The Field Study of U.S. Biotech Crops Since 1993

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This paper examines U.S. biotech field research data from 1993 through the first half of 2005. It identifies crops and traits of biotech research interest, and calculates the research area in acres, based on information in the APHIS data base. The research areas for eight major crop groups are shown in Table 1. Nine categories of trait research are shown in Table 2. The findings are summarized and each crop is briefly described. Crops and crop groups are sorted from the largest research area to the smallest. Annual acreage details for each crop and trait category are included in the appendix.

FIELD TEST DATA

Field studies are one step in deregulating a genetically modified plant for commercial use. All U.S. field studies using recombinant DNA technology must register with the USDA Animal and Plant Health Inspection Service (APHIS) Biotechnology Permits Branch. The first environmental release permit was issued to the University of California Berkley and Monsanto for pseudomonas research in 1985. In 1993, a new permit process improved information reporting. This study is based on the 9,100 field permits issued since 1993. It focuses on research conducted between 1993 and 2004, but also reported activity in the first half of 2005. Field permits allow, but do not require, open air studies. Permits can vary in duration, and be extended, although 1 year or growing season is typical. This analysis assumes the intended research acres were planted, and that it occurred the year the permit was issued.

Each record in the APHIS database identifies the type of plant, the biotech trait conferred, the research institutions involved, the test location by state, and the size of the research area in acres. Acres are a central measure in this analysis. The research area size may seem a poor proxy for research interest, since agricultural systems like corn and papaya are so different. But research acres can indicate the relative intensity of interest, particularly among similar crops, and whether research interest is recent, ongoing, or lost. A rapid change in acres can also signal a move toward a new biotech crop approval. The government approval following successful field studies can allow the environmental release, use as animal feed or for human consumption. Regulatory approval information reported below is from AGBIOS.com. Currently, 13 crops are approved for unregulated U.S. use. Six crops have regulatory approval and are commercially available: corn, cotton, soybean, rapeseed, tobacco, papaya. Seven crops have regulatory approval but are

not commercially available: rice, potato, wheat, sugarbeet, tomato, squash, creeping bent grass.

The study area can range widely depending on the stage of research. The smallest events are less than an acre, often for lab or green house experiments. The largest events coincide with commercial biotech crop releases. The ten largest events account for 55% of all biotech research acres between 1993 and 2004. The largest single study was 60,000 potato acres in 1995 for insect resistance and herbicide tolerance. The next 4 largest events were insect resistance studies in cotton (54,000 acres in 2002 and 41,000 acres in 1995) and corn (52,000 acres in 2002 and 25,000 acres in 2001).

BIOTECH RESEARCH CROPS

Since 1993, sixty-nine plants have been subject to some level of biotech field research. Field studies total 573,000 acres from 1993 to 2004, with another 58,000 acres added in the first half of 2005. These biotech crops can be divided into 3 major groups: field crops (20), fruits and vegetable (26), and horticultural grasses, trees, and flowers (23). See Appendix for annual crop acres. Table 1 divides the groupings further, and shows research total acres over four 3-year periods, and the first half of 2005.

TABLE 1 - Acres of biotech research by crop category

	1993-95	1996-98	1999-01	2002-04	TOTAL	*2005H1*
FIELD (TOP 10)	70,887	119,197	153,377	221,211	**564,672**	*57,879*
FIELD (10 MORE)	0	8	190	140	**337**	*11*
VEGETABLE (12)	520	713	321	130	**1,683**	*58*
FRUIT (14)	44	279	320	70	**712**	*13*
GRASS (4)	1	156	1,307	3,812	**5,275**	*2*
TREE (7)	2	36	83	166	**287**	*29*
FLOWER (12)	1	4	51	51	**107**	*10*
ALL BIOTECH CROPS	71,454	120,393	155,647	225,580	573,073	*58,002*

