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The Seed Industry in U.S. Agriculture

An Exploration of Data and Information on Crop Seed Markets, Regulation, Industry Structure, and Research and Development

Jorge Fernandez-Cornejo

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Abstract

The unprecedented growth in crop yields and agricultural total factor productivity over the past 70 years owes much to a series of biological innovations embodied in seeds, beginning with the development of hybrid crops in the United States in the early part of the 20th century, continuing with the adoption of high-yielding varieties during the Green Revolution of the 1960s and 1970s, and more recently, modern biotechnology. Throughout this period, the seed industry evolved, as small businesses gave way to larger enterprises that integrated plant breeding, production, conditioning, and marketing functions. The industry was further shaped by widespread mergers and acquisitions in the latter part of the century, rapid growth - in private research and development (R&D), shifting roles of public and private R&D, and a "coming of age" of agricultural biotechnology.

Keywords: Seed markets, seed costs and prices, regulation, plant breeding, field crops, research and development, industry concentration, biotechnology.

Note: The use of brands or firm names in this publication does not imply endorsement or approval by the U.S. Department of Agriculture.

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Contents

List of Figures

List of Tables

Summary

The U.S. seed industry changed dramatically over the past century, as more farmers purchased their seed (instead of using seed saved from the previous harvest) and small seed businesses gave way to larger enterprises that integrated plant breeding, production, conditioning, and marketing functions. The industry was further shaped by widespread mergers and acquisitions in the latter part of the 20th century, rapid growth in private research and development (R&D), shifting roles of public and private R&D, and a "coming of age" of agricultural biotechnology.

To assess these developments, this report examines the composition of U.S. and international seed markets, regulations affecting agricultural seeds, the structure and evolution of the seed industry, and trends in private and public R&D in plant breeding. Particular emphasis is placed on seeds for the major field crops: corn, cotton, soybeans, and wheat.

Improved Seed Is a Major Contributor to Crop Yield Gains

Over the past 70 years, yields of all major field crops in the United States registered a remarkable increase. For example, average corn yields rose from 20 bushels per acre in 1930 to 140 bushels per acre by the mid-1990s. Over the same period, cotton yields rose nearly fourfold, soybean yields increased more than threefold, and wheat yields climbed more than 2.5-fold. More than half of the yield gains are attributed to genetic improvements achieved by plant breeders.

Purchased Seed Use, Purchase Value, and Trade Have Grown in Recent Decades

The United States is the largest seed market worldwide, followed by China and Japan. Seed expenditures by U.S. farmers rose from about $500 million per year in 1960 to nearly $7 billion in 1997. In real terms, seed expenditures climbed about 2.5-fold in the same period, despite minimal real increases in the index of seed prices paid by farmers. A large portion of the increase in real seed expenditures may be explained by increases in the share of seed purchased by U.S. farmers from commercial sources, which, in turn, can be explained by increases in seed productivity attributable to scientific improvements in plant breeding. The United States is a net exporter of seed. In 1996, the U.S. seed trade surplus was $384 million: $698 million in seed exports, mainly to Mexico, Canada, Italy, Japan, and Argentina; and $314 million in seed imports, mainly from Canada, Chile, the Netherlands, and China.

Intellectual Property Rights Effect Significant Changes

Hybrid corn varieties developed in the first half of the 20th century and, widely accepted by farmers, provided the private sector a natural method of protecting plant breeding investments—saved hybrid corn seed produces substantially lower yields, encouraging farmers to repurchase seed every year. This development, combined with a strengthening of legal protection of intellectual property rights in the second half of the 20th century, brought large-scale change to the seed industry, particularly increases in R&D and industry concentration.

Seed Industry Structure Is Characterized by Growth and Consolidation

From the commercial production of hybrid corn seed in the 1930s to the recent mergers and acquisitions, the history of the U.S. seed industry is marked by extensive structural change and transition. Until the 1930s, most commercial seed suppliers were small, family-owned businesses lacking the financial resources necessary to pursue their own research and development. These small businesses depended almost exclusively on plant breeding research in the public sector. Seed businesses served primarily to multiply and sell seeds of varieties developed in the public domain.

Market concentration in the U.S. seed industry increased in the latter part of the 20th century, with the four largest corn seed firms accounting for nearly 70 percent of U.S. corn seed sales in 1997 and the four largest cotton seed firms providing more than 90 percent of the cotton seed varieties planted. In contrast, the public sector still accounts for a large share of the wheat seed varieties used by U.S. farmers. Although the increase in seed industry concentration has raised concerns about its potential impact on market power, preliminary empirical results for U.S. cotton and corn seed industries over the past 30 years suggest that increased concentration resulted in a cost-reducing effect that prevailed over the effect of enhanced market power.

Private and Public Sector Roles in Crop Seed R&D Have Shifted

Private R&D expenditures on plant breeding increased 1,300 percent between 1960 and 1996 (adjusted for inflation), while real public R&D expenditures changed little. With the development of commercially viable corn hybrids in the 1930s, R&D expenditures on corn varieties were the first to shift from public to private. Private seed companies' share of total expenditures on plant breeding R&D on corn increased from close to half in 1970 to more than 70 percent in 1989. The shift from public to private R&D expenditures on soybean plant breeding is more recent, as the share of private sector R&D for soybeans rose from 6 percent to almost 25 percent between 1970 and 1984. Private sector R&D for improved wheat varieties has been limited. As a result, farmers have relied on public sector wheat varieties for new sources of seed. Public sector research also emphasizes many minor field crops, such as oats and barley. Although a large amount of plant breeding R&D shifted from the public sector to the private sector, ample research opportunities still exist for both sectors.

Introductions and Trials of New Varieties Are Increasing Over Time

Improved plant varieties are a product of research and development. Seeds embody the scientific knowledge needed to produce a new plant variety with desirable attributes, such as higher yield potential, greater disease resistance, or improved quality. The number of plant variety protection (PVP) certificates issued by USDA provides a useful indicator of plant breeding research efforts. The number of PVP certificates issued by USDA has grown rapidly since the 1970 Plant Variety Protection Act. This growth suggests the positive effects of the Act on generating private sector incentives for plant breeding R&D. Growth in PVP certificates has been highest for soybeans and corn, which together account for more than half of all certificates issued for field crops. By the end of 2002, 2,612 certificates had been issued for varieties of U.S. origin for the four major field crops, including 1,078 for soybeans, 648 for corn, 568 for wheat, and 290 for cotton. Most PVP certificates are held by the private sector.

As indicated by the number of field releases issued by USDA's Animal and Plant Health Inspection Service (APHIS) to allow breeders to pursue field testing, plant breeding research through biotechnology is increasing. Between 1987 and June 2001, APHIS received over 7,600 applications for field releases of biotech varieties and approved 6,700. The number of applications received annually by APHIS increased from 9 in 1987 to 1,206 in 1998. The majority of applications for field releases received from private and public institutions are for testing improved varieties of major crops. By mid-2001, more than 3,300 applications had been received for corn varieties. Other field release applications included 761 for potatoes, 601 for soybeans, 532 for tomatoes, 481 for cotton, and 209 for wheat.

After undergoing years of field tests, extensive review, and determination by APHIS that unconfined release of a genetically modified organism does not pose a significant risk to agriculture or the environment, the organism in question is no longer considered a regulated article and can be moved and planted without APHIS authorization. As of mid-2001, APHIS had received 79 petitions for deregulation and had granted 53. Thirty-six percent of these deregulated varieties have herbicide-tolerance traits, 20 percent have insect-resistance traits, and 19 percent have traits to improve product quality.

The Seed Industry in U.S. Agriculture

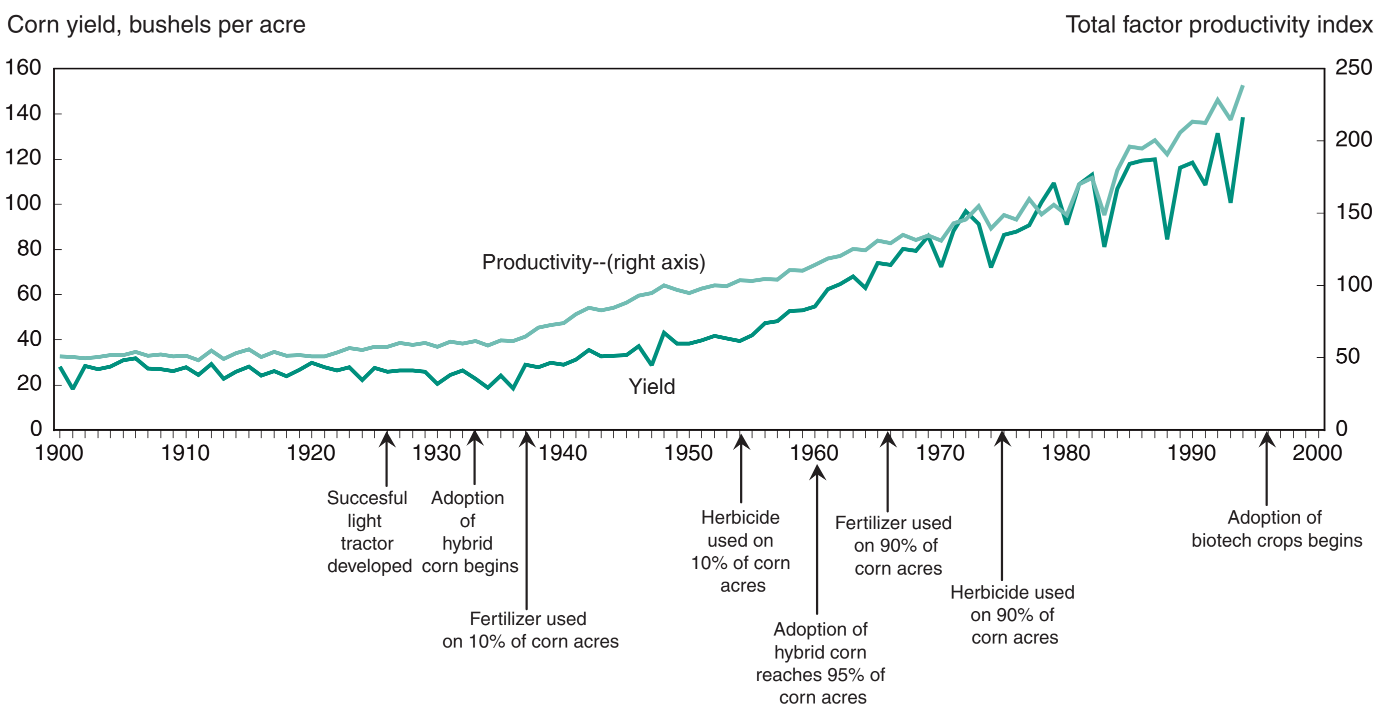
An Exploration of Data and Information on Crop Seed Markets, Regulation, Industry Structure, and Research and Development

Introduction

In 1798, Thomas Malthus predicted that geometric population growth and arithmetic food production increases would lead to chronic food shortages, with dire consequences for the future of humanity. Those predictions have failed to materialize largely because worldwide agricultural production has increased enough to accommodate a sixfold increase in population. In particular, the unprecedented growth in crop yields and agricultural total factor productivity (ratio of total outputs to total inputs) over the past 70 years owes much to a series of mechanical, chemical, and biological innovations driven by agricultural research and development (fig. 1).

To a large extent, these yield increases resulted from a series of biological innovations embodied in seeds. The first, and possibly most significant, innovation was the development of hybrid crops, particularly corn, in the United States in the 1930s. Improved varieties also raised yields in many other crops. Developing countries also adopted high-yielding crop varieties, spurring the Green Revolution of the 1960s and 1970s. More recently, modern biotechnology, especially genetic engineering, is facilitating the development of new biological innovations embodied in seed.

Figure 1
Corn yields and total factor productivity in U.S. agriculture



Source: Fernandez-Cornejo et al., 1999.

Background: The Science of Seed

Modern U.S. agriculture owes much to the application of science. Scientific discoveries in the fields of chemistry, engineering, and biology have contributed to the development of a highly productive and technologically innovative modern agricultural sector. Central to this modernization process has been the application of science to modern plant breeding.

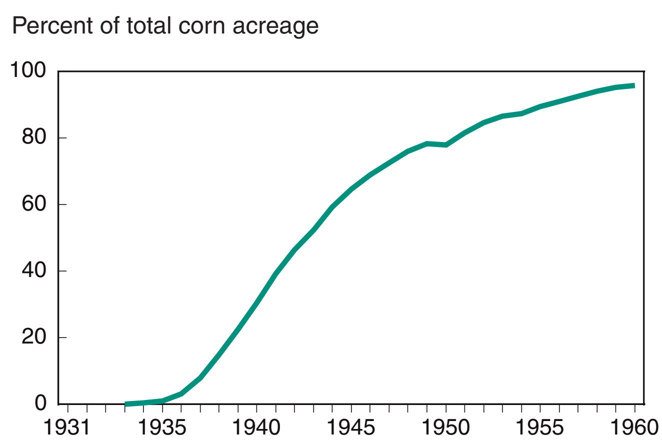
The first application of modern scientific methods to plant reproduction is credited to Gregor Mendel in the mid-19th century (Sears, 1947). Up to then, farmers engaged in plant breeding in a less systematic or conscious manner, usually by exploiting chance mutations and natural selection processes. Mendel's research focused on the identification of particular traits in garden peas, and the ways in which such traits were inherited by successive generations. Mendel's work on the laws of heredity, though lost for 34 years, eventually gave rise to extensive scientific research into the inheritance of traits in other plants and crops (Jenkins, 1936, p. 483).

A significant portion of this later research focused on corn and corn hybridization. Essentially, hybridization is a traditional breeding process in which inbred lines are crossed to create seed varieties with greater yield potential than exhibited by either parent (see box on terms and concepts). Hybridization allows breeders to enhance biological characteristics more predictably and more quickly than natural selection or chance mutations. Breeders also protect their intellectual property by keeping knowledge of their hybrid varieties from being passed on to others. Early 20th century studies, including De Vries and Correns (1900) on the inherited nature of corn endosperm texture, Shull and East (1908) on hybrid vigor arising from their experiments in corn breeding, and Jones (1918) on the commercial potential of higher yielding hybrid corn, led to major breakthroughs in plant breeding (Heisey, 1999).

By the late 1920s, hybrid corn breeding programs were showing signs of success, particularly large increases in yields. Corn, as an open-pollinated crop, was well suited to the inbreeding-hybridization process. From the perspective of the farmer, hybrid corn seed had many advantages, including higher yield potential, greater uniformity in maturity, and resistance to lodging, making large-scale mechanization possible (Sprague, 1961, p. 107). From the perspective of the seed firm, hybridization had two commercial advantages. First, simple examination of a hybrid seed does not reveal its lineage, thus offering companies proprietary control over the seeds they develop. Second, the enhanced vigor of hybrid seed is not transmitted to its offspring, thereby requiring farmers to buy new seed every year to ensure continued vigor. Crops cultivated from seed saved from a hybrid crop grown in the previous year are typically less vibrant and significantly lower in yield.

The application of science to plant breeding, and specifically to corn, was a timely development in U.S. agriculture. In the early 20th century, corn was the dominant field crop in U.S. agriculture. Yet, despite the crop's importance, corn yields were stagnant at the time. Publicly supported research and development of hybrid corn seed, an effort later taken over by commercial seed companies, helped reverse this trend during the 1930s (Airy et al., 1961, p. 145). The first seed company was organized for the commercial production of hybrid corn in 1926, but hybrid corn seed production only began to expand in the early 1930s, as several new firms began production (Jenkins, 1936, p. 479). By 1960, the share of corn acreage cultivated with hybrid seed in the United States had reached 95 percent (fig. 2), and almost all open-pollinated (OP) corn cultivated in the United States was

Figure 2
Adoption of hybrid corn



Source: *Agricultural Statistics,* NASS, USDA, various years.

Term and Concepts

Plant breeding concepts: "The essence of plant breeding is the discovery or creation of genetic variation in a plant species and the selection from within that variation of plants with desirable traits that can be inherited in a stable fashion. The plant breeders' final selections of superior plants will form the basis of one or more plant varieties. Plant breeders use all available technology both to create genetic variation and to select from within that variation.

"Different types of plant variety have been developed, depending upon the physiology of the plants of each species and the ways in which the plants of the species can be reproduced. For example, varieties of rose and potato can be reproduced vegetatively, that is to say, can be reproduced by using a part of a plant as the basis for producing another complete plant. Rose varieties can be reproduced by propagating a bud or a cutting from a plant of the variety. Potato varieties are normally reproduced by propagating a tuber of the variety.

"Varieties of grasses and most vegetables and cereals are reproduced sexually, that is by pollination of the female part of a flower (the stigma) by pollen from the male part of a flower (the anther). Here, however, one must make a distinction. The plants of some species, for example wheat, will tolerate, through successive generations, the fertilization of the stigma by pollen from the anthers of the same flower or from another flower on the same plant without loss of vigor. Plant varieties of such species can be based upon a single plant or on a small number of plants which will reproduce themselves precisely through successive generations. All the plants of a variety of this kind, known as "self-pollinated" varieties, will be genetically the same or very similar.

"The plants of many species are not adapted to self-fertilization or cannot tolerate self-fertilization through successive generations and will become less vigorous if forced to self-pollinate (they will suffer from "inbreeding depression"). In these plants, the female part of the flower must be fertilized by the pollen from another flower, or from a flower of another plant. Varieties of such species, known as "cross-pollinated" varieties, are populations of plants based upon the controlled cross-pollination of a sufficient number of selected diverse, superior plants to secure enhanced performance without suffering in-breeding depression.

"Yet a further category of variety is based upon the controlled cross-pollination of parent lines, so that the seed resulting from the cross-pollination inherits its genetic make-up from the parent lines. Such varieties, known as "hybrids," will typically exhibit greater vigor ("hybrid vigor") than the parent lines on which they are based, resulting, for example, in plants with higher yields, better resistance to stress, etc. The same controlled cross-pollination must be repeated each time the seed of those varieties is produced." (UPOV, 2003).

Agricultural biotechnology is the application of scientific techniques, including genetic engineering, to create, improve or modify plants, animals and microorganisms. Agricultural biotechnology improves upon conventional techniques, such as selective breeding, by enabling scientists to move genes and the desirable traits that they express with greater efficiency and precision (USDA, 2003).

Genotypes are the genetic traits or characteristics expressed by a particular variety (UPOV).

Germplasm is the genetic material that contains a variety's inherited characteristics.

Cross-pollinating species are those in which the pollen is primarily dispersed from one plant to another.

Self-pollinating species are those in which the pollen is primarily dispersed within the same plant.

Organisms are living things that may be categorized for purposes here as plants, animals, or microorganisms, including bacteria. An organism is categorized based on such factors as its structure, mobility, source of nutrition, or cell structure (UPOV; USDA 2000).

Sexual reproduction includes any production of a variety by seed but does not include the production of a variety by tuber propagation (PVP Act, Chapter 4, Sec. 41, USDA, Agricultural Marketing Service (AMS), 2001).

Tuber propagation means propagated by a tuber or a part of a tuber (PVP Act, Chapter 4, Sec. 41, USDA, AMS, 2001).

Variety refers to a plant grouping within a single botanical taxon [taxonomic group] of the lowest known rank, that, without regard to whether the conditions for plant variety protection are fully met, can be defined by the expression of the characteristics resulting from a given genotype or combination of genotypes, distinguished from any other plant grouping by the expression of at least one characteristic and considered as a unit with regard to the suitability of the plant grouping for being propagated unchanged. A variety may be represented by seed, transplants, plants, tubers, tissue culture plantlets, and other matter (PVP Act, Chapter 4, Sec. 41, USDA, AMS, 2001).

replaced by hybrids by the 1960s (Fernandez-Cornejo et al., 1999; Shoemaker et al., 2001, p. 9).

