31	Field Corn	HT	TX	0	0	-2,660	2,660	-266,000
29	Field Corn	IR (2)	TX	52,752	2,026	618	1,408	-2,850
27	Rice	HT	TX	0	0	-1,890	1,890	-75,000
26	Soybean	HT	TX	0	0	-384	384	26,195
31	Field Corn	HT	UT	0	0	-70	70	-7,000
22	Apple	BR	VA	9,000	1,000	-67	1,067	-500
33	Cotton	IR (2)	VA	572	343	-466	809	-12,600
32	Cotton	IR (1)	VA	792	495	85	410	-19,800
34	Cotton	HT	VA	0	0	-321	321	22,000
31	Field Corn	HT	VA	0	0	-330	330	-33,000
28	Field Corn	IR (1)	VA	2,688	96	82	14	-608
26	Soybean	HT	VA	0	0	-2,627	2,627	189,528
31	Field Corn	HT	VT	0	0	-40	40	-4,000
28	Field Corn	IR (1)	VT	560	21	-2	23	-760
08	Strawberry	HT	VT	0	0	-41	41	-450
22	Apple	BR	WA	125,000	21,200	-451	21,651	-3,900
19	Potato	HT	WA	140,843	7,020	5,400	1,620	41,850
18	Potato	FR	WA	0	0	-4,860	4,860	-2,556,000
17	Potato	IR/VR	WA	90,000	4,680	-603	5,283	-130,500
16	Raspberry	VR	WA	7,700	8,600	-1,925	10,525	-285,670
20	Sugarbeet	HT	WA	0	0	-3,100	3,100	-22,000
38	Wheat	VR	WA	681,780	28,654	-430	29,084	-43,056
31	Field Corn	HT	WI	0	0	-1,650	1,650	-165,000
28	Field Corn	IR (1)	WI	53,200	1,901	-1,089	2,990	-87,780
30	Field Corn	IR (3)	WI	0	0	0	0	-770,000
26	Soybean	HT	WI	0	0	-20,656	20,656	494,474
14	Sweet Corn	HT	WI	72,000	2,400	1,400	1,000	16,200

Case #	Crop	Type	State	Production (per year)			Total (000$/yr)	Pesticide Use (lbs AI/yr)
				Volume (000lb)	Value (000$)	Costs (000$)		
22	Apple	BR	WV	4,000	300	-27	327	-200
28	Field Corn	IR (1)	WV	168	6	5	1	-38
26	Soybean	HT	WV	0	0	-116	116	8,344
31	Field Corn	HT	WY	0	0	-30	30	-3,000
20	Sugarbeet	HT	WY	0	0	-2,800	2,800	50,000

Figure 1. Potential Benefits of Biotechnology Adoption by State



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