Source: APHIS. *Some rounding error may occur*

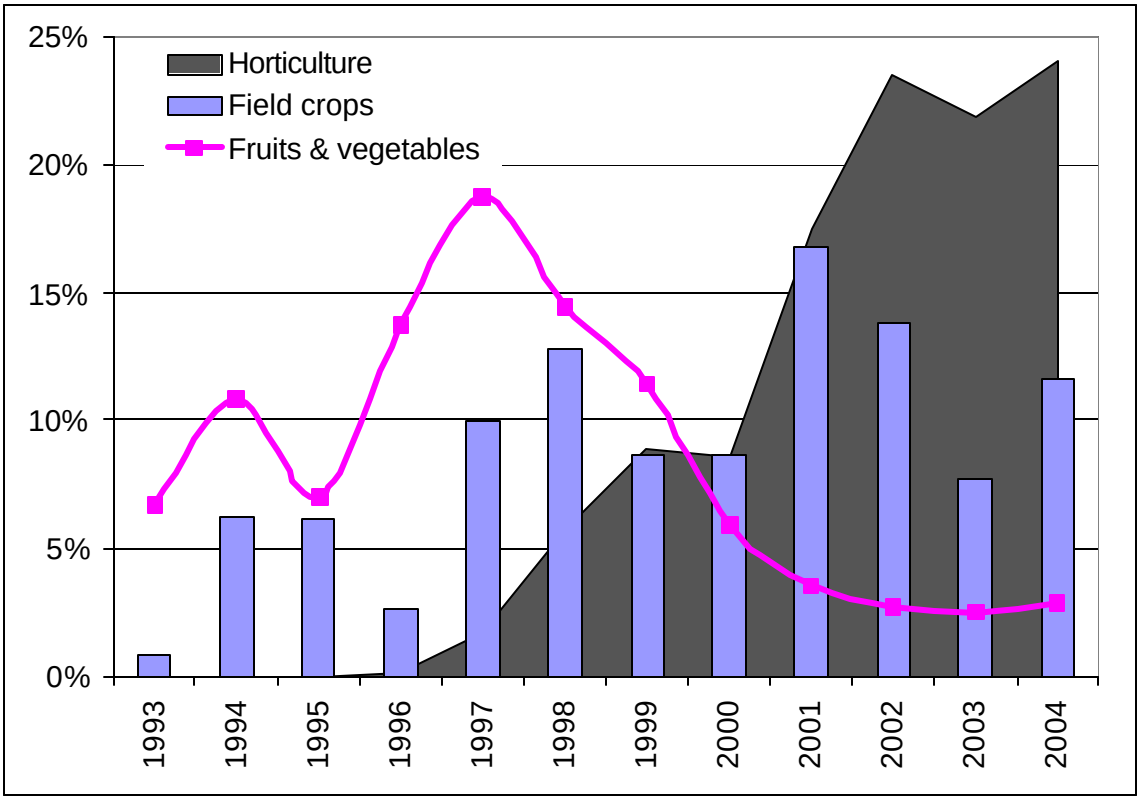
The top 10 field crops account for 99% of all research acres between 1993 and 2004. Corn is the dominate crop, explaining 40% of the total biotech research area. Cotton and potato have the next largest study areas, accounting for another 44% of the total area. The bottom 10 field crops, which include sunflower, barley, and sugarcane, have 337 field study acres collectively from 1993 to 2004. Tomato is the dominate plant among the vegetables, while melon and grape are the top research areas in fruits. Creeping bent grass has the largest research area of the horticultural grasses, trees, and flowers.

If crop research activity occurred evenly across all 12 years, then each year would represent 8% of the total area. This holds for individual crops, as well as crop groupings, and is roughly the case for Field crops (Figure 1). The annual distribution of Field crop research acres has been relatively stable since 1997, except for twin peaks in 1998 and 2001 associated with biotech corn and cotton approvals.