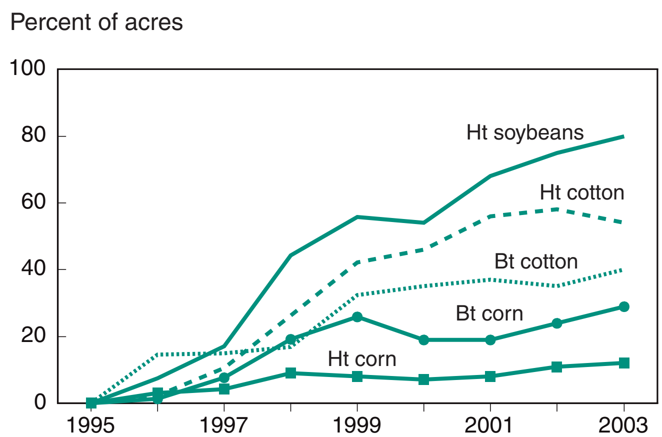
The commercial success of hybrid corn in the United States was followed by such plant breeding advances as hybrid sorghum and improved varieties of soybeans and cotton. The first commercial seed field of hybrid sorghum was planted in 1955; by 1960, 70 percent of the U.S. sorghum acreage was planted with hybrid seed (Airy et al., 1961, p. 145). Sorghum is now mostly grown from hybrid seed. Other vegetables, including onions, spinach, tomatoes, and cabbage, are also grown from hybrid seed (Emsweller, 1961).

The application of science to plant breeding also produced significant gains in crop yields in other countries. During the late 1960s and early 1970s, scientific breakthroughs in the breeding of key crops, such as rice and wheat, boosted production in many developing countries. When combined with the proper use of fertilizers, pesticides, and other inputs, these new varieties offered yield increases of 1 percent per year through the 1990s (Morris, 1998, pp. 3-4). The unprecedented growth in agricultural output in the developing world is often referred to as the "Green Revolution" and has played an important part in improving food security in such countries as India and China.

Despite its major role in plant breeding, the development of hybrids through interbreeding can require up to 12 years to develop market-ready seeds. Even then, those hybrids may still generate only limited desired traits or, possibly, unwanted characteristics (Gould, 1983; Ollinger and Fernandez-Cornejo, 1995, p. 17). Scientific discoveries in the field of genetics, beginning with Watson and Crick's postulate on the double helix model for DNA in 1953 and continuing through the creation of the first genetically engineered (GE) plant in 1982 (Shoemaker et al., 2001, p. 9), have significantly reduced the number of residual unwanted characteristics that often result from traditional plant breeding crosses, thus increasing the speed at which breeders can develop desirable new varieties.

GE crops are classified into one of three generations (Panos, 1998): crops with enhanced input traits, such as herbicide tolerance, insect resistance, and resistance to environmental stresses, such as drought; crops with added-value output traits, such as nutrient-enhanced seeds for feed; and crops that produce pharmaceuticals, bio-based fuels, and products beyond traditional food and fiber. At present, the adoption of GE crops is generally limited to those with first-generation traits. The most common herbicide-tolerant (HT) crops are characterized by resistance to the herbicide glyphosate. Commercially available HT crops include soybeans, corn, canola, and cotton and became available to a limited extent in 1996. The share of HT soybeans to total U.S. soybean acreage grew from 17 percent in 1997 to 68 percent in 2001 and 81 percent in 2003. HT cotton expanded from 10 percent of total U.S. cotton acreage in 1997 to 56 percent of cotton acreage in 2001 and 59 percent in 2003 (fig. 3). Insect-resistant GE crops in use today incorporate a gene from the soil bacterium *Bacillus thuringiensis* (Bt). The bacterium produces a protein toxic to lepidopteran insects. Plants produce the toxic protein throughout their life, providing them with long-term protection. The Bt gene has been incorporated in corn to protect the crop against the European corn borer, and in cotton to protect against the tobacco budworm, bollworm, and pink bollworm (Fernandez-Cornejo and McBride, 2000). Bt corn increased from 1 percent of total U.S. corn acreage in 1996 to 26 percent in 1999, fell to 19 percent in 2000 and 2001, and climbed back to 29 percent in 2002. Bt cotton increased from 15 percent of cotton acres in 1996 to 37 percent in 2001 and 41 percent in 2003.

Figure 3
Adoption of biotech crops in the United States



Source: Fernandez-Cornejo, 2003.

Improved Seed Is a Major Contributor to Crop Yield Gains and Agricultural Productivity

Over the past 70 years, there has been a remarkable increase in the yields of all major field crops in the United States, and more than half of the yield gains are attributed to genetic improvements achieved by plant breeders.

Among the four major field crops examined in this report, yield increases have been most significant for corn; the next highest increases were for cotton, soybeans, and wheat (fig. 4). Average per acre yields for corn in the United States rose from 20 bushels in 1930 to about 70 bushels in 1970 and reached 140 bushels by the mid-1990s (fig. 5). Soybean yields have also increased substantially since the 1930s (fig. 6). Overall per acre yields for soybeans increased from about 13 bushels in 1930 to nearly 40 bushels in the mid-1990s.

Cotton yields stagnated from 1866 to 1935. Yields grew rapidly from 1935 to 1960 as higher yielding cultivars were introduced together with synthetic fertilizers and pesticides (fig. 7) (Meredith and Bridge, 1984). After reaching a plateau during the 1960s and early 1970s, cotton yields resumed their rapid growth. Overall, cotton yields rose nearly fourfold during 1930-98 (figs. 4, 7). Wheat breeding has relied heavily on genetic improvement of self-pollinating varieties. Though wheat yields have grown steadily since 1950, the rate of growth has not been as high as that of corn and cotton (fig. 8). Still, overall wheat yields increased 2.5-fold during the period.

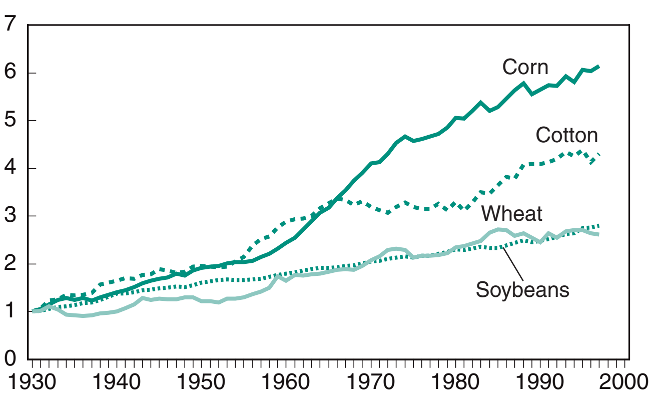
Contribution of Plant Breeding

Crop yields have benefited from genetic improvements through plant breeding as well as from improved pest management, mechanization, and fertilizer use. Still, extensive evidence suggests that crop yields have benefited the most from plant breeding, which includes the use of improved hybrids and varieties. Studies of the determinants of increased crop yields for corn, soybeans, and wheat conclude that 50 percent or more of the overall yield gain for each crop can be attributed to genetic improvements of plant varieties. For the same crops, the annual rate of yield gain due to plant breeding improvements is 1-3 percent per year (Duvick, 1992, p. 291).

Different estimates of plant breeding's contribution to crop yield gains reflect differences in the period covered and the complex nature of the research. Thirtle (1985, in Fuglie et al., 1996, p. 44) concludes that between 1939 and 1978, biological inputs (improved seed varieties and changes in agronomic practices) increased average annual yields by 1.7 percent for corn, 1.1 percent for soybeans, 0.5 percent for cotton, and 1.5 percent for wheat. Over the entire period, biological inputs contributed to 50 percent of the yield growth in corn, 85 percent for soybeans, 24 percent for cotton, and 75 percent for wheat. Fehr (1984, in Fuglie et al., 1996, p. 44) estimates that genetic improvements accounted for 89 percent of the

Figure 4
Yields for major crops

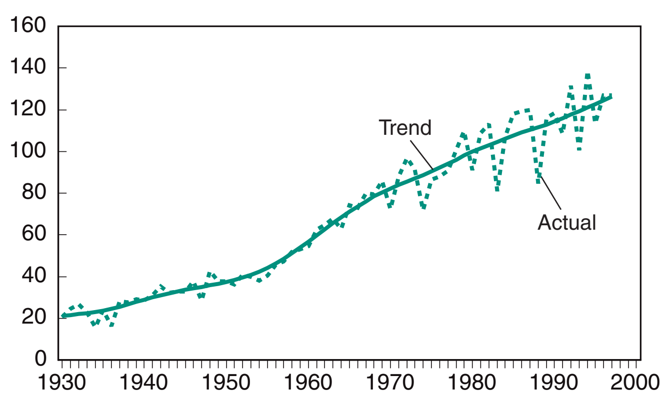
Yield index (1930=1.00) smoothed



Source: *Agricultural Statistics,* NASS, USDA, various years.

Figure 5
Corn yields

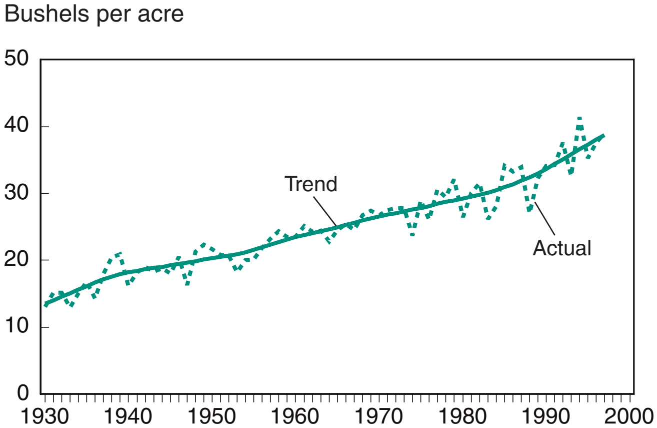
Bushels per acre



Source: *Agricultural Statistics,* NASS, USDA, various years.

Figure 6

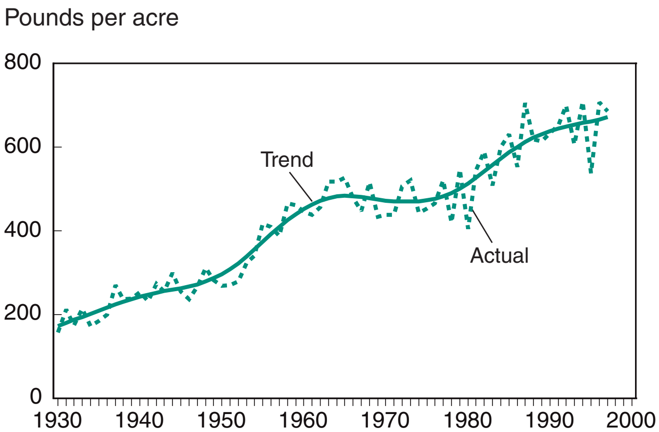
Soyebean yields



Source: *Agricultural Statistics,* NASS, USDA, various years.

Figure 7

Cotton yields



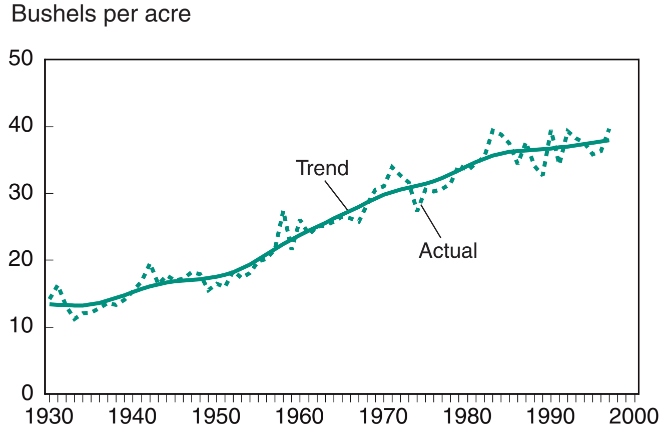
Source: *Agricultural Statistics,* NASS, USDA, various years.

gain in corn yields between 1930 and 1980, a 90-percent gain in soybean yields between 1902 and 1997, 67 percent of the gain for cotton yields between 1936 and 1960, and a 50-percent gain for wheat yields between 1958 and 1980.

The effects of other contributing factors to crop yield gains—fertilizers, pesticides, machinery, and labor—vary widely. For example, Cardwell (1982, reported in

Figure 8

Wheat yields



Source: *Agricultural Statistics,* NASS, USDA, various years.

Duvick, 1992, p. 29) concludes that, since 1930, better weed control has accounted for 23 percent of corn yield gains in Minnesota, synthetic nitrogen fertilizer has accounted for 19 percent, and plant breeding has accounted for 59 percent (16 percent for the shift from open-pollinated to hybrid seeds, and 43 percent for other breeding improvements).

The remarkable yield gains over the past 50 years are observed not only in crops cultivated under ideal conditions, where complementary inputs, such as soil fertility and water supply, are optimal, but also in crops cultivated under less ideal conditions, where yield-improving inputs are not optimized due to such conditions as drought or pests. Many new varieties possess genetic qualities that improve seed productivity in both favorable and unfavorable environments. For example, the improved root strength in newer hybrid corn varieties increased the plant's ability to resist stalk-rot fungi, heat, drought, limited nitrogen nutrition, and pests, such as the European corn borer (Duvick, 1992, pp. 292-293). Still, despite the improved plant varieties, crop yields have been subject to periods of stagnation or slow growth. Cotton yields, for example, stagnated between 1960 and 1980 before increasing again in the 1980s (Fuglie et al., 1996, p. 44).

Purchased Seed Use, Purchase Value, and Trade Have Grown in Recent Decades

Demand for seed is primarily determined by the profitability of the crop that the seed produces. Seed use by U.S. farmers depends on several factors, including the acreage under cultivation, the seeding rate per cultivated acre, cropping practices, and variations in geographic location and agroclimatic conditions.

Seed Market Size and Value

The U.S. seed market is rapidly growing in size and value. U.S. farmers used over 6.5 million tons of seed for major field crops in the 1996/97 crop marketing year (table 1). In 1997, the estimated total value of the commercial U.S. seed market was $5.7 billion, roughly 20 percent of the world market in seed (table 2) (FIS/ASSINSEL, 2001). The U.S. seed market is the largest seed market worldwide. China, at $3.0 billion, and Japan, at $2.5 billion, are the next largest seed markets.

Total seed expenditures by U.S. farmers rose from about $500 million in 1960 to over $6.7 billion in 1997 (table 3, fig. 9). In real terms, seed expenditures climbed about 2.5-fold in the same period, despite minimal real increases in the index of seed prices paid by farmers (about 7 percent in 38 years, table 3). Similarly, when measured as a share of total farm expenditures, seed expenditures increased from 2 percent in 1970 to 4 percent in 1997 (fig. 10).

A large portion of the increase in real seed expenditures may be explained by increases in the share of seed purchased by U.S. farmers from seed, particularly for major field crops, which account for the largest share of seed purchased (tables 4, 5). In 1997, 81 percent of all U.S. soybean acreage (up from 55 percent in 1982) and 78 percent of all U.S. cotton acreage (up from 50 percent in 1982) were cultivated with purchased seed. These increases, in turn, can be explained by increases in seed productivity attributable to scientific improvements in plant breeding. Seeding rates have also increased (tables 6, 7).

Seeding Rates and Costs for Major Field Crops

Seeding rates, acreage used in crop production, and share of seed purchased are the key agricultural factors affecting the demand for purchased seed in U.S. agriculture. Seeding rates, seed prices, and seed costs per acre for corn, soybeans, cotton, and wheat over time are presented in tables 6 and 7. For 1972-95, the average seed cost per acre is derived by multiplying seeding rate per acre and seed price. For 1986-97, average seeding rate and seed cost per acre are based on data from the Cropping Practices Surveys and the Agricultural Resource Management Survey (ARMS).

Seeding rates per acre can vary, depending on geographic location and cropping practices. Seeding rates tend to change slowly over time but the acreage

Table 1—-U.S. seed use for major field crops, by crop and marketing year

	Seed use										
Crops	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97
	Thousand tons										
Corn	468	482	523	529	540	566	528	563	510	571	580
Sorghum	44	36	42	36	34	48	39	34	34	45	39
Soybeans	1,653	1,684	1,766	1,664	1,701	1,705	1,726	1,914	1,877	1,929	2,064
Barley	429	376	360	324	350	310	314	283	266	283	278
Oats	608	505	433	374	306	290	285	240	205	194	219
Wheat	2,520	2,550	3,090	3,009	2,787	2,931	2,973	2,889	2,679	3,123	3,075
Rice	130	150	150	180	180	195	180	210	205	186	185
Cotton, upland	93	106	89	94	110	120	115	117	118	144	125
Total	5,945	5,889	6,453	6,210	6,013	6,165	6,160	6,250	5,894	6,475	6,566

Sources: ERS estimates, based on data from the Agricultural Resource Management Survey and the Cropping Practices Surveys (USDA, ERS, 2002).

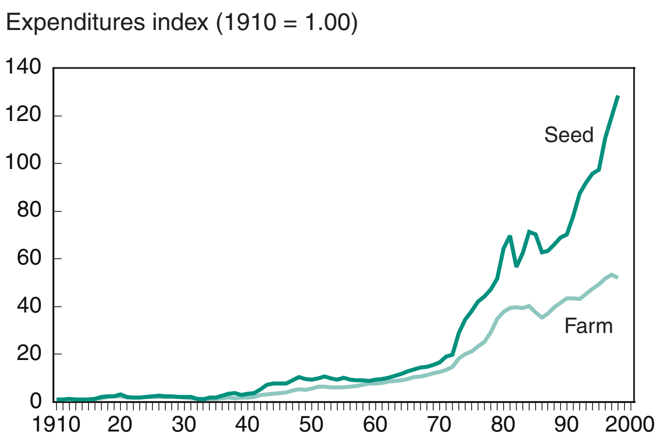
Table 2—Estimated values of commercial markets for seed

Country	Internal commercial market[1]
	Million dollars
United States	5,700
China	3,000
Japan	2,500
Comonwealth of Independent States[2]	2,000
France	1,370
Brazil	1,200
Germany	1,000
Argentina	930
India	900
Italy	650
United Kingdom	570
Canada	550
Poland	400
Mexico	350
Spain	300
Netherlands	300
Australia	280
Hungary	200
Denmark	200
Sweden	200
Other	1,967
Total	24,567

[1] Data provided in this table are the most recent figures (available at the Secretariat of the International Seed Federation). Data refer to different years depending on the countries. Data include planting materials. The total represents the sum of the commercial seed markets of the countries listed by FIS/ASSINSEL. See source for details. The commercial world seed market is assessed by FIS/ASSINSEL at approximately US$30 billion.
[2] States from the former Soviet Union (Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan).

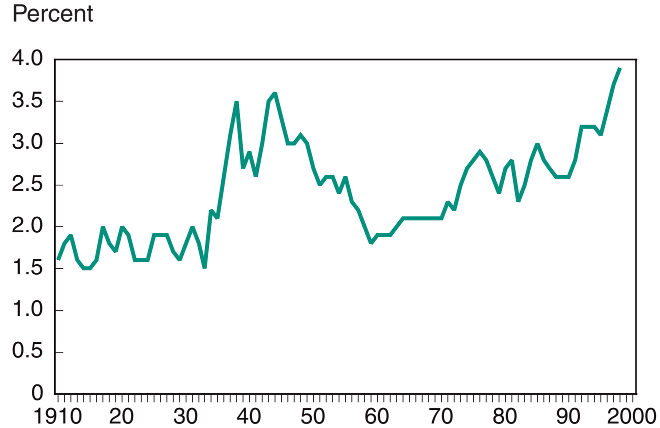
Source: FIS/ASSINSEL (2000).