The annual distribution of research acres for Fruit and Vegetable crops is more pronounced, with nearly half the total area planted between 1996 and 1998. This peak is largely associated with the approval of biotech tomatoes in 1998, and the 1999 pending approval of biotech melons. Since that period, the annual share of acres devoted to Fruit and Vegetable research has declined.

By contrast, two-thirds of all horticultural biotech research acres were planted between 2002 and 2004. The primary force behind this trend is the 2003 approval of biotech Creeping Bent grass. Nevertheless, very little research activity is evident for any horticultural grass, tree, or flower before 1997.

Figure 1 - Annual distribution of research acres for each major crop group



Source: APHIS. *data in Figure 1 is two-year moving average*

BIOTECH RESEARCH TRAITS

The total biotech study area of 573,000 acres can be organized into nine trait categories (Table 2). This view is irrespective of the host plant, but research in crops like corn, potato, and cotton strongly influence the results.

Table 2 - Research acres by biotech trait

	1993-95	1996-98	1999-01	2002-04	TOTAL	*2005H1*
Insect resistance	59,939	11,045	65,976	116,365	**253,325**	*4,727*
Multiple traits	745	84,330	56,101	33,515	**174,692**	*7,545*
Herbicide tolerant	4,610	16,057	19,210	36,106	**75,984**	*9,113*
Product quality	5,593	5,523	9,483	29,329	**49,928**	*21,617*
Agronomic properties	117	2,568	3,073	9,354	**15,111**	*14,749*
Other properties	126	522	1,457	728	**2,834**	*216*
Fungal resistance	27	219	203	216	**665**	*41*
Virus resistance	102	154	165	86	**507**	*6*
Bacterial resistance	208	13	37	4	**262**	*1*
ALL BIOTECH CROPS	71,454	120,393	155,647	225,580	573,073	*58,002*

Source: APHIS. *Some rounding error may occur*

Insect resistance research covered 253,000 acres between 1993 and 2004, or nearly half the total biotech research area. Activity peaked in 2002 with the approval of corn and cotton varieties (Bt) resistant to lepidopteran (corn borer) and coleopteran (root worm) insects. Between 1993 and 1995, insect resistance research focused on Colorado potato beetles in potato. Other insect resistance studies include sod worm resistance in Creeping Bent grass, cottonwood leaf beetle resistance in poplar, and Colorado potato beetle resistance in eggplant. Twenty-two of the 69 biotech plants had insect resistance studies.

Multiple Traits are studies with more than one biotech trait being researched in a single field event. Fifty-two of the 69 research plants were in multiple trait studies between 1993 and 2004, covering 175,000 acres, or 30% of the total biotech research area. The largest area was a stacked combination of insect resistance and herbicide tolerance. This pairing was widely tested in potato, corn, cotton, soybean, and other crops. But not all Multiple Trait research is for stacked traits, a large number of studies can have multiple trait objectives, ranging from multiple virus or fungi resistance to agronomic and product quality features. At the most extreme, and perhaps for proprietary reasons, a single corn study listed twelve biotech trait objectives.

Herbicide Tolerance studies covered 76,000 acres between 1993 and 2004, with the research area recently peaking. Herbicide tolerance was studied in 34 plants, commonly for glyphosate or phosphinothricin herbicides.

Produce Quality research has involved 35 plants, but most acres were for reducing nicotine in tobacco, increased Lysine and Tryptophan in corn, or changing soybean and rapeseed oil content. Another widely researched product quality trait is delayed ripening, most notably in tomato in 1994. In the first half of 2005, product quality acres increased by 21,000 acres, or nearly half the 50,000 product quality acres planted from 1993 to 2004. The 2005 studies are primarily to alter corn and soybean seed oil content.

Agronomic Properties studies include 26 plants, with most of the 15,000 acres between 1993 and 2004 to study increasing corn yields and improving drought tolerance. Other agronomic properties research crops were rapeseed, soybean, cotton, Creeping Bent grass, and wheat. As many research acres were planted in the first half of 2005, as were planted for all agronomic property studies in the prior 12 years. The 2005 research focus continues to be corn drought tolerance and yield improvement.