Figure 9
Farm and seed expenditure indices



Source: Data sources provided in table 3.

Figure 10
Seed expenditures' share of total farm expenditures



Source: Data sources provided in table 3.

planted with a particular crop can vary from year to year. For example, in 1996-97, planted acreage for soybeans, corn, and oats increased while acreage for cotton, sorghum, and wheat decreased. Demand for purchased seed may also be affected by decreases in the use of saved seed for such crops as soybeans. As a result, seed use for each of the crops varies from year to year (table 1). But, total seed consumption for the major field crops remained fairly constant between the 1986-87 and 1996-97 marketing years, ranging from 5.9 to 6.6 million tons per year.

Corn. Corn seeding rates and costs vary substantially by State. States where crops are mostly irrigated, such as California, or receive abundant rainfall, such as in the eastern Corn Belt, support heavier seeding rates, and consequently, higher seed costs per acre than other States. Within the Corn Belt, average seeding rates and seed costs per acre in selected States vary considerably, primarily because of differences in soil productivity, moisture availability, and seed price (table 6). For example, in 1989, Minnesota had the highest seeding rate (25,800 kernels) per acre. As a result, Minnesota had the highest average cost per acre at $21.44. South Dakota had typically lower and more variable precipitation than other corn-growing States, resulting in lower seeding rates.

The price of seed per unit also affects seeding costs. For example, in 1988 and 1989, the average corn seeding rate was constant at 24,100 kernels per acre, but the average seeding cost per acre for the 10 leading corn-producing States rose from $18.64 in 1988 to

Table 3—U.S. farm seed expenditures and farm seed price index

Year	Expenditures on seed	Total farm production expenditures	Share of total farm production expenditures	Farm seed price index 1984=100	Prices paid by farmers, index 1984=1.00	Real farm seed price index (relative to prices paid by farmers)	Real expenditures on seed
	——Million dollars——		*Percent*				*Million 1989 dollars*
1960	519	27,376	1.9	0.2247	0.2657	0.8456	1,953
1961	545	28,590	1.9	0.2226	0.2675	0.8321	2,037
1962	565	30,279	1.9	0.2311	0.2719	0.8499	2,078
1963	619	31,598	2.0	0.2460	0.2764	0.8902	2,240
1964	661	31,812	2.1	0.2439	0.2772	0.8797	2,384
1965	720	33,650	2.1	0.2524	0.2852	0.8850	2,524
1966	760	36,508	2.1	0.2492	0.2967	0.8398	2,561
1967	814	38,181	2.1	0.2535	0.3020	0.8392	2,695
1968	831	39,525	2.1	0.2630	0.3091	0.8509	2,688
1969	871	42,115	2.1	0.2684	0.3242	0.8278	2,687
1970	928	44,452	2.1	0.2843	0.3384	0.8404	2,743
1971	1,072	47,107	2.3	0.3131	0.3543	0.8837	3,026
1972	1,115	51,688	2.2	0.3419	0.3764	0.9081	2,962
1973	1,617	64,554	2.5	0.4228	0.4349	0.9722	3,718
1974	1,941	70,980	2.7	0.5453	0.4942	1.1032	3,927
1975	2,138	75,043	2.8	0.6198	0.5430	1.1415	3,938
1976	2,366	82,742	2.9	0.6113	0.5784	1.0569	4,091
1977	2,484	88,884	2.8	0.6613	0.6103	1.0837	4,070
1978	2,638	103,250	2.6	0.6922	0.6599	1.0490	3,998
1979	2,904	123,304	2.4	0.7252	0.7511	0.9656	3,866
1980	3,220	133,139	2.7	0.7838	0.8397	0.9335	3,835
1981	3,428	139,444	2.8	0.9137	0.9167	0.9967	3,739
1982	3,172	140,306	2.3	0.9340	0.9548	0.9782	3,322
1983	2,987	139,608	2.5	0.9350	0.9779	0.9562	3,055
1984	3,548	141,876	2.8	1.0000	1.0000	1.0000	3,548
1985	3,941	132,433	3.0	1.0106	0.9894	1.0215	3,983
1986	3,511	125,084	2.8	0.9776	0.9681	1.0098	3,627
1987	3,259	130,992	2.7	0.9819	0.9832	0.9987	3,315
1988	4,060	139,907	2.6	0.9915	1.0549	0.9399	3,849
1989	4,397	146,662	2.6	1.0937	1.1169	0.9792	3,937
1990	4,518	153,302	2.6	1.0777	1.1603	0.9288	3,894
1991	5,113	153,279	2.8	1.0469	1.1816	0.8860	4,327
1992	4,913	152,940	3.2	1.0394	1.1940	0.8705	4,115
1993	5,163	160,506	3.2	1.0671	1.2232	0.8724	4,221
1994	5,373	167,504	3.2	1.1406	1.2542	0.9094	4,284
1995	5,462	174,120	3.1	1.1587	1.2879	0.8997	4,241
1996	6,212	182,439	3.0	1.2162	1.3561	0.8968	4,581
1997	6,711	188,443	3.7	1.2556	1.3942	0.9006	4,814

Sources: Expenditures for 1910-80 from Lucier et al. (1986); expenditures for 1981-97 from *Agricultural Statistics* (USDA, NASS, various years). Price indices from *Agricultural Statistics* (USDA, NASS, various years).

Table 4—Estimated U.S. market and purchased seed value, 1982

Seed stock	Total market value of seed[1]	Share of total market value of seed	Share of acres planted with purchased seed	Market value of purchased seed	Share of market value of purchased seed
	Million dollars	*Percent*	*Percent*	*Million dollars*	*Percent*
Corn	1,294	27.8	95.0	1,230	40.2
Soybeans	954	20.5	55.0	525	17.2
Cotton	144	3.1	50.0	72	2.4
Wheat	888	19.1	10.0	89	2.9
Total, major crops	3,280	70.6	58.4	1,915	62.6
Other crops	1,369	29.4	83.4	1,142	37.4
Total	4,649	100.0	65.8	3,057	100.0

[1] Including the market value of saved seed.

Source: McMullen (1987b, pp. 86-87).

Table 5—Estimated U.S. market and purchased seed values, major crops, 1997

Seed stock	Acres planted	Seeding rate per acre[1]	Seed cost per acre[2]	Total market value of seed[3]	Share of total market value of seed	Share of acres planted with purchased seed	Market value of purchased seed	Share of market value of purchased seed
	Million acres	*Kernels or lbs*	*Dollars*	*Million dollars*	*Percent*	*Percent*	*Million dollars*	*Percent*
Corn	80.2	27,665	28.87	2,316	35.1	100.0	2,316	40.2
Soybeans	70.9	70	18.78	1,331	20.2	81.0	1,078	18.7
Cotton	13.3	14	10.49	139	2.1	78.0	109	1.9
Wheat[4]	71.0	83	12.21	867	13.1	37.0	321	5.6
Total, major crops	235.3			4,653	70.6		3,823	66.3

[1] For corn, kernels per acre was used; for soybeans, wheat, and cotton, pounds per acre was used. Based on figures from select States, from USDA, Agriculture Resource Management Survey (ARMS), 1998.
[2] Seed cost per acre is based on USDA's ARMS data.
[3] Including the market value of saved seed.
[4] Compiled from statistics provided in this report on winter wheat, spring wheat, and durum wheat. Seeding rate, seed cost per acre, and share of acres planted with purchased seed are based on the weighted averages of the three types of wheat. For durum, the seed cost per acre was not available and was estimated according to the percent change in the unit price of the crop.

Source: Acres planted from *Agricultural Statistics* (USDA, NASS, 1998); other data from ARMS.

$20.40 in 1989, due to an 11-percent increase (nominal; 5 percent in real terms) in corn seed price.

Soybeans. Soybean seeding rates per acre showed little year-to-year variation. For example, the seeding rate per acre was constant at 57 pounds from 1980 to 1985; the rate increased to 59 pounds in 1986 and 60 pounds in 1989 (table 6). Seeding costs per acre, however, varied significantly due to changes in the average seed price of soybeans. Seeding rates per acre were the same (70 pounds) in 1995 and 1996, but seeding costs per acre were higher in 1996 ($18.62) than in 1995 ($16.80) due to higher seed prices. Soybean seeding rates tend to be lower in Southern States, such as Arkansas, Georgia, Mississippi, Tennessee, and Louisiana. Northern States, on the other hand, have higher seeding rates and yields, and therefore have higher seed costs per acre than Southern States.

From 1986 to 1996, farmers in the major soybean-producing States used purchased seed on more than 70 percent of the planted acreage and consequently had higher production costs per acre. The choice of purchased versus homegrown seed is influenced by many factors, such as difference in seed price and yield. Although homegrown seed is cheaper than purchased seed, homegrown seed requires cleaning, inoculation before planting, and germination tests, and in some instances, the seeding rate may have to be increased. Furthermore, the yield potential of new purchased varieties may exceed that of (older) home-grown varieties.

Table 6—Seeding rate, cost per acre, and share of acres with purchased seed, major field crops in surveyed States

Year	Corn				Soybeans				Cotton				Deflator: (Index of prices paid by U.S. farmers) 1984=1.00	Real price of seed		
	Average rate per acre	Average cost per acre	Acres with purchased seed	Seed price per bushel	Average rate per acre	Average cost per acre	Acres with purchased seed	Seed price per bushel	Average rate per acre	Average cost per acre	Acres with purchased seed	Seed price per bushel		Corn per bushel	Soybean per bushel	Cotton per 100 lbs
	Kernels	*Dollars*	*Percent*	*Dollars*	*Pounds*	*Dollars*	*Percent*	*Dollars*	*Pounds*	*Dollars*	*Percent*	*Dollars*		*———1984 dollars———*		
1972	20,955	4.90	NA	21.50	68	5.90	NA	5.21	25.00	4.35	NA	17.40	0.38	57.11	13.84	46.22
1973	20,955	5.03	NA	22.20	68	9.89	NA	8.75	25.00	4.56	NA	18.30	0.43	51.05	20.12	42.08
1974	20,955	5.66	NA	25.00	68	10.74	NA	9.50	25.00	6.33	NA	25.30	0.49	50.58	19.22	51.19
1975	22,110	8.74	NA	36.50	63	11.03	NA	10.50	26.00	8.74	NA	33.60	0.54	67.22	19.34	61.88
1976	22,110	8.74	NA	36.50	63	7.77	NA	7.40	26.00	7.41	NA	28.50	0.58	63.11	12.79	49.27
1977	22,110	9.57	NA	40.00	63	13.65	NA	13.00	26.00	7.88	NA	30.30	0.61	65.54	21.30	49.65
1978	22,110	10.29	NA	43.00	63	12.10	NA	11.50	26.00	8.06	NA	31.00	0.66	65.16	17.43	46.98
1979	22,110	10.88	NA	45.50	63	12.60	NA	12.00	26.00	8.61	NA	33.10	0.75	60.58	15.98	44.07
1980	21,945	12.46	NA	52.50	57	9.88	NA	10.40	26.00	9.15	NA	35.20	0.84	62.52	12.39	41.92
1981	21,945	14.23	NA	60.00	57	13.30	NA	14.00	24.00	9.74	NA	40.60	0.92	65.45	15.27	44.29
1982	21,879	15.12	NA	63.70	57	10.17	NA	10.70	24.00	9.98	NA	41.60	0.95	66.71	11.21	43.57
1983	21,896	15.26	NA	64.60	57	9.60	NA	10.10	24.00	10.27	NA	42.80	0.98	66.06	10.33	43.77
1984	21,900	16.67	NA	70.20	57	12.73	NA	13.40	24.00	11.52	NA	48.00	1.00	70.20	13.40	48.00
1985	21,912	16.96	NA	71.80	57	13.31	NA	11.90	24.00	11.57	NA	48.20	0.99	72.57	12.03	48.72
1986	23,800	19.09	100	65.60	59	10.44	73	10.80	18.13	7.81	68	46.60	0.97	67.76	11.16	48.13
1987	24,000	18.30	100	64.90	59	10.05	73	11.30	19.09	8.46	81	48.10	0.98	66.01	11.49	48.92
1988	24,100	18.64	100	64.20	62	12.86	73	11.90	18.00	8.36	86	47.70	1.05	60.86	11.28	45.22
1989	24,100	20.40	100	71.40	60	15.52	68	14.70	18.00	8.17	67	50.10	1.12	63.93	13.16	44.86
1990	24,700	20.50	100	69.90	62	14.20	71	12.50	17.00	7.80	70	54.30	1.16	60.24	10.77	46.80
1991	24,906	20.79	100	70.20	64	15.07	73	12.80	17.00	8.11	66	58.20	1.18	59.41	10.83	49.26
1992	25,304	21.35	100	71.80	65	15.40	73	12.40	16.00	8.74	74	59.70	1.19	60.14	10.39	50.00
1993	25,564	22.72	100	72.70	NA	16.29	73	12.40	16.00	9.39	69	62.70	1.22	59.43	10.14	51.26
1994*	25,824	23.54	100	73.40	NA	17.25	72	13.60	16.00	9.49	66	63.50	1.25	58.52	10.84	50.63
1995*	26,588	24.50	100	77.10	70	16.80	71	13.40	15.00	9.67	64	68.20	1.29	59.87	10.40	52.96
1996**	27,500	25.97	100	77.70	70	18.62	76	14.80	14.00	9.85	66	73.00	1.36	57.30	10.91	53.83
1997**	27,665	NA	100	83.50	70*	NA	81	16.10	14.00	NA	78	74.90	1.39	60.07	11.58	53.88

* States included: corn: IL, IN, IA, MI, MN, MO, NE, OH, SD, and WI; soybeans: IL, IN, IA, MN, MO, NE, OH, AR, GA, KY, LA, MS, NC, and TN; cotton: AR, GA, CA, LA, MS, and TX.

**States included: corn: IL, IN, IA, MI, MN, MO, NE, OH, SD, and WI; soybeans: IL, IN, IA, MN, MO, NE, OH, AR, LA, MS, and TN; cotton: AR, CA, GA, LA, MS, TN, and TX.

NA = not available

Sources: Average rate per acre is based on data from Cropping Practices Surveys and Agricultural Resource Management Survey (ARMS). Cost per acre for 1972-85 is computed by multiplying rate per acre (pounds) with the price of seed per pound; cost per acre for 1987-96 is based on data from Cropping Practices Surveys and ARMS. Seed prices and deflator are from *Agricultural Statistics* (USDA, NASS, various years).

Table 7—Seeding rate, cost per acre, and share of acres with purchased wheat seed in surveyed States

Year	Winter wheat				Spring wheat				Durum wheat			Deflator: (Index of prices paid by U.S. farmers) 1984=1.00	Real price of seed	
	Average rate per acre	Average cost per acre	Acres with purchased seed	Price per bushel	Average rate per acre	Average cost per acre	Acres with purchased seed	Price per bushel	Average rate per acre	Average cost per acre	Acres with purchased seed		Winter wheat, per bushel	Spring wheat, per bushel
	Pounds	*Dollars*	*Percent*	*Dollars*	*Pounds*	*Dollars*	*Percent*	*Dollars*	*Pounds*	*Dollars*	*Percent*		—— *1984 dollars* ——	
1972	68	3.36	NA	2.97	73	3.21	NA	2.63	NA	NA	NA	0.38	7.89	6.99
1973	66	7.92	NA	7.20	74	3.97	NA	3.20	NA	NA	NA	0.43	16.56	7.36
1974	68	8.55	NA	7.50	75	10.5	NA	8.40	NA	NA	NA	0.49	15.17	17.00
1975	74	7.50	NA	6.10	75	10.4	NA	7.70	NA	NA	NA	0.54	11.23	14.18
1976	74	7.38	NA	6.00	81	8.78	NA	6.50	NA	NA	NA	0.58	10.37	11.24
1977	70	5.15	NA	4.40	86	7.44	NA	5.20	NA	NA	NA	0.61	7.21	8.52
1978	69	6.79	NA	5.90	81	6.89	NA	5.10	NA	NA	NA	0.66	8.94	7.73
1979	67	8.21	NA	7.40	72	6.48	NA	5.40	NA	NA	NA	0.75	9.85	7.19
1980	69	8.72	NA	7.40	79	8.71	NA	6.60	NA	NA	NA	0.84	8.81	7.86
1981	73	8.89	NA	7.41	79	0.53	NA	7.22	NA	NA	NA	0.92	8.08	7.88
1982	73	9.10	NA	7.42	79	9.10	NA	6.89	NA	NA	NA	0.95	7.77	7.22
1983	72	8.74	NA	7.28	87	9.70	NA	6.69	NA	NA	NA	0.98	7.44	6.84
1984	73	8.51	NA	7.40	69	7.33	NA	6.37	NA	NA	NA	1.00	7.40	6.37
1985	72	8.23	NA	7.16	79	8.03	NA	6.10	NA	NA	NA	0.99	7.24	6.17
1986	70	7.22	43	NA	89	7.67	52	5.94	93	7.13	33	0.97	NA	6.14
1987	73	6.20	40	NA	88	6.97	49	5.56	102	7.62	44	0.98	NA	5.66
1988	75	7.67	53	7.55	90	8.58	46	5.89	99	8.05	47	1.05	7.16	5.58
1989	77	9.59	41	6.57	89	8.82	40	6.71	99	10.13	47	1.12	5.88	6.01
1990	74	8.61	39	8.01	88	8.40	39	6.05	97	7.50	27	1.16	6.90	5.21
1991	74	8.65	36	6.89	89	6.52	32	4.72	100	6.66	27	1.18	5.83	3.99
1992	74	8.65	36	7.41	91	8.39	41	6.06	96	7.56	36	1.19	6.21	5.08
1993	72	8.25	40	7.73	93	8.54	40	5.98	100	7.69	40	1.22	6.32	4.89
1994*	71	7.68	39	7.90	95	10.11	38	7.37	103	12.60	37	1.25	6.30	5.88
1995*	74	9.10	33	7.80	96	10.24	36	7.12	109	12.24	41	1.29	6.06	5.53
1996**	69	8.27	32	8.50	101	14.61	21	8.10	107	13.88	20	1.36	6.27	5.97
1997*	73	NA	36	10.00	98	NA	41	7.30	112	NA	12	1.39	7.19	5.25

* States included: winter wheat: CO, ID, IL, KS, MO, MT, NE, OH, OK, OR, SD, TX, and WA; spring wheat: MN, MT, ND, and SD.

** States included: winter wheat: CO, ID, KS, MT, NE, OK, OR, SD, TX, and WA; spring wheat: MN, MT, and ND.

NA = not available.

Sources: Average rate per acre is based on data from the Cropping Practices Surveys and Agricultural Resource Management Survey (ARMS) ARMS. Cost per acre for 1972-85 is computed by multiplying rate per acre (pounds) with the price of seed per pound; cost per acre for 1987-96 is based on Cropping Practices Surveys and ARMS. Seed prices and deflator are from *Agricultural Statistics* (USDA, NASS, various years).

Cotton. Average cotton seeding rates and seed costs per acre vary from year to year. From 1972 to 1985, average seeding rates per acre ranged from 24 to 26 pounds. However, average cost per acre was highest in 1985 ($11.57) due to a higher cotton seed price of $48.20 per 100 pounds. From 1986 to 1996, cotton seeding costs per acre were lower due to lower seeding rates. Although cotton seed price over the same period was much higher than in previous years, lower seeding rates offset the higher cost of producing cotton. From 1986 to 1997, the share of the cotton acres planted with purchased cotton seed ranged from 64 to 81 percent.