Other Properties research involved 22 plants on 2,800 acres between 1993 and 2004, including research on novel or value-added proteins in rice and tobacco. Other Property traits include gene expression and visual markers, but the largest area was in corn studies of pharmaceutical traits, antibodies, and novel proteins.

Fungal resistance research involved 26 crops on 665 acres between 1993 and 2004. Most study acres were for fusarium resistance, head blight in wheat or ear rot in corn, or potato late blight and soybean Sclerotinia. Other fungal disease studies include apple scab, strawberry and tomato soft rot, or tobacco black shank and blue mold.

Virus resistance studies include 23 plants on 507 acres between 1993 and 2004. Most acres involve resistance to several viruses in melon, tomato, and grapes. Most virus resistance research is related to some form of mosaic virus.

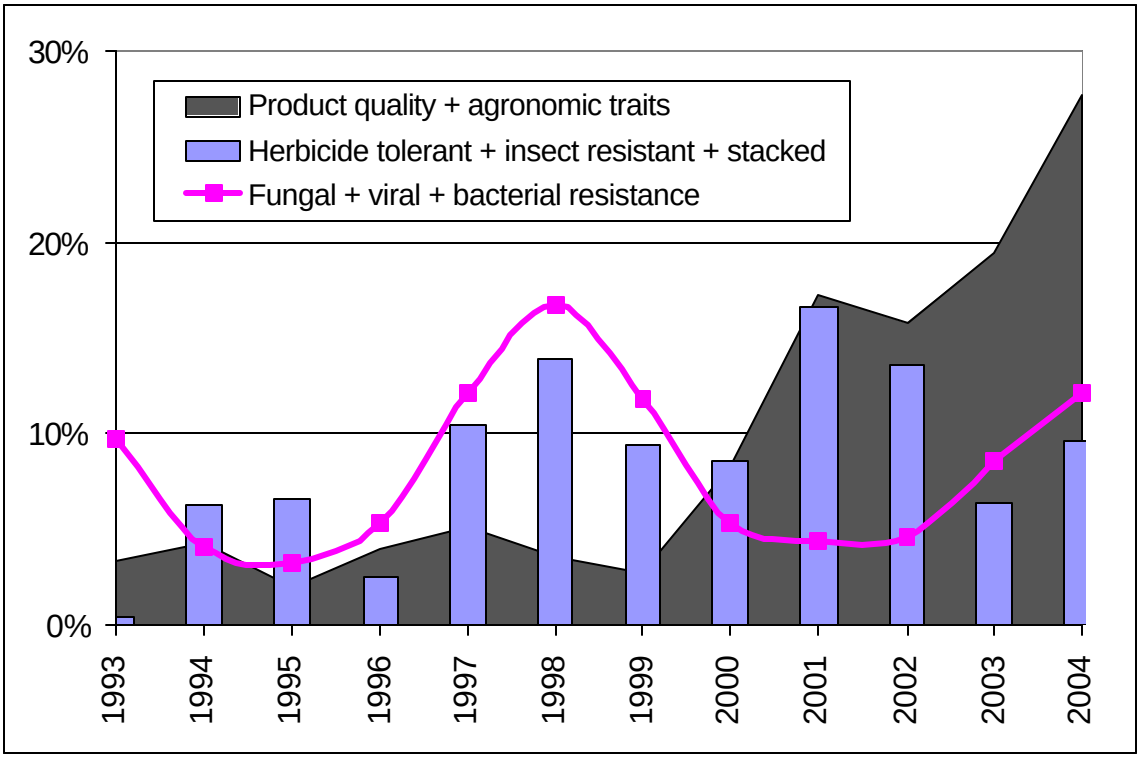
Bacterial Resistance research peaked in 1993 with a 200 acre study in potato, and only 62 acres have been added since. Eleven crops were in bacteria resistance field studies, including fire blight in pears and apples, crown gall in grapes, Bunchy top in papaya, tomato speck, and walnut leaf blight.

The nine trait classifications can be reduced further into three broad groups (Figure 2). The first group combines acres from herbicide tolerance, insect resistance, and multiple trait studies. After 1997, the planted area is fairly stable year-to-year, much like Field crops in Figure 1. There are similar twin peaks in 1998 and 2002, first with approval of stacked (herbicide tolerant and insect resistant) potato, then later for stacked corn and cotton.

The second grouping includes research acres dedicated to product quality, agronomic, and Other traits, with half the total study area planted since 2002, most notable in low nicotine tobacco, and to alter corn, rapeseed, and soybean oil profiles.

The third group combines resistance traits for fungal, viral, and bacterial diseases. The diseases resistance study area peaked between 1997 and 1999, but increased dramatically in 2004 with two 50-acre fusarium resistance studies in corn and wheat.

Figure 2 - Distribution of research acres over time by major biotech traits



Source: APHIS. *data in Figure 2 is two-year moving average*

TOP 10 FIELD CROPS

The top 10 field crops account for virtually all of the research acres. All 10 crops have some form of U.S. regulatory approval.

CORN (maize) - field studies total 223,000 acres from 1993 to 2004. The corn research area has doubled every 3 years since 1993, and now accounts for 39% of the cumulative biotech study acreage. Corn research peaked at 69,000 acre in 2002. One event alone was 52,000 acres of coleopteran (root worm) resistance corn, primarily in Nebraska (28k), Colorado, Kansas and Hawaii. Since 1993, corn has undergone the widest range of trait studies of any biotech plant. Herbicide tolerance and insect resistance have been approved and commercialized individually and stacked. Field studies have investigated agronomic properties, product quality traits, and disease resistance strategies. In 2004, the corn research area totaled 45,000 acres. In the first half of 2005, another 40,000 acres were permitted. Research currently focuses on enhanced herbicide tolerance and insect resistance, increased yields, and drought tolerance, as well as product traits like higher lysine and Tryptophan levels. Twenty biotech corn varieties have been approved in the U.S. since 1995.

COTTON research totals 143,000 acres between 1993 and 2004. In 1995, the year Monsanto's Bollgard was approved, a single event of 41,000 acres involving (Bt) lepidopteran insect resistance was permitted in Arizona and Mississippi. Cotton research peaked at 56,000 acres in 2002, corresponding to the (2002) approval of Bollgard II. Again, the trait of interest was (Bt) lepidopteran resistance, and the field work was done in Arizona and Mississippi. Herbicide tolerance, approved in 1994, was the first biotech cotton trait. The single largest event is 6,800 acres of herbicide tolerant cotton in 2004. A stacked herbicide tolerant and insect resistance cotton variety was approved in 1998. Eleven biotech cotton varieties have been approved in the U.S. since 1994.

POTATO research (116,000 acres) between 1993 and 2004 is the third largest study area of any biotech crop, despite virtually no potato research activity since 2000. The first trait approval was (Bt) Colorado potato beetle resistance in 1994, and research hit an intermediate high of 7,600 acres the following year. In 1998, a new stacked variety was approved with Colorado potato beetle resistance and potato virus resistance (two viruses separately). The all time high research area was 62,000 acres in 1998. Biotech varieties were withdrawn from the market in 2000 and 2001, and since then field studies have averaged 20 acres a year.

SOYBEAN research totaled 26,000 acres from 1993 to 2004. During the same period, the potato research area was three times larger, cotton acreage was four times greater, and corn covered seven times more study area. Soybean research increased dramatically in the first half of 2005 to more than 10,000 acres. The primary focus is an increase in the seed amino acid content. Six biotech soybean varieties have been approved in the U.S since 1994.