Wheat. The average seeding rates per acre for winter wheat vary from year to year (table 7). From 1972 to 1996, the average seeding rates per acre ranged from 66 to 77 pounds. Areas where moisture is plentiful in the growing season, due to either heavy rain or irrigation, support heavier seeding rates. Seeding costs per acre reflect either seed price or seeding rate per acre or both. Average share of winter wheat acres planted with purchased seed also varied from year to year. The type of winter wheat (white, soft red, and hard red), as well as local economic situations, seed prices, and yield of purchased seed, apparently account for much of the variation. For example, in 1993, Washington, Idaho, Oregon, Ohio, and Illinois used purchased seed on more than 60 percent of the winter wheat acreage. In the rest of the producing States, the share of acreage planted from purchased seed ranged from 21 to 51 percent (USDA, 1993). The average seed cost per acre of spring and durum wheat also varied across geographic regions and from year to year due to changes in seeding rate and seed price. Farmers used homegrown spring and durum wheat seed on more than 50 percent of their acreage.

International Seed Markets

The United States is a net exporter of seed, with a seed trade surplus of $384 million in 1996 (table 8). The value of U.S. seed exports grew from $305 million in 1982 to $698 million in 1996. This increase primarily reflects increases in exports of seed for forage crops, vegetables, flowers, and corn. Mexico, Canada, Italy, Japan, France, the Netherlands and, more recently, Argentina, are the largest importers of U.S. seed. Together, these countries accounted for approximately 72 percent of total U.S. seed exports in 1996 (table 9). On a regional basis, North America and Central America (39 percent), Western Europe (29 percent), Middle East and Asia (18 percent), and South America (10 percent) accounted for 96 percent of the total value of U.S. exports in 1996.

Some demand for seed in the United States is met by imports, which compete with U.S.-grown seed in quality, price, and other factors. While both exports and imports of seeds grew substantially over the past two decades, the growth rate of seed imports has exceeded that of seed exports in the United States. The value of total seed imports increased from $87 million in 1985 to $314 million in 1996, a growth rate more than three times that of exports (table 8). This increase is largely reflected in increased seed imports for corn, forage, vegetables, flowers, and other crops. Moreover, the United States also takes part in an extensive amount of multidirectional trade in international seed markets, in which the seeds for many of the same crops are exported and imported.

In 1996, U.S. demand for imported seed was met by a number of different countries. Canada (28 percent), Chile (18 percent), and the Netherlands (9 percent) had the highest shares of total value of U.S. seed imports. On a regional basis, the leading suppliers of seed to the United States were North America and Central America, followed by South America, Asia, and Western Europe (table 10).

In terms of volume, the six leading importing countries of U.S. field corn seed are Italy, Mexico, Canada, France, the Netherlands, and Spain. Shares of these countries' imports of U.S. field corn, which vary from year to year, dropped from 79 percent in 1995 to 63 percent in 1996 (table 11). Over the same period, the volume of U.S. corn seed exports to the six leading importers fell to 53,955 metric tons, a 19-percent decline. Despite this drop, total U.S. corn seed exports to all countries reached 86,183 metric tons in 1996, an increase of 2 percent over 1995 (table 11).

The top three importing countries of U.S. soybean seed by volume are Mexico, Italy, and Japan. In 1996, volume of U.S. soybean seed exports to these three leading trading partners was 63,881 metric tons, an increase of 11 percent from 1995. Together these countries accounted for 86 percent of total U.S. soybean seed exports. From 1995 to 1996, soybean seed exports to Japan increased 41 percent but exports to Italy declined 12 percent and exports to Mexico remained unchanged. Over the same period, however, the volume of total U.S. soybean seed exports to all countries increased 16 percent, from 63,982 metric tons to 73,911 metric tons.

Table 8—Exports and imports of U.S. seed for planting

Item	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
							Million dollars								
Exports:															
Forage	66	65	70	59	74	75	94	96	104	101	114	116	120	115	139
Vegetables	115	122	135	120	128	138	167	153	176	220	221	218	240	242	231
Flowers	5	6	9	8	9	8	9	11	13	14	19	19	22	27	32
Corn[1]	55	73	46	89	77	63	66	68	138	181	177	168	181	165	144
Grain sorghum	28	32	33	33	29	16	29	55	27	28	34	34	20	12	19
Soybeans	22	12	19	17	19	36	26	54	45	41	30	28	23	25	25
Trees/shrubs	2	2	2	2	2	2	3	4	2	2	3	2	2	2	4
Sugarbeets	4	4	3	2	2	1	2	1	2	3	3	3	4	2	3
Other	8	14	5	28	31	33	26	68	81	82	68	31	41	77	101
Total exports	305	330	322	358	371	372	422	510	588	672	669	619	652	667	698
Deflator, index of prices received by farmers	0.938	0.948	1.000	0.901	0.854	0.867	0.966	1.015	1.017	0.974	0.965	0.991	0.977	0.995	1.097
Exports in 1984 $	325.0	348.2	322.0	397.2	434.6	428.8	436.8	502.3	578.2	690.1	693.6	624.8	667.4	670.1	636.2
Imports:															
Forage	17	34	17	18	39	65	52	43	35	31	45	45	39	44	52
Vegetables	31	31	32	34	42	49	58	56	60	79	82	83	85	97	107
Flowers	12	10	18	18	18	21	21	24	23	24	27	31	35	43	56
Corn[2]	12	6	22	14	9	5	10	37	18	15	35	29	44	35	63
Trees/shrubs	1	1	1	1	1	1	2	2	2	2	2	2	1	2	4
Other	3	2	1	2	3	4	4	6	9	14	10	17	23	22	32
Total imports	76	84	90	87	112	146	147	168	147	165	201	208	227	243	314
Imports in 1984 $	81.0	88.6	90.0	96.5	131.2	168.3	152.2	165.5	144.6	169.4	208.4	209.9	232.4	244.1	286.2
Trade balance	229	246	231	271	258	226	275	342	441	507	463	411	425	424	384
Trade balance in 1984 $	244.0	259.6	231	300.6	303.4	260.5	284.6	336.8	433.7	520.6	485.2	414.8	435.1	426.0	350.0

[1] Does not include seed for sweet corn or corn seed provided as food aid.
[2] Certified corn.

Source: Compiled by Mohinder Gill from USDA's Foreign Agricultural Service (FAS) data.

Table 9—Regional and country shares of U.S. seed exports

Region and country	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
								Percent of total value							
North and Central America	30.0	32.8	31.2	25.0	20.7	24.7	23.0	33.4	26.4	24.8	30.7	33.7	31.7	29.5	39.0
Canada	9.5	8.8	8.9	7.4	6.3	9.4	8.3	6.2	10.2	10.0	11.3	11.8	11.9	13.2	12.2
Mexico	18.0	21.9	19.6	15.1	12.3	13.0	12.6	25.4	14.4	13.2	17.8	20.1	18.0	14.7	25.5
Other	2.5	2.1	2.7	2.5	2.0	2.3	2.1	1.8	1.8	1.6	1.6	1.8	1.8	1.6	1.3
South America	6.9	8.0	8.8	7.0	9.0	7.6	10.9	5.7	4.3	4.1	5.6	7.4	8.1	8.6	9.8
Argentina	0.7	1.0	2.0	1.1	2.5	2.5	3.0	2.0	1.4	1.4	3.0	3.0	4.1	4.4	6.0
Brazil	1.7	2.0	1.0	1.1	1.1	1.2	1.2	0.6	0.5	0.6	0.5	1.0	0.9	1.1	0.8
Chile	0.3	0.6	1.1	0.3	0.4	0.5	0.8	0.6	0.6	0.6	0.6	1.0	1.1	1.0	1.0
Colombia	1.0	1.2	1.4	0.8	1.0	0.9	1.1	0.6	0.6	0.6	0.6	0.7	0.6	0.7	0.6
Venezuela	2.4	1.9	2.2	2.9	3.0	1.4	3.3	0.6	0.6	0.6	0.4	0.7	0.5	0.5	0.4
Other	0.8	1.4	1.0	0.8	1.0	1.1	1.5	1.4	0.5	0.5	0.5	1.1	0.8	0.9	1.0
Western Europe	35.2	29.8	26.4	37.5	36.4	39.7	34.9	29.4	40.7	42.3	36.1	30.3	30.3	34.9	29.3
France	5.5	4.9	4.2	9.6	6.2	4.5	4.5	3.7	7.4	7.2	6.3	6.0	4.9	5.1	4.2
Germany	2.7	2.0	1.7	1.8	1.7	1.6	1.4	1.3	1.7	3.0	1.9	1.8	2.8	1.6	1.9
Greece	2.3	1.7	1.4	1.9	2.3	1.3	1.8	1.0	1.4	2.0	1.3	1.8	2.8	1.9	3.4
Italy	10.2	8.5	8.3	12.5	12.7	19.3	12.4	11.2	16.8	16.2	14.8	10.7	10.0	11.5	10.1
Netherlands	4.8	4.8	3.4	4.6	5.8	5.4	4.4	4.2	4.9	6.0	4.4	4.7	4.7	6.6	3.7
Spain	1.5	1.0	1.2	1.4	1.6	2.1	4.4	2.9	3.4	2.5	2.4	2.0	2.3	3.7	2.5
United Kingdom	3.4	2.6	2.2	2.7	2.8	2.6	2.9	2.6	1.9	1.7	1.7	1.4	1.4	1.9	2.0
Other	4.6	4.2	4.0	3.1	3.4	2.8	3.1	2.5	3.2	3.5	3.5	1.8	1.3	2.6	1.5
Eastern Europe and former Soviet Union	0.9	1.1	0.5	3.3	4.8	0.2	2.0	1.0	2.0	3.7	1.6	7.2	5.4	1.3	0.8
Romania	0.2	0.2	0.2	0.3	0.5	0.0	0.6	0.3	0.8	1.5	0.5	2.0	2.2	0.0	0.0
Ukraine	0.4	0.1	0.0	0.3	0.7	0.0	0.0	0.0	0.0	0.0	0.0	4.7	0.5	0.7	0.1
Other	0.3	0.8	0.5	2.7	3.6	0.2	1.3	0.7	1.2	2.2	1.1	0.6	2.7	0.5	0.7
Middle East and Asia	20.8	21.3	26.5	21.9	23.9	22.6	24.4	26.0	22.3	21.2	21.6	17.1	20.9	19.8	17.6
Hong Kong												0.4	2.6	0.6	0.3
Japan	11.9	11.2	11.5	10.7	9.5	12.3	11.8	8.9	7.8	7.1	8.1	8.2	9.0	8.8	9.8
Saudi Arabia	3.4	3.1	4.5	2.8	3.6	2.0	4.2	10.4	10.0	9.4	7.9	2.3	2.6	1.7	1.5
South Korea	0.5	0.7	1.5	0.8	0.9	1.0	1.0	0.7	0.6	0.7	0.9	1.2	1.7	1.4	1.3
Other	5.0	6.3	9.0	7.6	9.9	7.4	7.5	6.0	3.9	4.0	4.7	4.9	5.0	7.2	4.7
Africa	4.1	4.5	4.7	2.9	3.2	3.0	2.9	2.7	2.7	2.5	2.9	3.0	2.1	3.8	1.3
Oceania	2.1	2.6	1.9	2.4	1.9	2.2	2.0	1.5	1.5	1.4	1.4	1.3	1.7	2.0	1.7
Australia	1.7	2.2	1.5	2.0	1.6	1.8	1.7	1.2	1.2	1.2	1.2	1.0	1.3	1.6	1.4
Other	0.4	0.4	0.4	0.4	0.3	0.4	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.4	0.3
World[1]	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Totals may not add due to rounding

Source: Compiled by Mohinder Gill from USDA's Foreign Agricultural Service (FAS) data.

Table 10—Regional and country shares of U.S. seed imports

Region and country	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
	Percent of total value														
North and Central America	30.0	32.8	31.2	38.5	43.4	44.4	35.8	33.2	33.4	31.4	32.6	31.2	33.9	37.1	33.5
Canada	9.5	8.8	8.9	26.7	35.1	37.7	30.4	27.0	26.1	24.9	25.4	22.8	27.2	29.2	27.5
Mexico	18.0	21.9	19.6	4.0	2.9	2.0	2.1	3.2	3.4	3.8	3.2	4.5	3.1	3.8	3.5
Other	2.5	2.1	2.7	7.7	5.4	4.7	3.2	3.2	4.0	2.7	3.9	3.9	3.6	4.1	2.5
South America	6.9	8.0	8.8	9.2	7.0	6.0	8.3	17.7	12.3	11.7	21.2	17.2	18.9	17.4	24.0
Argentina	0.7	1.0	2.0	0.0	0.0	1.5	0.7	4.0	1.0	0.7	3.6	3.3	2.8	2.0	4.9
Chile	0.3	0.6	1.1	8.2	6.2	4.0	6.8	13.3	11.2	10.7	17.2	13.5	15.7	14.8	18.1
Other	5.9	7.0	5.6	1.0	0.8	0.5	0.8	0.4	0.1	0.3	0.4	0.5	0.4	0.6	1.0
Western Europe	35.2	29.8	26.4	21.0	18.7	19.2	16.8	16.3	15.7	18.0	16.2	21.7	18.7	18.1	15.9
Denmark	1.1	0.9	0.7	1.6	1.2	2.1	1.9	1.5	1.4	1.2	1.7	2.6	1.3	1.5	1.8
France	5.5	4.9	4.2	1.4	1.1	1.7	1.0	1.3	1.4	1.8	1.7	2.2	2.4	2.3	2.0
Germany	2.7	2.0	1.7	1.4	2.2	2.5	2.2	1.8	1.6	2.2	2.0	2.5	2.4	1.9	2.0
Italy	10.2	8.5	8.3	1.7	1.1	1.2	1.6	1.0	1.0	1.2	1.2	0.9	0.9	1.1	0.9
Netherlands	4.8	4.8	3.4	11.7	10.5	10.2	9.2	8.9	9.3	10.7	8.7	12.3	10.6	10.2	7.8
Other	10.7	8.6	8.0	3.2	2.5	1.5	0.9	1.9	0.9	1.0	0.9	1.2	1.2	1.1	1.4
Eastern Europe and former Soviet Union	0.9	1.1	0.5	1.8	0.4	0.5	1.3	3.3	0.7	0.1	0.5	1.7	1.9	0.5	0.4
Asia	20.8	21.3	26.5	20.1	22.2	19.4	24.5	24.9	30.5	31.3	22.4	21.1	20.0	19.9	21.1
China				0.0	0.0	0.0	2.4	3.9	6.8	9.0	5.5	4.8	6.0	7.0	7.3
India	0.0	0.0	0.0	3.3	6.5	2.9	7.5	3.5	3.1	5.2	2.7	1.8	1.9	2.4	2.4
Japan	11.9	11.2	11.5	6.1	6.1	6.0	6.4	6.9	7.6	7.8	6.2	9.0	7.7	6.3	5.3
Taiwan	0.0	0.0	0.0	7.6	6.0	6.7	4.5	6.2	4.8	3.5	3.6	1.8	0.8	1.1	1.0
Thailand	0.0	0.0	0.0	0.0	0.0	0.7	1.6	2.8	5.4	5.3	4.0	2.8	2.0	2.5	2.6
Other	8.9	10.1	15.0	3.0	3.6	3.1	2.0	1.5	2.9	0.5	0.4	0.8	1.5	0.6	2.5
Africa	4.1	4.5	4.7	6.4	4.0	3.9	3.8	0.7	0.9	1.3	1.1	1.4	1.0	1.6	1.0
Oceania	2.1	2.6	1.9	3.0	4.3	6.5	7.4	4.0	6.4	5.5	4.5	4.6	3.1	3.3	3.5
Australia	1.7	2.2	1.5	2.2	1.8	2.1	1.8	1.6	2.2	1.9	2.0	1.4	1.9	1.6	1.6
New Zealand	0.4	0.4	0.4	0.8	2.6	4.5	5.6	2.4	4.2	3.5	2.5	3.2	1.2	1.7	1.9
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
World[1]	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Totals may not add due to rounding

Source: Compiled by Mohinder Gill from USDA's Foreign Agricultural Service (FAS) data.

Table 11—U.S. exports of corn and soybean seed by country of destination and volume

Commodity/country	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
						Metric tons					
Corn seed:											
Canada	1,621	2,505	2,582	1,548	4,076	7,561	8,192	8,678	15,421	16,890	13,217
France	2,121	2,542	2,439	2,873	9,666	10,953	13,859	8,177	6,188	7,732	5,030
Italy	7,939	12,229	8,741	12,168	20,889	21,773	23,955	14,178	11,782	15,042	10,383
Mexico	3,703	3,143	3,151	10,205	10,329	7,963	12,472	15,750	16,453	15,175	15,088
Netherlands	5,127	695	1,060	351	2,437	10,354	2,791	4,834	7,977	7,062	6,691
Spain	1,245	2,049	4,134	1,836	4,132	2,076	2,853	2,492	4,004	4,796	3,546
Subtotal	21,756	22,121	22,915	28,981	51,529	66,952	65,054	56,039	62,170	66,697	53,955
All others	22,906	10,291	10,632	7,876	18,837	26,770	13,455	32,690	43,126	17,724	32,228
Total, all countries	44,662	32,412	33,547	36,857	70,366	93,722	78,509	88,729	105,296	84,421	86,183
Soybean seed:											
Italy	NA	44,348	27,833	20,185	55,937	65,571	34,500	27,764	15,711	14,672	12,970
Japan	NA	4,151	5,277	1,608	2,325	6,947	7,341	7,439	9,654	19,741	27,751
Mexico	NA	12,630	8,922	100,380	36,731	4,827	32,674	19,472	8,891	23,116	23,160
Subtotal	NA	61,129	42,032	122,173	94,993	77,345	74,515	54,675	34,256	57,572	63,881
All others	NA	14,035	11,698	6,409	11,998	13,659	9,070	14,216	13,700	6,410	10,030
Total, all countries	NA	75,164	53,730	128,582	106,991	91,004	83,585	68,891	47,964	63,982	73,911

NA = not available.

Source: Compiled by Mohinder Gill from USDA's Foreign Agricultural Service (FAS) data.

Regulations Have Affected the Seed Industry

Agricultural innovations, such as improved plant varieties, are a product of research and development. Seeds embody the scientific knowledge needed to produce a new plant variety with desirable attributes, such as higher yield, greater disease resistance, or improved quality. To fully understand the nature of the seed industry, it is necessary to consider the regulations that affect the costs and benefits faced by public and private sector innovators, agricultural producers, and other agents in the seed market.

Appropriability and Agricultural R&D

Some agricultural innovations are imperfectly appropriable, meaning that the innovation, or the knowledge embodied in the innovation, can be transmitted to, imitated by, or reproduced by prospective competitors with minimal difficulty or at a low cost, and with little or no obligation to compensate the innovators (Cohen and Levin, 1989, pp. 1090-1991). Plant breeders, in particular, face both the risk of imitation by competing seed firms and the risk of seed reproduction by farmers themselves. For example, once marketed, plant breeding innovations embodied in the seeds of improved self-pollinated varieties, such as wheat, can be easily adapted by competing seed firms into their own product lines without compensation to the innovators if property right protections are not available (Beach and Fernandez-Cornejo, 1994, p. 5). Once the seeds are sown, they can also be reproduced and used by farmers as seed for planting in subsequent years, again without compensation.

If innovators are unable to assert property rights over their innovations or the knowledge used in creating innovative products, they may be unable to realize the full rewards of their efforts. This effect may reduce the private incentives for further innovations. If the innovation provides social benefits, as is frequently the case with agricultural sector innovations, then limited private incentives may result in research underinvestment. The establishment of patent laws and other forms of enforceable legal protection, which provide innovators limited market power, thereby generating private incentives for research, offer a potential solution to this appropriability problem and its social consequences. Public investments in socially desirable research and development, particularly in areas in which private incentives are inadequate, offer another possible solution.