RAPESEED (Argentine canola) research totaled 19,000 acres between 1993 and 2004. The first biotech market approval came in 1994, with a modification to the seed oil content that increased laurate and myristic acid levels. Rapeseed field studies covered 4,000 acres that year, accounting for half of all biotech research acres. Rapeseed studies peaked in 1997 and 1998 at 5,000 acres per year. The first herbicide tolerant variety was approved in 1999. by three more varieties have been approved since, most recently Monsanto's glyphosate tolerant variety in 2003. Nevertheless, rapeseed research has averaged less than 100 acres annually since 2000.

ALFALFA had virtually no biotech research area until 2001, when herbicide tolerance was studied on 3,000 acres. Total alfalfa research between 1993 and 2004 totals 17,000 acres. In the first half of 2005, another 5,000 acres was permitted for Monsanto's Round-Up Ready alfalfa. If approved, alfalfa would be the first herbicide-tolerant perennial.

TOBACCO research totals 11,000 acres since 1993, almost entirely in 2001 and 2002 to develop a low nicotine variety. In most other years, tobacco research has average less than 100 acres. One biotech tobacco variety was approved in 2002, and low nicotine cigarettes are available in some U.S. markets.

RICE field research has totaled 5,000 acres since 1997. Half came in 1999, the year a variety of herbicide tolerant rice was approved. The rice research area fell by half in 2000, and half again in 2001. Since then, rice field study has averaged less than 200 acres annually.

WHEAT research has totaled 2,600 acres since 1993. Herbicide tolerant wheat was approved in 2004, and is the only approved variety. Another important biotech wheat research trait is fungal (Fusarium) resistance.

SUGAR BEET biotech field research began in 1994, and totaled 2,500 acres by 2004. The peak year was 1998 with 721 acres. Two herbicide tolerant sugar beet varieties were approved in 1998. Sugar beet research since has averaged between 200 and 400 acres a year.

10 MORE FIELD CROPS

The next 10 field crops have had fewer than 350 research acres collectively since 1993. None has U.S. regulatory approval.

SUNFLOWER field studies started in 1998 and ended in 2002, covering 200 acres in total. Two biotech traits were investigated, insect (lepidopteran) resistance and resistance to Sclerotinia fungus.

BARLEY field studies since 1998 total fewer than 50 acres, yet continue into 2005. The main traits are viral and fungal resistance, and improved digestibility.

SUGARCANE research started in 1997, and totals 40 acres through 2005. Most activity was in herbicide tolerance, along with a number of small viral, bacterial, and insect resistance studies.

SAFFLOWER research activity began in 2002, had 27 acres in 2003, and the 12 acres in the first half of 2005. The trait in development is a novel pharmaceutical protein.

PEANUT research started in 1994, but only totals 24 acres. The first trait was resistance to the TSWV virus, and the work continues into 2005. Another trait with active research since 2000 is Sclerotinia and Aspergillum fungi resistance.

- RYEGRASS field research totaled 4 acres over 5 years. One study in 2004 was to reduce allergens in the pollen. Two earlier studies examined salty and drought tolerance.

- CLOVER had a 4 acre event in 2001 tagging marker genes.

- CASSAVA research activity from 2001 to 2004 totaled 1.1 acre altering the starch metabolism.

- SORGUM had 0.5 acres in 2002 investigating fungal (fusarium) resistance.

- OAT research total 0.1 acre in 1998 for viral (BYDV) resistance.

12 VEGETABLES

Vegetable research totaled 1,683 acres between 1993 and 2004, with an additional 58 acres in the first half of 2005. Tomato and squash have approved biotech varieties.

TOMATO field research has been active every year since 1993, and totals 1,250 acres. Two traits account for most of the research area. Delayed ripening was the first trait investigated, and five varieties were approved through 1998. One lepidopteran resistant (Bt) variety was also approved in 1998. Smaller trait studies have included herbicide tolerance, fungus, virus, and bacteria resistance, salt, drought, and cold tolerance, plus changes to fruit size and color.

LETTUCE research totals 166 acres since 1994, with a peak in 1999 investigating herbicide tolerant. Other research traits include increasing the yield, iron content, and chlorophyll levels.

SQUASH field studies totaled 111 acres between 1994 and 2001, with a peak in 1995-96. The research focus was resistance to mosaic viruses, and two biotech squash variety were approved in 1994 and 1997.

CUCUMBER field studies started in 1994 and total 70 acres. Research traits include virus resistance, herbicide tolerance, and since 2001, salt tolerance.

PEA research activity since 1998 totals 66 acres, with 22 acres alone in the first half of 2005. The trait of interest is herbicide tolerance. the only other research trait was viral resistance, which stopped 2002.

ONION field research totals 22 acres since 2001, with 11 acres in the first half of 2005 alone. The trait of research interest is herbicide tolerance.

SWEETPOTATO field research totals 12 acres since 1999. Virus resistance, and most recently, herbicide tolerance are the study traits.

BRASSICA (kale) research totaled 11 acres from 1997 to 2004. Insect resistance has been the primary trait, but prolonging shelf life, salt tolerance and herbicide tolerance were also studied.

- CARROT research covered 6 acres between 1993 and 2000. Traits include changes in the nutritional quality, fungal resistance, and herbicide tolerance.

- PEPPER research totaled 2.1 acres between 1996 and 2000. Research traits include delayed ripening and CMV virus resistance.

- EGGPLANT field research includes 1.5 acres in 1997-98. The two traits were insect resistance (Colorado potato beetle) and fungus resistance

- AVOCADO had a 0.5 acres research event in 2003 studying fungal resistance.

14 FRUITS

Fruit research total 712 acres, and peak in 1998. Papaya is the only fruit with U.S. regulatory approval.

MELON field studies total 319 acres, with the peak activity in 1998, and none since 2002. The research traits were viral resistance and delayed fruit ripening. The U.S. approval for a delayed ripening variety has been pending since 1999.

GRAPE field activity totaled 194 acres between 1995 and 2004, with 127 acres in 1997 alone. Since then activity has covered less than 20 acres. Viral, bacterial, and fungal resistances are the study traits.

APPLE field research totaled 101 acres between 1994 and 2004. Peak activity was in 1999 and 2000 investigating insect (lepidopteran) resistance. Other trait studies include bacterial (fire blight) and fungal (apple scab) resistance, changes to the sugar profile (increase alcohol levels), and delayed ripening.

WATERMELON research totaled 20 acres between 1998 and 2004, with 8 more acres in the first half of 2005. Before 2001 research focused on viral resistance, since then parthenocarpy (seedless) is the study trait.

PEAR research activity totaled 17 acres from 1999 to 2001, with 1 acre investigating bacterial (fire blight) resistance, and the rest on delayed fruit ripening.

PAPAYA research totals 15 acres from 1995 to 2004. Traits include viral, fungal, and bacterial resistance. A biotech papaya variety resistant to the ringspot virus was approved in 1997, and is grown commercially in Hawaii.

STRAWBERRY field research covered 13 acres from 1994 to 2001. Study traits include herbicide tolerance, delayed fruit ripening, and fungal resistance.

- RASPBERRY (rubusidaeus) research totaled 4.6 acres between 1998 and 2003, for delayed fruit ripening and virus resistance.

- PERSIMMON had 4 acres of research in 1999 to examine fungal and insect (lepidopteran) resistance, plus cold and drought tolerance.

- BANANA has 1.3 acres of research in 2004, and 1.3 acres in the first half of 2005. The research trait is fungal (mycosphaerella) resistance.

- PINEAPPLE field research is limited to 2 acres in 2003. The research traits were delayed fruit ripening and viral resistance.

- BLUEBERRY has 1 acre in the first half of 2005 to research herbicide tolerance.

- PLUM research is limited to a half acre for viral resistance in 1995, and a half acre in 1999 for delayed fruit ripening.