IPR Protection in the Seed Industry

Providing private incentives to innovators and inventors is a clear and longstanding priority in U.S. agriculture and industry. The U.S. Constitution charges the Congress with the responsibility of establishing laws that award innovators exclusive proprietary rights over their inventions and ideas for limited periods of time. The first intellectual property rights (IPR) legislation passed by Congress was the Patent Act of 1790, which protects the intellectual property rights of inventors, discoverers, and innovators, and establishes a framework through which they may obtain financial rewards through the functioning of the market system (see box on timeline of regulations). The Patent Act and its subsequent amendments, however, do not extend IPRs to new plant varieties; rather, they classify biological innovations, such as new plant varieties, as "products of nature" and exclude them from protection (Fuglie et al., 1996, p. 35).

In 1790, the lack of protection over plant varieties was of limited relevance to most farmers, breeders, and other agricultural sector participants because farmers of that era relied on nonhybrid varieties of seed for planting new crops. These plant varieties were seeded by the natural processes of pollination. Seeds from self-pollinating crops, such as wheat or cotton, could be saved from one crop harvest and planted for the next without the seed losing yield potential or vigor. Seeds from cross-pollinating crops, such as corn, could also be saved from one harvest and planted for the next. However, before the advent of hybrid varieties, farmers had to select more carefully among these seeds to maintain the desirable characteristics they wanted.[1]

The use of saved seeds to plant subsequent crops severely limited the extent to which innovators might realize the benefits of plant breeding efforts. In practical terms, it was nearly impossible for an innovator to maintain appropriability over nonhybrid seeds, thus

[1] This genetic malleability of corn, on the other hand, meant that farmers could more easily select for characteristics they wanted on their own.

Timeline of Regulations Related to Intellectual Property Rights to Plant Varieties

1790. The first intellectual property rights (IPR) legislation passed by Congress was the ***Patent Act of 1790***, which protects the intellectual property rights of inventors, discoverers, and innovators and establishes a framework through which these individuals may obtain financial rewards through a functioning market system. The Patent Act and its subsequent amendments do not, however, extend IPRs to new plant varieties; rather, they classify biological innovations, such as new plant varieties, as "products of nature" and exclude them from protection.

1883. One of the oldest international IPR agreements is the ***Paris Convention for the Protection of Industrial Property*** of 1883, which seeks to harmonize patent regimes among its 100 signatory countries. However, the convention provides its members only limited property rights protection for innovation of plant varieties and biological processes for plant production.

1930. The first IPR legislation enacted to specifically address issues of plant breeding was the ***Plant Patent Act of 1930 (PPA)***. Administered by the U.S. Patent and Trademark Office (PTO), the PPA provides patent protection over asexually or vegetatively reproduced plant varieties. The PPA also includes patent protection for spores, mutants, hybrids, newly found seedlings, or plants found in an uncultivated state, and extends property rights for a period of 17 years.

1952. The ***Patent Act of 1952 (PA)*** extends patent rights to agricultural innovations under a much more general category that includes "any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvements thereof." Patent protection under the PA covers agricultural machinery, equipment, chemicals, production processes, and similar inventions, and is termed "utility patent protection." More importantly, the PA's broad definition of what may be entitled to patent protection leaves an important opening for covering innovations in biotechnology and genetic engineering.

1961. The International Convention for the Protection of New Varieties of Plants was adopted in Paris, France, with the objective of providing intellectual property rights to the breeders of new varieties of plants. The Convention established the ***International Union for the Protection of New Varieties of Plants*** (UPOV—*Union Internationale pour la Protection des Obtentions Végétales*), an intergovernmental organization headquartered in Geneva, Switzerland. The Convention was revised in 1972, 1978, and 1991. The 1991 revision attempts to expand protection to address new issues in agricultural biotechnology.

1960s. The American Seed Trade Association formed the Breeders' Rights Study Committee to examine issues related to plant breeders' property rights. This effort helped enact the Plant Variety Protection Act in December 1970.

1970. ***The Plant Variety Protection Act (PVPA)*** grants breeders a Certificate of Protection that gives them exclusive rights to market a new plant variety for 18 years from the date of issuance. These exclusive rights are subject to a research exemption and a farmer's exemption.

1971. The Consultative Group on International Agricultural Research (**CGIAR**) is established as a key institution in the free international exchange of plant genetic materials. CGIAR, a global network of agricultural research centers, receives funding from multilateral agencies, governments of both industrialized and developing countries, and private foundations. Included within CGIAR's charter is the coordination of efforts to preserve plant genetic material and distribute these resources to research institutions in member countries.

1980. Breeders' rights were strengthened by the U.S. Supreme Court's 1980 decision in ***Diamond*** v. ***Chakrabarty***, which extends patent rights to genetically engineered microorganisms, an important tool and product of biotechnology.

1983. FAO member countries passed Resolution 8/83, the International Undertaking on Plant Genetic Resources (the Undertaking), to ensure free access to genetic material whether existing in the public domain or developed commercially.

1985-88. A series of rulings by the PTO's Board of Appeals and Interferences widened the scope of patent protection for genetically engineered organisms by including plants and nonhuman animals. These rulings extend IPR to a wide range of new biotechnology products in the form of utility patents awarded under the PA. These products include seeds, plants, plant parts, genes, traits, and biotechnology processes.

1994. The ***1994 amendment to the PVPA***, which went into effect in April 1995, brought the PVPA into conformity with international standards established by the International Union for the Protection of New Varieties of Plants and allowed the United States to ratify the 1991 International Convention for the Protection of New Varieties. Protection provided by Certificates of Protection extended from 18 to 20 years for most crops.

2000. A case involving Pioneer Hi-Bred brought before the U.S. Federal Court of Appeals reinforced plant breeders' intellectual property protection through protection certificates issued under the PVPA or through utility patents awarded under the PA. This ruling extended the options available to plant breeders seeking to assert property rights over their innovations.

2001. FAO members approved an International Treaty on Plant Genetic Resource for Food and Agriculture growing out of the International Undertaking in November 2001, although the agreement is subject to ratification by member states.

limiting the role of an IPR regime where nonhybrid seeds play a central role in agriculture.

By the 1920s, the development of hybrid corn seed offered farmers an alternative to open-pollinated corn. Hybrids also proved beneficial to plant breeders: As long as the lineage of a hybrid remains known only to the breeder, the hybrid cannot be easily reproduced, thus providing the plant breeder with control and appropriability over the innovation. Moreover, seed saved and planted from the harvest of a hybrid crop tends to diminish in yield and vigor in subsequent harvests, thus ensuring breeders a continuous market for their seed so long as other higher performing hybrid seeds do not enter the market. The unique nature of hybrids led to extensive commercialization of the corn seed industry in the 1930s, even in the absence of a regulatory framework to protect new plant varieties.

The first IPR legislation passed to specifically address issues of plant breeding was the Plant Patent Act of 1930 (PPA). Administered by the U.S. Patent and Trademark Office (PTO), the PPA provides patent protection over asexually or vegetatively reproduced plant varieties. PPA specifically covers plants derived from parts of the parent other than its seeds or tubers, and thus covers plants that contain the exact genetic makeup as the parent plant. The protection includes spores, mutants, hybrids, newly found seedlings, or plants found in an uncultivated state and extends property rights for a period of 17 years (USITC, 1995, p. 16). Patent owners have the right to exclude others from reproducing their plants asexually or vegetatively and may enforce ownership through civil action brought against parties alleged to be infringing upon their patents. The PPA's explicit exclusion of plants that are sexually reproduced or propagated by tubers reflects the perception at the time that such varieties were not adequately identifiable, uniform, or stable enough to constitute varieties requiring patent protection.

The Patent Act of 1952 (PA) extended patent rights to agricultural innovations under a much more general category, which includes "any new and useful process, machine, manufacture, or composition of matter, or any new and useful improvements thereof" (35 U.S.C. § 101, in USITC, 1995, p. 16). The PA also includes patent protection for agricultural machinery, equipment, chemicals, production processes, and similar inventions and is termed "utility patent protection." The protection and exclusionary rights offered under the 1952 PA are, under many circumstances, significantly greater than similar protections and rights offered by the 1930 PPA and the 1970 Plant Variety Protection Act. More importantly, the PA's broad definition of what may be entitled to patent protection left an opening for covering innovations in biotechnology and genetic engineering.

Still, neither the 1930 PPA nor the 1952 PA contained language that extended IPR to seed- and tuber-propagated varieties. In the early 1960s, the American Seed Trade Association (ASTA) formed the Breeders' Rights Study Committee to examine the issue, an effort that contributed to the enactment of the Plant Variety Protection Act (PVPA) in December 1970 (USITC, 1995, p. 16).

The 1970 PVPA grants breeders a Certificate of Protection that gives them exclusive rights to market a new variety for 18 years from the date of issuance. These exclusive rights are subject to two exemptions: (i) a research exemption, which allows the use of the seed to develop new varieties; and (ii) a farmer's exemption, which allows a farmer whose primary occupation is growing crops for sale to save seed from a protected variety to plant on the farmer's land, and to sell from that seed to another farmer whose primary occupation also is to grow crops (Strachan, 1992). Saved seed that is sold under exemption (ii) must meet the applicable State seed laws and must be labeled to show the variety name as protected under the PVPA. Further, the PVPA does not extend protection to fungi, bacteria, and first-generation hybrids. Like the 1930 PPA, the 1970 PVPA is enforceable through the actions of a protected variety's owner. To enforce protection, an owner of a protected variety may bring civil action against parties allegedly infringing on his/her property rights, and would typically seek an injunction to prevent others from further violations (USDA, AMS, 2000a).

The 1994 amendment to the PVPA, which went into effect in April 1995, brought the PVPA into conformity with international standards established by the International Union for the Protection of New Varieties of Plants (UPOV)[2] and allowed the United States to ratify the 1991 International Convention for the Protection of New Varieties (Fuglie et al., 1996, p. 35). The amendment extends the length of protection

[2] Acronym from the French *Union Internationale pour la Protection des Obtentions Végétales*.

provided by a Certificate of Protection from 18 to 20 years from the date of issuance for most crops (25 years for trees, shrubs, and vines) (USDA, AMS, 2000a). The amendment also prohibits farmers from selling saved seed of protected varieties without the permission of the variety owner (Fuglie et al., 1996, p. 35). In addition, the amendment extends protection to tuber-reproduced plants (such as potatoes). The amendment's introduction of an "essentially derived" plant variety category, which entitles such varieties to protection, is specifically designed to address technological advances made in biochemistry and genetic engineering that enable breeders to develop varieties that may differ on the basis of a single gene or micromolecule within the DNA structure. The category extends the definition of distinctness to include varieties of GE plants for which the uniqueness exists at miniscule levels, thereby providing property rights to plant breeders over even the smallest of genetic manipulations of their varieties (USITC, 1995, p. 16; USC, 1970, § 2401, 2541).

The PVPA affords IPR to plant varieties that are demonstrably "new, distinct from other varieties, and genetically uniform and stable through successive generations" and includes protection for both nonhybrid and hybrid seeds (USDA, AMS, 2000a).[3] According to the PVPA, distinctness, a key determinant of a variety's potential for protection, may be based on "one or more identifiable morphological, physiological, or other characteristics (including any characteristics evidenced by processing or product characteristics, such as milling and baking characteristics in the case of wheat) with respect to which a difference in genealogy may contribute evidence" (USDA, AMS, 2001a).

The PVPA is administered by USDA's Plant Variety Protection Office (PVPO). The PVPO is responsible for scrutinizing applications for Certificates of Protection, including information on the variety's lineage, genealogy, and breeding methodology, as well as seed or cell-culture samples and other proof of the variety's distinctness, uniformity, and stability. Plant breeders applying for protection of new wheat varieties must also submit information on the milling and baking characteristics of the variety (USDA, AMS, 2000a). Applications may be submitted by both domestic and foreign breeders seeking protection for their variety in the U.S. marketplace.

Breeders' rights were strengthened by the U.S. Supreme Court's 1980 decision in *Diamond* v. *Chakrabarty*, which extends patent rights to genetically engineered microorganisms, an important tool and product of biotechnology. In the case brought before the Supreme Court, the underlying question was whether a genetically engineered bacterium designed to digest and break down crude oil was a "product of nature" that was not covered by the Patent Act or whether it was a new invention for which a patent could be awarded. Among the arguments brought before the Court was the fact that patents had been previously awarded for compositions containing living organisms, such as microbial spores, vaccines, yeast compositions, and certain dairy products. Ultimately, the Supreme Court determined that GE microorganisms were, in fact, patentable (Schor, 1994, pp. 60-61). A series of rulings by the PTO's Board of Appeals and Interferences widened the scope of patent protection for genetically engineered organisms by including plants and nonhuman animals. These rulings extend IPR to a wide range of new biotechnology products in the form of utility patents awarded under the PA. Products protected under the rulings include seeds, plants, plant parts, genes, traits, and biotechnology processes (Fuglie et al., 1996, p. 35; USITC, 1995, p. 16).

Breeder's rights were extended further with the Supreme Court's 1995 decision in *Asgrow* v. *Winterboer*, which precluded farmers from selling protected seed without a license from the variety's owner for varieties developed before April 1995 and not covered by the PVPA's 1994 amendment. This decision, along with the PVPA amendment, addressed the issue of appropriability in terms of the threat posed to plant breeders not by competing firms but by farmers who save and reproduce nonhybrid seed from their own crops for resale purposes (Fuglie et al., 1996, p. 35).[4]

A more recent case involving Pioneer Hi-Bred brought before the U.S. Federal Court of Appeals in 2000 reinforced plant breeders' intellectual property protection through protection certificates issued under the PVPA

[3] This does not apply to open-pollinated corn because it would not be "genetically uniform and stable through successive generations."

[4] This case is particularly relevant to the issue of genetically engineered nonhybrids such as herbicide tolerant "Roundup Ready" soybeans. Monsanto, the largest producer of these varieties, required farmers purchasing the soybean seed to enter into contracts that specifically prevented them from saving seed for future planting.

or through utility patents awarded under the PA (*AgBiotech Reporter*, 2000). This ruling extended the options available to plant breeders seeking to assert property rights over their innovations.

Both legislative and judicial action have contributed to an IPR regime in the United States that provides an extensive set of incentives to developing new plant varieties: plant patents for asexually or vegetatively propagated varieties under the PPA; certificates of protection for sexually or tuber-propagated varieties under the PVPA; and utility patents under the PA. Although the number of plant patents issued under the PPA exceeds all other types of property protection awarded to plant innovators, the number of protection certificates and utility patents has increased significantly in recent years (Fuglie et al., 1996, pp. 36-37).

IPR in the International Context

Although the U.S. IPR regime provides a comprehensive framework to protect plant breeders' rights and create incentives for plant breeding R&D, the relevance of the U.S. regime is better understood within an international context because the expansion of U.S. IPR has implications for genetic resource conservation worldwide. Historically, the United States and several other countries have facilitated the free exchange of plant genetic resources for research purposes as a means of increasing worldwide agricultural production and food security. However, the role of intellectual property rights in this context remains unclear and has been the subject of much international debate (USDA, ERS, 2000, p. 14).

A key institution in the free global exchange of plant genetic materials is the Consultative Group on International Agricultural Research (CGIAR), an international network of agricultural research centers established in 1971. CGIAR receives funding from multilateral agencies, governments of both industrialized and developing countries, and private foundations. Included within CGIAR's charter is the coordination of efforts to preserve plant genetic material and distribute these resources to research institutions in member countries. Historically, the free exchange of plant genetic resources has been important to the United States, not only because of its membership in CGIAR but also because of its need for access to genetic materials beyond U.S. borders. The relative lack of genetic diversity among indigenous plants makes the United States a "germplasm-deficient" country, and free exchange ensures the United States continued access to genetic resources from other countries to support its extensive work in agricultural R&D (Day-Rubenstein and Heisey, 2001, p. 22). In fact, as a result of collection and breeding activities, the United States is currently a net supplier of plant germplasm to the rest of the world (Day-Rubenstein and Heisey, 2001, p. 18).[5]

The United States, however, is also committed to supporting plant breeders and private sector investment in plant breeding R&D, a commitment that is shared with many other countries. As a result, the United States is party to a number of international agreements and conventions designed to protect the rights of plant breeders. One such agreement, the Paris Convention for the Protection of Industrial Property (1883), seeks to harmonize patent regimes among its 100 signatory countries. However, the Paris convention provides only limited property rights protection for plant varieties and biological processes for plant production (Van Wijk, 1993, p. 17). The UPOV provides for a more explicit IPR regime to its 52 member states by extending protection to distinct, uniform, and stable plant varieties for a minimum of 15 years.[6] The 1991 Act of the UPOV convention attempts to expand protection to address new issues in agricultural biotechnology. For instance, the 1991 Act eliminates an exemption for essentially derived varieties, under which breeders who created new varieties by incorporating single genes into an existing protected variety did not require permission from the variety owner (Van Wijk, 1993, pp. 6-7). Out of 52 member states, only 23, including the United States, have become a party to the 1991 Act (UPOV, 2003).

The difficulty of balancing free access to plant genetic materials with protecting breeders' rights was apparent in 1983, when member countries of the United Nations Food and Agriculture Organization (FAO) passed Resolution 8/83, the International Undertaking on Plant Genetic Resources (the Undertaking), seeking to ensure free access to genetic material, whether existing in the

[5] For some quantitative results, see Smale and Day-Rubenstein (2002).

[6] UPOV is an intergovernmental organization headquartered in Geneva, Switzerland. UPOV was established by the International Convention for the Protection of New Varieties of Plants with the objective of protecting new varieties of plants through intellectual property rights. The Convention was adopted in Paris in 1961, and it was revised in 1972, 1978, and 1991. These revisions, or amendments, are referred to as the "1972 Act," "1978 Act," and "1991 Act" (UPOV, 2003).

public domain or developed commercially. As a result of objections from the United States and other FAO member countries, compliance with the resolution was deemed nonbinding on members. Disagreements arose during subsequent rounds of discussion on key issues related to plant breeding, such as compensating farmers, particularly in developing countries, for their contribution to past plant genetic improvements; protecting the rights of plant breeders over their inventions, ideas, and products; ensuring free and equitable access to genetic materials; and establishing programs to preserve diverse genetic resources for future use. Members approved an International Treaty on Plant Genetic Resource for Food and Agriculture growing out of the Undertaking in November 2001, although it is subject to ratification by member states (FAO, 2001).

The UN Convention on Biological Diversity (1992) also addressed issues relevant to plant breeding, such as the equitable use and preservation of plant genetic resources, although the convention's provisions relating to IPRs were found wanting by the United States and other members (Day-Rubenstein and Heisey, 2001, pp. 20-21; Van Wijk, 1993, pp. 26-27). The convention was signed by the United States in 1993 but has not been ratified by the U.S. Senate (Day-Rubenstein and Heisey, 2001, p. 22).

While FAO, the UN, and CGIAR efforts focus on preserving genetic diversity and, to the extent possible, making plant genetic material available worldwide, a new international regulatory regime is poised to establish a much stricter international IPR regime. The 1986 Uruguay Round of the General Agreement on Tariffs and Trade (GATT) established the framework for an initiative on trade-related aspects of intellectual property rights (TRIP). Under TRIP, member countries of the World Trade Organization (WTO) are required to update their IPR legislation to meet new international standards. These new standards include the protection of seed and plant varieties with patents or similar property rights (Day-Rubenstein and Heisey, 2001, p. 22). Moreover, the WTO's authority to sanction members for noncompliance with TRIP would enable the organization to more effectively enforce the initiative, resulting in a stronger international IPR regime that will reflect and support the present IPR regime in the United States.

Regulation To Ensure Seed Quality

Along with the comprehensive framework designed to protect plant breeders' rights, the United States also offers protections to farmers who purchase seed, directly or indirectly, from plant breeders. Because the quality of most seed cannot be determined by visual inspection, the risks associated with seed choice are high. U.S. farmers are protected by a comprehensive system to ensure seed quality.

Varietal registration, a key protection for farmers who purchase seed, provides a system for establishing a variety's genetic identity and its performance characteristics, such as yield or disease resistance. In the United States, plant breeders register varieties with Federal agencies responsible for awarding plant patents or protection certificates. These agencies can provide farmers with information on the characteristics of different varieties that might otherwise be overly complicated or difficult to obtain in the marketplace. U.S. plant breeders are not required to provide information on a variety's performance characteristics, which is typically ascertained through field tests (Tripp, 1998, p. 160). Field testing is mandatory, however, in cases involving the introduction of GE organisms.

Seed certification and quality testing also offer protection to farmers. Seed certification establishes the genetic purity of a seed, while quality testing ascertains such information as germination rates, moisture content, or seed size. Individual States oversee the process of seed certification through State agencies, such as agricultural extension services; State agricultural departments; or independent bodies, such as crop improvement associations. The certification system is not a rigorous process of mandatory testing; rather, seed companies are required to adhere to truthful labeling provisions that permit companies to sell seed as long as seed quality information is completely disclosed on the packaging. This labeling provision is considered highly effective (Tripp, 1998, p. 164).

Environmental and Consumer Protection

Much like the laws that protect plant breeders' property rights and the interests of farmers, a regulatory framework provides protection for the environment and for consumers of agricultural commodities. These laws are particularly relevant in light of the expanding role of biotechnology in U.S. agriculture.

The Animal and Plant Health Inspection Service (APHIS) of the U.S. Department of Agriculture plays a central role in regulating the release of agricultural biotechnology products into the environment. Such products, which include genetically engineered plants, microorganisms, and invertebrates, are considered "regulated articles." Private firms and public institutions wishing to move or release these organisms must receive authorization from APHIS through either a notification or permit procedure. APHIS requires that the notifications and permit applications contain specific details about the organism's genetic makeup and lineage, as well as the testing and safety measures designed to prevent the organisms from being disseminated from the test site or persisting beyond the duration of the test. In the case of permits, APHIS often imposes additional conditions to ensure confinement. APHIS determines whether to authorize the test, based on whether the release will pose a risk to agriculture or the environment. APHIS and State authorities maintain a continuing right to inspect test sites at any time (USDA, 2000b). After years of field tests, an applicant may petition APHIS for a determination of nonregulated status in order to facilitate commercialization of the product. If, after extensive review, APHIS determines that the unconfined release does not pose a significant risk to agriculture or the environment, then the organism is "de-regulated." At this point, the organism is no longer considered a regulated article and can be moved and planted without APHIS authorization.

APHIS is also responsible for plant quarantines, a function that is crucial to protecting the environment from the spread of disease or pests. APHIS enforces regulations that govern the import and export of plants and seeds and are designed to ensure that sanitary and phytosanitary threats do not affect U.S. agriculture or the agriculture sectors of U.S. trading partners. The agency is also responsible for imposing quarantines on areas within the United States where disease or pests pose a threat. APHIS authority to impose quarantines is particularly important with the increase in adoption of bioengineered crops and concerns over genetic exchanges among these crops, weeds, and other crops (Tripp, 1998, p. 171).

If a plant is engineered to produce a substance that "prevents, destroys, repels, or mitigates a pest," then such substance is considered to be a pesticide and is subject to regulation by the U.S. Environmental Protection Agency (EPA) (Federal Register, November 23, 1994). The U.S. Food and Drug Administration (FDA) maintains regulatory control over all food applications of crops, including those crops that are developed through the use of biotechnology. Shoemaker et al. (2001, pp. 31-32) describe the EPA and FDA regulation of agricultural biotechnology products.

Seed Industry Structure Is Characterized by Growth and Consolidation

From the first ventures into the commercial production of hybrid corn seed in the 1930s, to the recent mergers and acquisitions, the seed industry has experienced extensive structural change and transition.

Early Industry Structure: 1920-1970

Until the late 19th century, most U.S. farmers depended on seed saved from their own crops cultivated in the previous year and did not purchase significant quantities of seed from commercial sources. It was not uncommon for farmers to share surplus seed with friends and neighbors. The advent and expansion of seed certification programs between 1915 and 1930 brought about large increases in the number of farmers who purchased seed from commercial traders instead of producing it themselves or obtaining it locally from neighbors. Seed certification programs provided quality assurances to farmers, leading to a rise in the role of commercial seed markets.

Most commercial seed suppliers at that time were small, family-owned private businesses lacking the financial resources necessary to pursue their own R&D activities. The primary role of seed businesses at the time was to multiply and sell seeds of varieties developed in the public domain, as R&D of improved plant varieties was carried out almost exclusively by land-grant colleges and universities, State agricultural experimental stations, and other public agencies (Duvick, 1998; McMullen, 1987).

At the end of the 19th century, the seed used in corn (the dominant field crop in U.S. agriculture) was almost entirely based on open-pollinated varieties (OPV) that farmers saved from prior crops and subsequently planted (Schor, 1994, p. 35). In the early part of the 20th century, public researchers developed high-yielding hybrid corn varieties that consistently outperformed OPVs. Capitalizing on these breakthroughs and the growing demand for hybrid seeds (and given the implicit form of proprietary rights enjoyed by hybrid corn breeders over their innovations), the private sector's role in the commercial market for hybrid corn seed increased significantly beginning in the 1930s (Duvick, 1998, pp. 198-200).

The development and diffusion of hybrid corn varieties, with their inherent capacity to protect returns to private investment, transformed the U.S. seed industry. Beginning in 1930, approximately 150 companies formed to produce hybrid corn seed and some 40 existing seed companies expanded their businesses to include production of hybrid corn seed. While most firms were established to produce and sell seed, some also instituted inhouse research and breeding programs to improve existing hybrids. As long as the lineage of a company's hybrid remained unknown to competitors or farmers, the company continued to hold a unique and marketable product until an even better hybrid was developed. By 1944, U.S. sales in the seed corn market had expanded to over $70 million, establishing corn seed as the core business of the U.S. seed industry (Duvick, 1998, p. 199).

The early growth of the seed industry shifted corn production to hybrids swiftly and extensively; by 1965, over 95 percent of American corn acreage was planted with hybrid seed. Industry expansion also generated profits sufficient to support reinvestment in plant breeding R&D, leading to continual increases in corn seed productivity and crop yields (McMullen, 1987, p. 89). By constantly improving their products through new research, private seed firms were able to maintain the corn seed market's longrun viability. The seed industry reshaped itself primarily around large firms highly vested in the corn seed industry. The smaller firms in the industry tended to be family-run, regionally oriented firms active only in producing, distributing, and marketing varieties developed by the public sector or larger private companies (Kimle and Hayenga, 1993, pp. 19-20). The ability of farmers to save nonhybrid seeds limited the expansion of the seed industry into other agricultural seed markets, establishing corn as the historical force behind the growth of the seed industry.

Modern Industry Structure: 1970-Present

With the exception of hybrid seed firms, few companies had proprietary rights over the plant varieties they sold as seed until the early 1970s.[7] Most private seed firms focused primarily on cleaning, handling, storing, packaging, and selling seed developed in the public domain. The 1970 PVPA, subsequent amendments and rulings, and other actions strengthened property rights by providing proprietary rights over sexually- and tuber-propagated new plant varieties, creating an incentive for private firms to enter the seed market.

Over the past three decades, the U.S. seed industry has been marked by transition. As recently as 1970, most seed firms were independent. During the 1970s, most small seed firms vanished, as mergers and acquisitions created a new seed industry structure dominated by large companies with primary investments in related sectors. For example, more than 50 seed companies were acquired by pharmaceutical, petrochemical, and food firms following the passage of the 1970 PVPA (Lesser, 1998). The acquiring companies were drawn to the potential profits available through the purchase of strong, well-developed seed companies. Those large corporations, many of them multinational conglomerates, possessed the resources needed to achieve scale economies in research and development. Many chemical firms entered the U.S. seed market because the agricultural chemicals market had reached maturity and profits in that sector were declining (Kimle and Hayenga, 1993, pp. 20-21).[8] Pursuing new, high-growth opportunities, large multinational corporations specializing in chemicals and pharmaceuticals, such as Ciba-Geigy, Sandoz, Royal Dutch/Shell, Upjohn, and Celanese, entered the seed industry in the mid-1970s (Kimle and Hayenga, 1993, pp. 19-20). As a result, private sector acquisitions expanded rapidly, and, by the early 1980s, several international firms were among the top seed sellers worldwide (table 12).

Table 12—-Global seed sales of top international seed companies

Company	1983	1989	1983	1989
	Million current dollars		*Million 1989 dollars*[1]	
Royal Dutch/Shell	650		784	
Pioneer Hi-Bred	557	840	672	840
Sandoz	319	471	385	471
Cardo	285		344	
Asgrow		270		270
DeKalb/Pfizer	187	205	226	205
ICI		250		250
SICA France Mais		170		170
Takii		170		170
Clause		159		159
Claeys-Luck	155		187	
Sakata		152		152
Upjohn	139		168	
Limagrain	130	268	157	268
Ciba-Geigy	107	148	129	148
Suiker Unie	100		121	
K.W.S.	80		97	
Cebeco	65		78	
Svalof	55		66	
Cargill	50	241	60	241

[1] Calculated using the U.S. GDP deflator.

Source: McMullen (1983), p. 94; Kimle and Hayenga (1989), p. 21.

In the early 1980s, developments in biotechnology created an additional incentive for firms to increase their R&D capacity and expand further into seed production. As the first products of crop biotechnology began large-scale extensive testing in the 1980s, the seed industry's structure underwent additional transformation. The industry again reorganized through extensive mergers, acquisitions, and joint ventures as companies sought to achieve economies of scale to offset the high costs of biotechnology R&D. Strong demand complementarities provide the rationale for joint ventures between chemical and seed businesses (Just and Hueth, 1993). An example is the case of the herbicide glyphosate and soybeans tolerant to glyphosate.

Despite these incentives, many large chemical and industrial manufacturing companies that invested heavily in the seed industry during the early 1980s are no longer in the seed business. Royal Dutch/Shell, a market leader in 1983 with seed sales topping $650 million, sold its seed unit and had exited the seed industry completely by 1989. Other large players in the market, such as Occidental Petroleum, Upjohn, Lubrizol, and Celanese, similarly shed their seed subsidiaries. Of the 14 companies that led industry sales in 1983, only 7 occupied top global sales positions by 1989. Pioneer Hi-Bred main-

[7] Apart from corn, the only other field crops that have been successfully hybridized are sorghum and sunflower. Breeders also successfully hybridized a number of vegetable crops, such as onions, tomatoes, broccoli, cabbage, melons, and spinach, but the market shares of these crops are marginal, compared with those of corn (McMullen, 1987, p. 89; Leibenluft, 1981, p. 95). Until recently, farmers growing other major field crops remained dependent on saved seed, thus limiting the growth of seed industries for those crops: only 55 percent of the soybean acreage, 50 percent of cotton acreage, and 10 percent of wheat acreage was cultivated with purchased seed as late as 1982 (McMullen, 1987, pp. 86-87).

[8] The chemical industry experienced its most marked growth—15 percent or more annually—during the late 1960s and 1970s. Since then, market growth has been under 10 percent and was predicted to slow in the late 1990s (Storck, 1987).

tained the leadership position in the market in 1989, followed by Sandoz, Asgrow, and Limagrain.

Mergers and acquisitions, along with increased private sector R&D expenditures, continued to grow through the 1990s. According to some industry experts, the acceleration in seed company acquisitions stemmed from efforts by acquiring companies to raise their market share in a market with rich profit potential (Kidd, 1989). Some businesses active in mergers and acquisitions may also have been attempting to consolidate market share and distribution infrastructure/capacity in selected species in anticipation of new biotechnology product developments. In addition, companies may seek to acquire others to facilitate access to protected intellectual property, particularly when licensing is costly (Blonigen and Taylor, 2000).

Some firms evolved toward developing "life sciences" complexes organized around the development of such products as agricultural chemicals, seeds, foods and food ingredients, and pharmaceuticals based on applications of related research in biotechnology and genetics. Monsanto, Novartis, and AgrEvo gained a significant share of the market through such strategic behavior (Begemann, 1997) (table 13). Most of those life sciences companies, however, divested their agricultural operations over the past 3 years (King, 2001; Fulton and Giannakas, 2002).

Table 13—Estimated seed sales and shares of U.S. market for major field crops, 1997

Company	Total sales	Total market share[1]	Corn market share	Soybean market share	Cotton market share
	Million dollars	*Percent*			
Pioneer Hi-Bred	1,178	33.6	42	19	0
Monsanto[2]	541	15.4	14	19	11
Novartis	262	7.5	9	5	0
Delta & Pine Land[3]	79	2.3	0	0	73
Dow Agrosciences / Mycogen	136	3.9	4	4	0
Golden Harvest	93	2.6	4	0	0
AgrEvo/Cargill	93	2.6	4	0	0
Others	1,121	32.0	23	53	16
Total	3,503	100.0	100	100	100

[1] Total market shares in this table include only corn, soybeans, and cotton.
[2] Monsanto acquired Dekalb in 1997 and Asgrow in 1998.
[3] The merger between Monsanto and Delta & Pine Land in 1998 was called off in December 1999.

Sources: Market shares for corn and soybeans: Hayenga (1998); cotton: USDA, AMS. Total crop sales calculated from acreages and seed cost per acre: USDA's Agricultural Resource Management Survey data (1998) and *Agricultural Statistics* (USDA, 1998).

The changing nature of the seed industry following the entry of large firms has been the subject of much debate. Many large firms enjoy economies of scale in R&D and have been able to subsidize seed research with resources and revenues from other corporate divisions (Butler and Marion, 1985, p. 51). The development of biotechnology has also generated opportunities for economies of scope (i.e., producing several products together at a cost less than producing them separately). According to Fulton and Giannakas (2002), once a specific gene has been isolated (e.g., a gene that confers resistance to a particular herbicide) this gene can be used in a number of crops. Furthermore, the entry of large multinational firms in the industry also expands markets, from domestic or regional to global, increasing sales volume and profits supporting R&D.

The entry of multinational firms in the seed industry may also have drawbacks. First, the relatively small size of the commercial seed market—$5.7 billion in the United States and $25 billion worldwide (table 2)—means that seed divisions in large firms are less likely to exert influence on corporate decisions than those divisions involved in larger markets, such as pharmaceuticals and chemicals (FIS/ASSINSEL, 2000). Second, the time-consuming nature of seed R&D requires a long-term perspective on R&D investments, which may not appeal to a firm's shareholders (Butler and Marion, 1985, p. 51). Third, and most importantly, the presence of large firms in the industry raises concerns about increasing market concentration and oligopolistic competition among and between firms (see, for instance, Leibenluft, 1981; Begemann, 1997; Kalaitzandonakes and Hayenga, 1999).

The seed market is still somewhat small in size, compared with other agricultural input markets, such as

Table 14—Global seed and pesticide sales of major multinational firms, 1999

Company	Seeds	Pesticides
	Million dollars	
Syngenta (Novartis/AstraZeneca)	1,173	7,030
Aventis (Hoechst & Rhone Poulenc)[1]	135	4,582
Dupont (inc. Pioneer)	1,835	2,309
Monsanto/Pharmacia	600	3,230
Dow Agrosciences	220	2,132

[1] Recently acquired by Bayer.

Source: Merrill Lynch (2000).

the pesticide market (table 14). Still, the total market value of purchased seed in the United States grew substantially in the past three decades. This growth has been particularly rapid in the seed markets for major field crops—corn, soybeans, wheat, and cotton—which constituted 70 percent of the overall seed market in 1982. These markets are dominated by a few large firms which, through strategic corporate behavior, have come to play a central role in some or all of these markets. Together, their seed sales amounted to approximately $4 billion in 1999 (table 14).

Before discussing firm- and crop-specific details of the modern seed industry and its structure, it is useful to review the workings of the seed market, or how seeds are developed, manufactured, and distributed to farmers. Though different types of seed have very distinct production processes and markets, a fairly general description of the process is applicable across all types (see box on the process of seed production).

The Process of Seed Production, Marketing, and Distribution

Different types of seed have very distinct production processes and markets, but a general description of the overall process is applicable across most seed types. The seed firm can be viewed in terms of four separate functions: (1) Plant breeding R&D, (2) seed production, (3) seed conditioning, and (4) seed marketing and distribution.

Plant breeding. Plant breeding constitutes the foundation of the modern seed industry in that it creates a unique and marketable product through the application of science. Plant breeders develop seeds embodying such improvements as high yields, resistance to disease and pests, or traits specific to regional agroclimatic conditions. A seed's success in the market depends primarily on its improved traits, which embody the R&D effort.

The high costs associated with large-scale R&D limit it to a relatively small number of large companies and to Federal Government agencies and land-grant colleges and universities. High R&D costs require private sector varieties to be commercially viable, highly competitive, and well protected by intellectual property rights (IPR). Where each breeder holds the exclusive rights to produce and distribute his or her variety, competition tends to be based more on product performance—yield, disease resistance, quality—than price (Leibenluft, 1981, p. 107). Given the size of their R&D investments, these plant breeders play a central role in managing the entire production, distribution, and marketing processes in the seed industry, resulting in extensive vertical integration of the industry (Butler and Marion, 1985, pp. 18-19). Moreover, there are economies of scale in R&D, marketing, and distribution, but there are not many economies of scale in seed conditioning (Morris, 1998).

Seed production. Seed firms with a marketable seed product typically contract out the production and multiplication processes to farmers, farmers' associations, and private firms. Breeders provide contract growers the *foundation seed* (parent seed stock produced from the original seed developed by plant breeders) to produce either more foundation seed for continued R&D purposes, or *registered seed* for large-scale production purposes. Registered seed is contracted out in a similar manner to produce *certified seed*, sold to farmers conforming to standards of genetic purity and quality established by State agencies (Agrawal et al., 1998, pp. 104-105, Butler and Marion, 1985, p. 16). The production of certified seed requires strategic planning to ensure that market demand is adequately met. This planning may include determining the quantities of each variety to be produced; determining inventories necessary to produce in excess of forecasted demand to avoid immediate or future shortages; and reducing the risks associated with the unpredictable effects of weather conditions, disease, and pests. Production may also require estimating the quantity of saved seeds farmers will use instead of purchased seed, and the differences in quantity and type of seed demanded in different geographic markets (Leibenluft, 1981, p. 109; Butler and Marion, 1985, pp. 18-19). Corn seed firms, for example, disperse seed-growing contracts throughout the United States (and to countries of the Southern Hemisphere as well) to minimize disease and weather risks and often intentionally overproduce by 25 percent of forecasted demand for the coming season to ensure adequate supply.

The production of both registered and certified seed through contract growers is closely managed by seed firms to ensure that the desirable plant characteristics are carried through to subsequent generations, and to prevent open pollination, disease or pest infestation, or other types of problems that could affect product quality. Contract growers are carefully selected by seed firms and are provided with technical assistance or supervision. Seed firms closely control all stages, from seedbed preparation and planting densities to the timing of input application (Agrawal et al., 1998, pp. 106-107).

Seed conditioning. Once harvested, certified seed is conditioned for sale to farmers, a process that typically includes

Continued on page 29

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drying, cleaning, and sorting the seed; treating the seed with insecticides and fungicides; and packaging the seed for distribution and sale (Krull et al., 1998, p. 133; *Seed World*, 1999, p. 41). Seed is also subject to inspection under various State programs to ensure that the final product meets certain quality standards. This inspection may include tests for purity, germination, presence of noxious weed seeds, and moisture content.