- GRAPEFRUIT had 1.32 acres of research between 1999 and 2001, for viral resistance, bacterial resistance, and insect (aphid) resistance.

HORTICULTURE

Horticultural research crops - 4 grasses, 7 trees, and 12 flowers - were planted to 5,667 total acres, with 1,360 acres grown in 2004 alone. Research areas peaked in 2002, with the 2003 approval of herbicide tolerant Creeping bent grass. Biotech tree field research totaled 288 acres between 1993 and 2004, with most of the activity since 2000. Flower field studies total 105 acres between 1994 and 2004, with 9.5 acres in the first half of 2005.

GRASS (4)

Creeping bent grass field studies total 4,431 acres, or 84% of all grass research, with most associated with the 2003 approval of a herbicide tolerant variety (Scotts Roundup-Ready). Other research includes drought, heat, and salt tolerance, altered growth rate, and resistance to insects (sod worm) and fungi (dollar spot and fusarium).

Kentucky Blue grass had 638 acres of study between 1999 and 2004, with similar traits as the creeping bent grass studies.

Saint Augustine grass research totals 193 acres between 2001 and 2004, focused on herbicide tolerance and altered growth rate.

Bermuda (Poa) grass field research totaled 13.3 acres from 1999 to 2004. Research includes herbicide tolerance, salt tolerance, and drought tolerance.

TREES (7)

Poplar field research totals 148 acres between 1997 and 2004. Another 58 acres were added in the first half of 2005. The primary focus has been herbicide tolerance and altering flowering, growth and lignin biosynthesis. Other studies involve heavy metal bioremediation, Bacterial (crown gall) resistance, fungus (septoria) resistance, and insect (cottonwood leaf beetle) resistance.

Pine studies total 45 acres from 1999 to 2004, with 13 acres added in the first half of 2005. Research includes gene markers, herbicide tolerance, and altered growth rates.

Eucalyptus research totals 50 acres from 1993 to 2004, with 41 acres in 2004 alone. Traits include reduced lignin, increased growth, and gene markers. A 4 acre cold tolerance study was added in the first half of 2005.

Sweet gum field studies total 25 acres between 1999 and 2004, with research on altered growth and fertility, and herbicide tolerance.

Walnut research totals 16 acres between 1997 and 2000. Traits include insect (lepidopteran) resistance, bacterial (leaf blight) resistance, and increasing root (cuttings) formation.

- American Elm field research was 1.3 acres in 2004 examining fungal (Dutch Elm) resistance.

- Guayule (rubber tree) research totals 1.3 acres from studies in 2001 and 2004 for drought resistance.

FLOWERS (12)

Petunia research totals 64 acres between 1999 and 2004, with 29 acres in 2000 studying herbicide tolerance. Other traits include altered color, extending shelf life, drought and cold tolerance.

Pelargonium research totals 14 acres from 2000 to 2004, with 2 acres added in the first half of 2005. The research traits are herbicide tolerance and altered flower color.

- Begonia research totals 10 acres between 2003 and 2004 studying herbicide tolerance and flower color.

- Gladiolus research totals 1.3 acres between 1994 and 2004, with 5 acres added in the first half of 2005. Viral resistance (BYMV) is the research trait.

- Chrysanthemum research is 4 acres in 1997 for virus resistance.

- Marigold research totals 4 acres between 2002 and 2003 for herbicide resistance.

- Rose field studies totals 4 acres between 2003 and 2004 for fungal resistance.

- Dendrobium research is 3 acres in 1999 for bacteria (Calonectria and Erwinia) resistance, viral resistance, and flower color alterations.

- Belladonna research is 1 acre for insect (lepidopteran) resistance in 2000.

- Rhododendron research totals 0.9 acres between 2000 and 2004 for fungus (phytophthora) resistance.

- Clary (sage) research totals 0.3 acres in 2000 and 2001 to alter flower color.

- Peppermint research totals 0.2 acres in 2001 to alter the oil profile.