Seed marketing and distribution. Large seed firms play a direct role in marketing and distributing their end product to regional, national, and international markets. Many firms also license or outsource marketing and distribution to private firms and individuals to improve access to local markets (Butler and Marion, 1985, 16). Local distribution is typically run by independent agents, such as farmer-dealers, farmers' associations, company salespeople, and private wholesalers and retailers. Different distribution channels are used in different regions and markets. In the Midwest, for example, most corn seed is sold to farmers by part-time farmer-dealers who have received training directly from the seed firm. In the South, corn seed sales are channeled through agricultural supply stores. On large farms throughout the country, seed company salespeople sell straight to farmers (Leibenluft, 1981, p. 109).

Seed pricing. The market price of seed incorporates the costs associated with development, production, marketing, and distribution. In the long run, the price must be responsive to the farmers' willingness to purchase while at the same time ensuring a profit margin that provides an attractive return on capital to investors. Furthermore, the price depends on the competitiveness of the particular seed market, and the pricing behavior of those firms that hold large shares of the market.

R&D costs account for an important portion of the market price for seed, particularly for hybrids or transgenic seeds over which private firms own exclusive proprietary rights. In recent decades, private sector R&D costs have been rising with the application of new technologies, and much of the increase in seed prices has been associated with this trend (Krull et al., 1998, pp. 133-134). R&D costs vary among the different seed markets. For example, the corn seed market depends extensively on private sector R&D and passes these costs on to farmers, while the wheat seed market depends largely on public sector research, which is almost cost-free to farmers.

Seed production is another major cost, contributing up to about a quarter of the seed price, but the share of these production costs varies as the marketing and distribution costs change. Production costs include paying farmers to grow seed for exclusive resale to the seed firm. Contract growing typically requires that the seed firm pay a margin above the commodity market price for the seed to ensure that optimal growing conditions are maintained to produce a good quality product (Agrawal et al., 1998, p. 115). For example, for corn, a contract payment formula may be $R=1.1(P_{ch} - 0.08)[2(y-y_{av})+185]$, where P_{ch} is the expected price of the commodity, such as a futures price, y is the farm corn yield (given a certain nitrogen application and weather) and y_{av} is the regional average yield (also given nitrogen application). Thus, the grower payment is based on an adjusted yield that is equal to a typical yield of 185 bushels per acre plus twice the difference between the farm yield and regional average yields. The grower receives an additional bonus of 10 percent to make the contract desirable (Preckel et al., 1997).

Seed conditioning and treatment may account for around 15 percent of the seed price. This process benefits from scale economies arising from the relatively intensive use of capital equipment.

Advertising, promotion, and distribution are other major costs. These costs vary with the stage of the product cycle and their share may account for more than 20 percent of the seed price. Advertising and promotion are necessary to distinguish a seed firm's product from other firms' products on the market, to educate dealers on the best crop management practices to ensure high seed productivity, and to induce farmers to adopt the firm's particular seed. Distribution costs include costs of transportation and communication between production facility, wholesalers, retailers, and farmers, as well as storage costs (including financial costs) if seed is held as inventory between seasons (Krull et al., 1998, pp. 133-134; Agrawal, 1998, p. 120).

Mergers and Acquisitions Rose in the Past Three Decades

In the present seed industry structure, large private firms play a central role in developing and marketing seed for major field crops, such as corn, soybeans, cotton, and wheat. Moreover, the evolution of those firms provides insights into the dynamics of the modern seed industry (see box on evolution of the major seed companies).

In discussing market concentration in the seed industry, it should be noted first that the number of firms participating in the seed industry increases through each step of the production process. Plant breeding is a concentrated stage of the industry, while the production and distribution of certified seed is carried out by hundreds of companies operating in different volumes and markets. A larger numbers of firms are involved in the production and distribution of public varieties: the absence of exclusive property rights means that, in these cases, any individual or firm may produce the seed without permission and may distribute it without licenses (Butler and Marion, 1985, pp. 16-17). Market concentration is usually measured using the four- or eight-firm concentration ratio (CR4 or CR8), which is the share of total industry sales of the four or eight largest firms. Alternatively, market concentration may be measured by the Herfindahl-Hirschmann Index (HHI), which is the sum of squared market shares (in percentage terms) of each firm in the industry. Although it is difficult to precisely determine market size and concentration for the overall seed industry, estimates can be made of individual seed markets for major field crops.

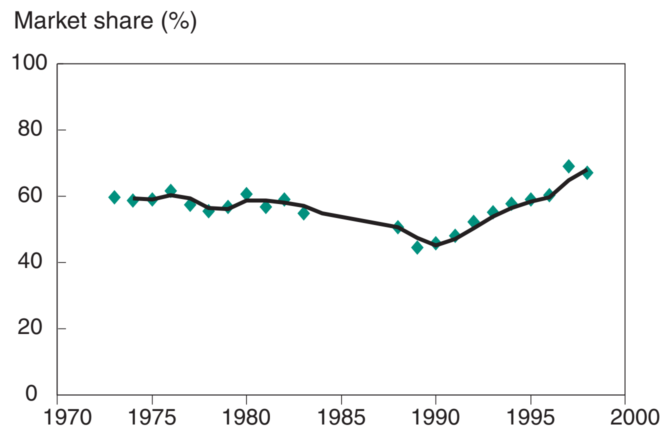
Corn. Since its inception, the corn seed industry has included many small firms—105 of the original 190 companies operating in the 1930s were still in existence in the 1990s—together with larger market leaders, such as Hi-Bred Corn Company (which later became Pioneer), Funk Brothers Seed Company, DeKalb Agricultural Association, and Pfister Hybrid Corn (Duvick, 1998, p. 198). The size and success of the corn seed market is reflected by the fact that nearly all acreage planted in 1997 used seed purchased from the private sector.

Until the 1970s, the corn seed market was characterized by small firms controlling approximately 30 percent of the industry and larger market leaders controlling 70 percent. Between 1973 and 1983, the four largest firms in the U.S. corn seed industry are estimated to have held (CR4) between 50 and 60 percent of the market (fig. 11, table 15).

By the mid-1980s, Pioneer had expanded its market share to 38 percent while most other large firms, including Pioneer's largest competitor, DeKalb, experienced sharp declines in their market shares. The decline of other large firms, and the concurrent expansion of market share held by smaller firms, is reflected in a decrease in the CR4 ratio between 1973 and 1983 from 60 to 55 percent. In the 1990s, market concentration in corn seed had grown with the strategic entry into the industry of multinational firms. By 1997, the CR4 ratio had risen to 69 percent, as Pioneer continued to control 42 percent of the market, followed by Monsanto with 14 percent and Novartis/Syngenta with 9 percent (table 16). Smaller firms still control over 20 percent of the market.[9]

[9] For comparison, the market structure of the seed industry is much more concentrated than the market for pesticides, another key agricultural input (Ollinger and Fernandez-Cornejo, 1995). In the seed and pesticide markets for corn and cotton, where both inputs are primarily purchased from the private sector, the CR4 ratio is higher in seed markets than in pesticide markets. From 1972 to 1989, the estimated CR4 ratio for the pesticide market averaged 45 percent, compared with 60 percent for the cotton seed market and 58 percent in the corn seed market, both of which have increased in recent periods. Recent data for corn, soybeans, and cotton, which represent a large share of the market, suggest that the seed industry is more concentrated than the pesticide industry.

Figure 11
Market shares of four largest firms, U.S. corn seed industry



Source: Data sources provided in tables 15 and 16.

Table 15—-U.S. market shares of corn seed by company[1]

Company	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
						Percent					
Pioneer	23.8	25.5	24.6	27.3	30.9	26.2	32.9	36.9	34.8	38.8	38.1
DeKalb[2]	21.0	18.8	18.8	19.5	15.8	17.9	13.3	13.0	15.9	12.2	10.3
Asgrow	0	0	0	0	0	0	0	0	0	0	0
Funk[3]	8.8	9.4	8.9	9.2	6.4	8.1	6.7	5.7	5.4	5.2	3.9
Trojan[4]	5.9	5.1	6.8	5.6	4.2	5.4	3.8	2.0	0	0	0
Northrup-King[5]	6.1	4.5	4.7	3.4	3.8	3.3	3.8	4.9	3.4	2.6	2.5
Zeneca/ICI	0	0	0	0	0	0	0	0	0	0	0
Cargill/PAG[6]	4.8	6.8	3.9	3.5	4.1	4.6	3.3	4.7	5.6	5.4	4.2
Golden Harvest	0	0	1.8	2.4	2.5	3.1	2.9	1.3	3.2	2.3	2.6
Dow/Mycogen	0	0	0	0	0	0	0	0	0	0	0
Jacques/Agrigenetics[7]	0	1.3	1.7	2	1.9	2.1	2.7	2.2	0	0	0
Other	29.6	28.6	29.8	27.1	30.4	29.3	30.6	29.3	31.7	33.6	38.4
Largest 8 firms	72.5	70.7	69.8	71.2	68.1	67.0	69.7	69.4	70.0	68.3	64.0
Largest 4 firms	59.7	58.8	59.1	61.6	57.3	55.6	56.7	60.5	59.5	59.1	54.9
Herfindahl index	0.1171	0.1159	0.112	0.1269	0.1049	0.1138	0.1354	0.1609	0.1501	0.1723	0.1604

Note: Due to the sample size of the surveys, the shares are estimates that may vary plus or minus two percentage points.
[1] Market shares are based on percentage of acres sown with respective firm's seed.
[2] Merged with Pfizer in 1982.
[3] Aquired by Ciba-Geigy in 1974.
[4] Aquired by Pfizer in 1975.
[5] Aquired by Sandoz in 1976.
[6] Acquired by Cargill in 1971.
[7] Acquired by Agrigenetics in 1980.

Sources: 1973-80: Butler & Marion (1985), p. 90; 1981-83: McMullen (1987), p. 96.

Table 16—-U.S. market shares of corn seed by company

Company	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
						Percent					
Dupont/ Pioneer Hi-Bred	34.5	32.0	33.4	35.8	39.6	42.7	44.9	45.0	41.0	42.0	39.0
Monsanto[1]										14.0	15.0
DeKalb	9.0	8.5	9.0	8.0	8.2	8.2	8.6	9.8	10.1	10.0	11.0
Asgrow									2.0	4.0	4.0
Novartis[2]										9.0	9.0
Northrup-King / Sandoz[3]	4.0	4.0	3.5	4.4	4.6	4.3	4.2	4.1	5.0		
Dow Agro/Mycogen[4]									4.3	4.0	4.0
AgrEvo/Cargill[5]	3.0	3.0	3.0	3.5	3.7	3.8	3.9	4.0	3.3	4.0	4.0
Ciba									3.1		
ICI/Zeneca/Advanta[6]									2.9	3.0	3.0
Golden Harvest	2.0	2.0	2.0	2.9	3.0	3.0	3.0	3.3	2.3	4.0	3.0
Others	39.7	42.7	41.7	36.7	33.1	31.3	28.6	28.4	25.6	20.0	23.0[8]
Largest 8 firms[7]	52.5	49.5	50.9	54.6	59.1	62.0	64.6	66.2	72.0	80.0	77.0
Largest 4 firms	50.5	44.5	45.9	48.2	52.4	55.2	57.7	58.9	60.4	69.0	67.0
Herfindahl index	0.1300	0.1125	0.1222	0.1386	0.1679	0.1932	0.2132	0.2165	0.1864	0.2098	0.1877

[1] Monsanto acquired DeKalb in 1997 and Asgrow in 1998.
[2] Result of the merger between Ciba and Sandoz in 1996.
[3] Northrup-King is Sandoz's American seed subsidiary.
[4] Mycogen was bought by Dow Agrosciences in 1998.
[5] AgrEvo acquired Cargill's domestic seed business in 1998.
[6] ICI split in 1993 and Zeneca, the pharmaceutical spinoff, was left in control of the company's seed operations. Later in 1996, Zeneca became a part of the Advanta Seed Group.
[7] In 1997 and 1998, market shares of only seven companies were available.
[8] Market share amount adjusted from reported figure in Kalaitzandonakes and Hayenga to make the market add up to one.

Source: 1988-95: Merrill Lynch (various years); 1996: Kalaitzandonakes (1997); 1997: Hayenga (1998); 1998: Kalaitzandonakes and Hayenga (1999).

The Evolution of the Major Seed Companies

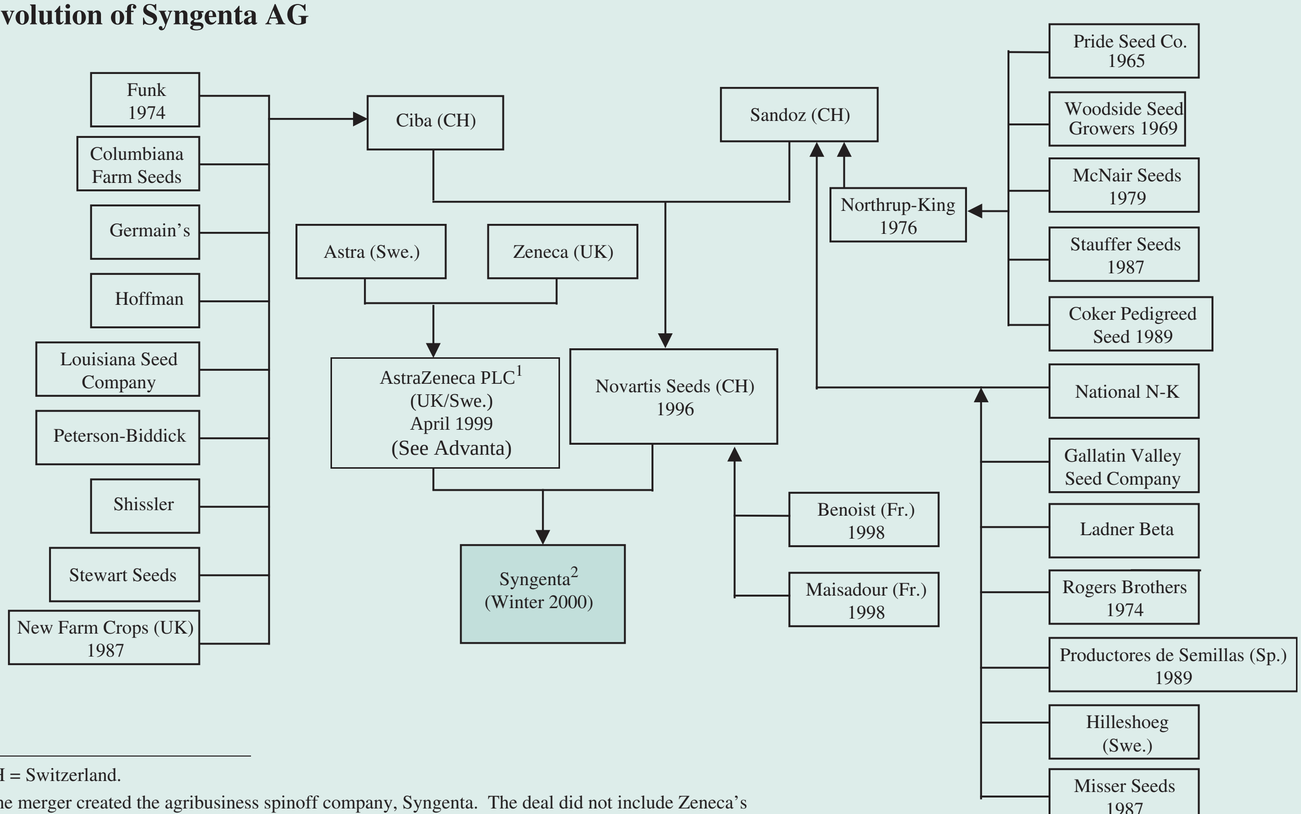
The evolutionary paths of four major seed companies—Pioneer/Dupont, Novartis/Syngenta, Monsanto, and Advanta Seed Group—provide some insight into the modern structure of the seed industry (figs. A-1-A-4). In each figure, the horizontal arrows pointing to a company indicate an acquisition, vertical arrows pointing down represent a merger, and a line with arrowheads at both ends indicates a joint venture. Where possible, the nationality of the company is given in parentheses next to the company's name, along with the cost and date of acquisition.

Novartis/Syngenta. Novartis was formed in 1996 by the merger of two Swiss life science giants, Ciba-Geigy and Sandoz. Sandoz brought to the merger Northrup-King, a brand name company acquired in 1976 that was well established in field crops, especially hybrid corn and sorghum. Northrup-King's own position in the market was the result of its past acquisitions of field seed companies, including Pride Seed Company, Stauffer Seeds, and Coker Pedigreed Seed. Ciba-Geigy also contributed to the merger with a long list of previously acquired seed companies, including Funk Brothers Seeds and its extensive U.S. distribution network. The 1996 merger gave rise to a new seed division called Novartis Seeds, which controlled 7 percent of the seed market for major crops in 1997. In 1999, after operating as a complete life sciences company for only 3.5 years, Novartis announced plans to merge its agricultural business with the Swedish/English pharmaceutical giant AstraZeneca which had been formed only 6 months earlier. The agricultural spinoff, Syngenta, became a global leader in both seed and pesticide sales. According to the most recent sales figures from Merrill Lynch, Syngenta is only second to Pioneer with $1.2 billion in annual seed sales, and first in pesticide sales with more than $7.0 billion in annual sales (fig. A-1).

Pioneer/Dupont. Pioneer was one of the first four firms active in the emerging corn seed market in the early 1930s. Its modern achievements can be partly attributed to its success as the largest player in the corn seed market for about 40 years (Pioneer, 2001). Between 1973 and 1980, Pioneer made a series of acquisitions that further strengthened its

Figure A-1

Evolution of Syngenta AG



CH = Switzerland.

[1]The merger created the agribusiness spinoff company, Syngenta. The deal did not include Zeneca's stake in Advanta Seed group.

[2]Merger of Novartis's crop protection and seed businesses with AstraZeneca PLC's agrochemicals business.

Sources: Fox, 1990, p. 39-40; Joly and Lemarie, 1999; Leibenluft, 1981, p. 115-116; Northrup-King Co., 2000; Schor, 1984; and Shields, 1999.

Continued on page 33

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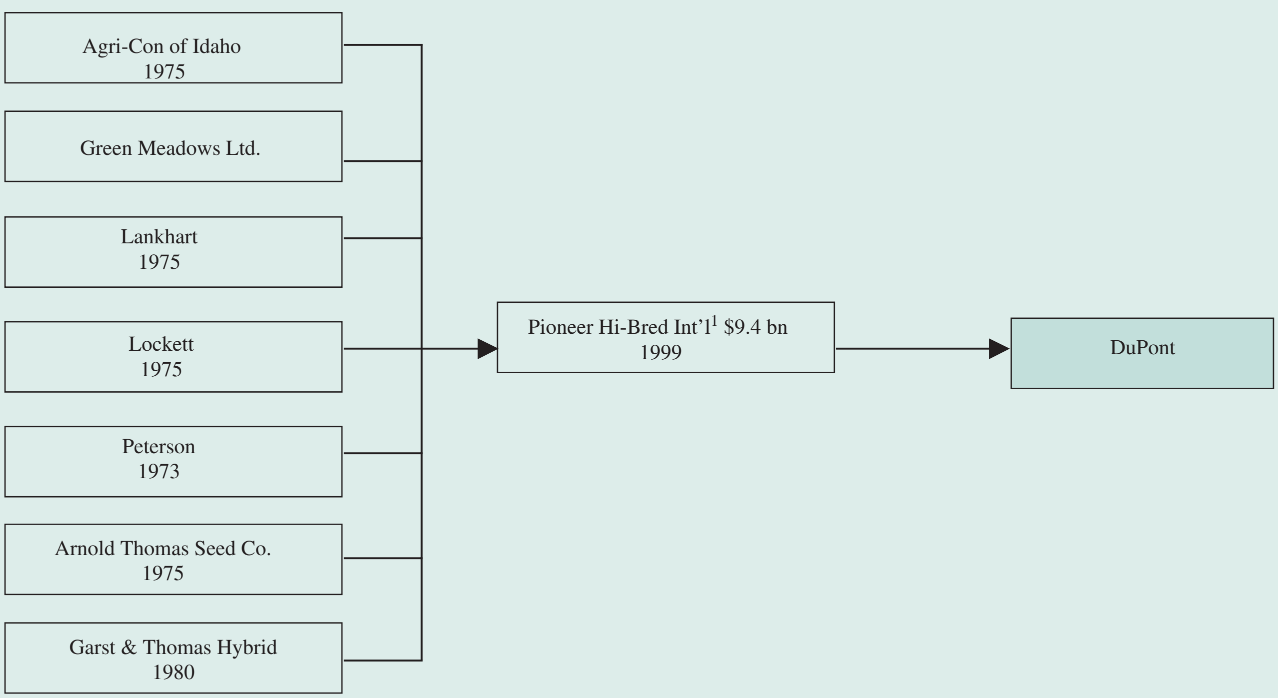
overall position in the seed market: The purchase of Lankhart and Lockett in 1975 allowed Pioneer to expand its activities in the cotton seed (used for planting and not cotton seed sold for oil or other uses) market, while its 1973 purchase of Peterson seeds gave it a larger presence in a soybean market otherwise dominated by public varieties. Bought by the chemicals giant DuPont in 1999, Pioneer continues to operate from its headquarters in Des Moines, Iowa, under the well-established Pioneer name as a part of the DuPont conglomerate. Dupont is the world's leader in production of low-use-rate herbicides, and its acquisition of Pioneer is an important element of its life sciences strategy focusing on the commercialization of a new generation of food, feed, and nutrition products developed with new biotechnology applications (fig. A-2)

Monsanto. Barely active in the seed industry until the mid-1990s, Monsanto, originally considered a chemical, then a pharmaceutical, company, acquired major players in the seed industry in a short period. In 1997, Monsanto bought Asgrow from a Mexican firm, ELM, and Calgene; in 1998, it bought out DeKalb and Cargill's international seed business. Through the acquisition of biotechnology research companies, including Ecogen, Agracetus, and the Plant Breeding Institute, Monsanto also acquired the rights to recently developed seed technologies (fig. A-3). Monsanto also attempted to acquire more than 70 percent of the U.S. cotton seed industry with the acquisition of Delta & Pine Land in 1998. Although Monsanto sold its other cotton subsidiary, Stoneville Pedigreed, to make way for the Delta & Pine Land acquisition, the deal was called off in 1999, ultimately leaving Monsanto with no market share in cotton seed. In March 2000, Monsanto merged with Pharmacia & Upjohn, a multinational pharmaceuticals giant. The agricultural side of the merger retained the Monsanto name while the pharmaceutical and related side operates under the name of Pharmacia Corporation. After a partial initial public offering of Monsanto was launched in October 2000, Pharmacia retained 84 percent ownership. Then, on August 13, 2002, Pharmacia Corporation distributed its 84-percent stake in Monsanto Company to Pharmacia shareowners via a special stock dividend. This distribution completed Phar-

Figure A-2
Evolution of Pioneer/Dupont



bn = billion.
[1]Dupont bought 20 percent of Pioneer in August 1997 and bought the remaining 80 percent in October 1999. As a DuPont company, Pioneer continues to operate under the Pioneer name from its headquarters in Des Moines, Iowa.

Sources: Butler and Marion, 1985, p. 87; Joly and Lemarie, 1999; Leibenluft, 1981, p. 116; and Seedquest, 1999.

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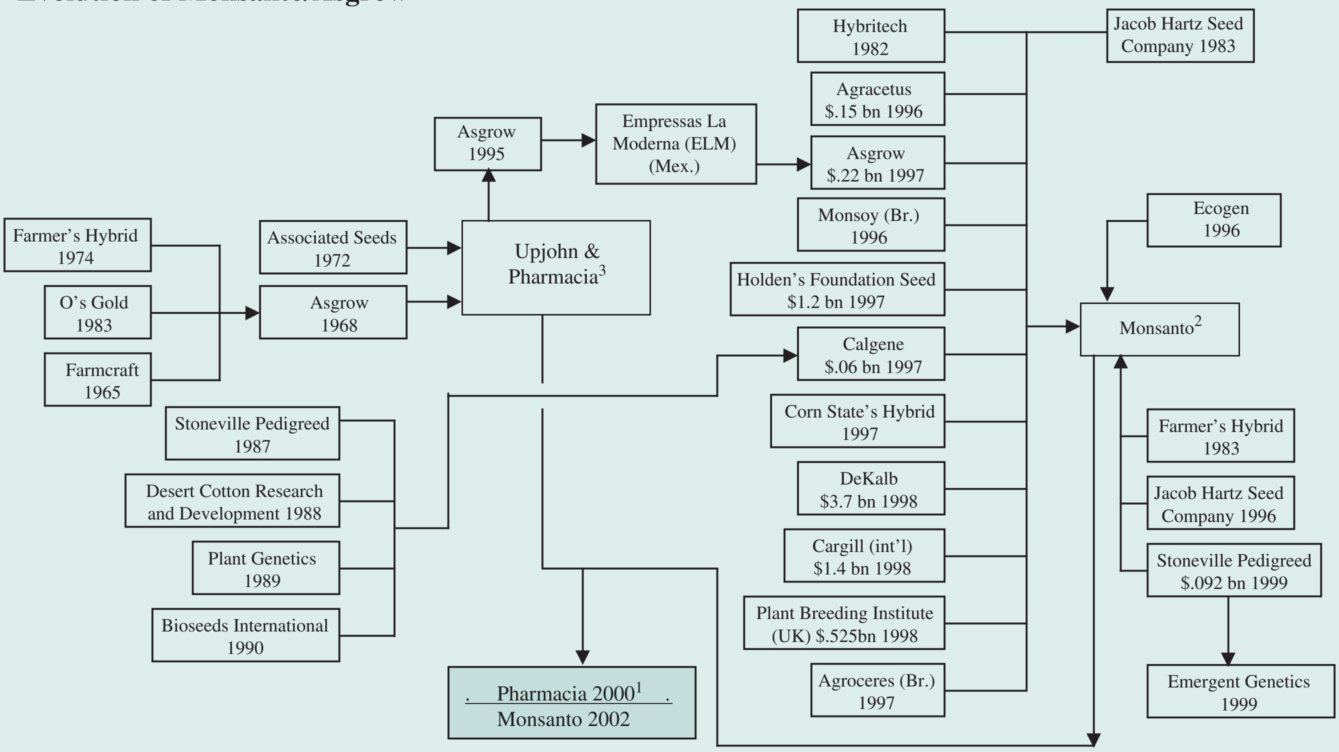
Figure A-3
Evolution of Monsanto/Asgrow



bn = billion. Br. = Brazil.

[1] Monsanto Company became an agricultural subsidiary of Pharmacia Corporation in April 2000. Monsanto became completely separate and independent from Pharmacia on August 13, 2002.

[2] In late December 1999, Monsanto called off its $1.9-bn deal with Delta & Pine Land (D&P). With D&P Land, Monsanto would have acquired more than a 70 percent market share in the cotton seed market since it sold Stoneville Pedigreed in mid-1999 to make way for its acquisition of D&P Land.

[3] Formed in November 1995 by the merger of Pharmacia Aktiebolag and the Upjohn Company, prior to this point, Upjohn had owned Asgrow solely since 1968.

Sources: Asgrow, 2000; Fox, 1999, p. 39; Joly and Lemarie, 1999; Merrill Lynch; Monsanto website; Pharmacia, 2000; PR Newswire, 1999; Schor, 59; Seedquest, 1998; Shimoda, 1999; Wall Street Journal Interactive, 1998.

macia's spinoff of Monsanto and established Monsanto as a 100-percent publicly traded company (PR Newswire, 2002).

In terms of sales, Monsanto is thus the third largest player in the seed industry worldwide and the fourth largest player in the pesticide market (Monsanto, 2000). However, in terms of agricultural biotech products, Monsanto has the largest market share.

Advanta Seed Group. Advanta Seed Group similarly emerged from numerous acquisitions and joint ventures. In 1993, Imperial Chemical Industries (ICI), a British chemical manufacturing giant, split its company into ICI and Zeneca. Zeneca took over ICI's production of agrochemicals and seeds. In the deal, the ownership of Garst Seed Company, an American seed firm bought by ICI in 1985, was transferred over to Zeneca, thereby securing Zeneca's position in the U.S. market. In 1996, Zeneca merged its seed business with Royal VanderHave, the international seeds business of Dutch food manufacturer Cosun. Together with Royal VanderHave, Zeneca Seeds forms the backbone of the international seed group Advanta (box fig. A-4).

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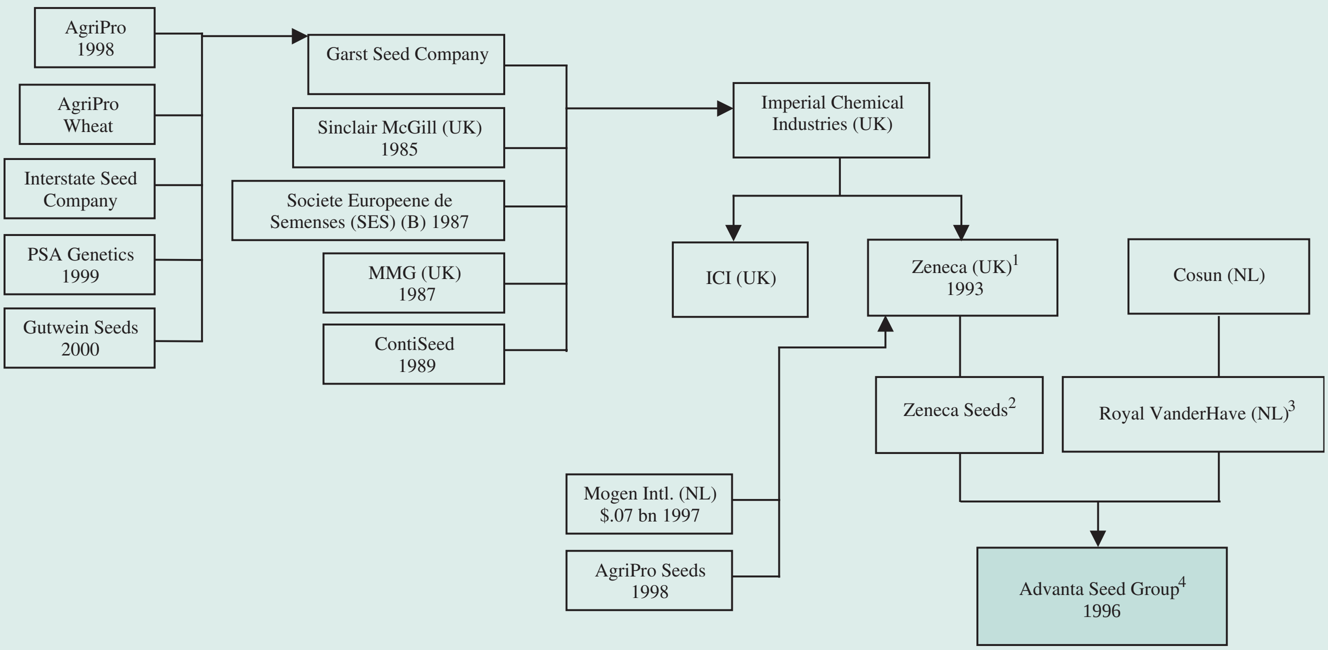
Figure A-4

Evolution of Advanta Seed Group



bn = billion. B = Belgium. NL = Netherlands.

[1]On June 1, 1993, ICI split, creating a separately quoted company called Zeneca. Zeneca's industrial pursuits encompass ICI's drugs, agrochemicals and seeds, and specialties businesses.

[2]Zeneca Seeds is a part of Zeneca Agrochemicals. In 1999, Astra (Swe) merged with Zeneca (UK) to form AstraZeneca PLC. The agribusiness merger of Novartis AG and AstraZeneca, called Syngenta, will not change the ownership of Garst Seed Company and its subsidiaries because Advanta was not included in the deal.

[3]Royal VanderHave group is Cosun's international seeds business.

[4]50:50 joint venture between Zeneca Seeds and Cosun.

Sources: Abrahams, 1993; Clark, 1997; Garst Seed Co., 2000; Zeneca, 2000; Shields, 1998; Fox, 1990, p.40, 85; and Seedquest, 1999.

Soybeans. The development of soybean seed varieties was dominated by the public sector until the 1980s (table 17). However, the transformation from public to private was fairly rapid, relative to the transformation in the corn sector. In 1980, over 70 percent of soybean acres harvested in the United States were planted with publicly developed varieties, but by the mid-1990s, the public share had decreased to as low as 10 percent of the market. The increasing role of the private sector appears to have been largely due to the strengthening of intellectual property rights. The private sector's expansion into soybean seed led to a fairly concentrated industry: In the late 1980s, the four largest firms controlled about 40 percent of the soybean seed market, a relatively smaller share than in the corn seed market (table 18) (Knudson and Hansen, 1991).

However, it is difficult to discern a clear leader among these large firms in the soybean seed market. Pioneer may have held a strong position in this market, but with Monsanto's acquisitions of Asgrow and DeKalb, and with the expansion of Novartis into the market, no single firm seems to consistently outsell the others. In fact, figures may indicate that the soybean market is becoming less concentrated over time: The absence of a clear market leader, the presence of a large number of small firms, and a decrease in the HHI between 1994 and 1998 from 0.1115 to 0.0915 all point to decreasing market concentration. Such conclusions, however, depend on the number of small firms categorized as "Others" in tables 18 and 19.

Cotton. Until the early 1980s, private firms and some public institutions maintained a strong presence in the development of cotton seed varieties (table 20). The two largest private firms, Delta & Pine Land and Stoneville, together controlled roughly 40 percent of the varieties planted. Smaller public and private breeders, such as Coker Pedigreed, Lankart, and University of New Mexico AES, each held between 5 and 15 percent.

In the 1980s, the cotton seed market expanded as new developments in cotton breeding brought improved seed varieties to producers, and producers recognized that the traditional practice of cleaning and separating out saved seed was less economical than purchasing seed. Between 1982 and 1997, the use of purchased seed increased from 50 to 75 percent, and large private firms rapidly replaced smaller firms and public institutions as suppliers of seed varieties. Delta & Pine Land continued

Table 17—U.S. shares of soybean varieties, public versus private

Year	Public sector varieties	Private sector varieties	Unknown varieties	Varieties from leading four private firms
	Percent of area planted			
1980	70	8	22	7
1997*	10-30	70-90	--	37-47

-- = not applicable.
* Estimated figures. Smaller figure for public sector (and larger figure for private sector) assumes planted areas are roughly proportional to seed sales. Larger figure for public sector (and smaller figure for private sector) assumes most farmer-saved seed is from public sector varieties. About 25 percent of soybean seed in 1997 was estimated to be farmer saved.

Source: Heisey (1999a).

Table 18—U.S. market shares of soybean seed varieties

Institution/Company	1980	1988
	Share of acreage harvested with varieties from given breeder	Share of market sales
	Percent	
Major public breeders:		
University of Illinois	20.5	NA
Mississippi AES	16.6	NA
Iowa State University	8.4	NA
University of Florida	6.2	NA
Purdue AES	4.9	NA
Arkansas AES	4.3	NA
Virginia AES	3.4	NA
Minnesota AES	3.2	NA
North Carolina State AES	2.7	NA
Total major public	70.2	30.5
Major private breeders:		
Northrup-King (Sandoz)	2.0	7.6
Asgrow (Upjohn)	1.8	14.9
Pioneer/Peterson	1.4	13.7
Monsanto	0.0	3.4
DeKalb	0.0	5.5
FS	0.0	2.2
Stine	0.0	3.4
North American Plant Breeders (Shell/Olin)	1.4	0.0
Ring Around Products (Occidental Petroleum)	1.0	0.0
Others	22.2	18.8
Total private and public	100.0	100.0
Largest 4 firms	6.6	42.0
Herfindahl index	0.1216	0.0526

NA = not available.
AES = Agricultural Experiment Station.

Sources: 1980: Butler and Marion (1985), p. 91; 1988: Kimle and Hayenga (1992).

Table 19—U.S. market shares of soybean seed, by company

Company	1994	1997	1998
		Percent	
Dupont/Pioneer Hi-Bred[1]	22.0	19.0	17.0
Monsanto[2]		19.0	24.0
Asgrow	15.0	11.0	16.0
DeKalb	19.0	8.0	8.0
Novartis		5.0	5.0
Dow Agrosciences/Mycogen[3]	3.7	4.0	3.0
Stine	4.0	4.0	4.0
FS	3.9		
Jacques			
Others	41.2	39.0	39.0
Public	3.2	10.0	10.0
Largest 8 firms[4]	NA	NA	NA
Largest 4 firms	60.0	47.0	50.0
Herfindahl index[5]	0.1115	0.0779	0.0915

NA = not available.
[1] Pioneer Hi-Bred was fully bought by Dupont in 1999.
[2] Monsanto acquired Asgrow in 1997 and DeKalb in 1998.
[3] Mycogen was acquired by Dow Agro in 1998.
[4] The market shares of only six companies were available in 1994, and only five in 1997/8.
[5] The "others" category was not included in calculation of the Herfindahl index because the category is very large and the number of companies in the others category is also unknown. Public varieties were also not included in this figure.

Sources: 1994: Kalaitzandonakes (1997); Hayenga (1998); 1998: Kalaitzandonakes and Hayenga (1999).

to lead the market, a position that was strengthened by its acquisition of Paymaster in 1994 and Sure-Grow in 1996, resulting in a 76-percent share of the market by 1999. The second largest firm in the market, Stoneville, controlled only 13 percent of the market in 1999. Of the 19 small breeders (public and private) operating in 1990 with at least a 1-percent share of the market, only 7 still exist. In effect, the cotton market has become highly concentrated, a fact reflected by a CR4 ratio in 1999 of 96 percent (table 20) (fig. 12).

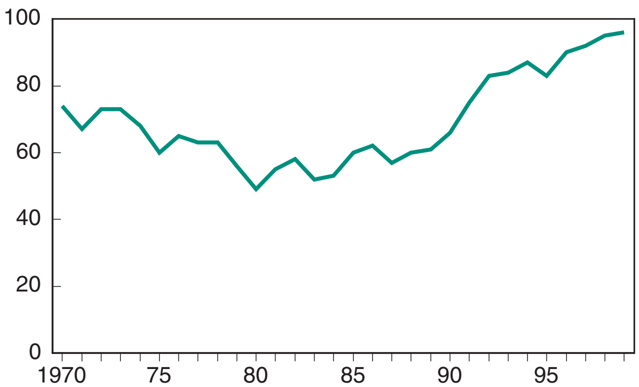
Wheat. Most U.S. wheat is cultivated from saved seed, implying that the incentives to private firm entry, research and development, and strategic behavior in the wheat seed industry are fairly limited (table 21). Furthermore, limited development of viable hybrid alternatives to self-pollinated varieties during the 1970s further constrained private sector interest in the market (Fuglie et al., 1996, p. 54-55). See also Knudson (1990) and Hansen and Knudson (1996).

As late as 1997, purchased seed accounted for only 37 percent of all acreage planted with wheat. Moreover, the public sector still plays a central role in the wheat seed market, despite more recent increases in private sector

Figure 12

Market shares of four largest firms, U.S. cotton seed industry

Market share of cotton varieties (%)



Source: Data source provided in table 20.

participation (table 22) (Heisey et al., 2001). In 1980, public breeders accounted for 72 percent of sales of hard red spring wheat seed, 80 percent for soft red winter wheat, and 85 percent for hard red winter wheat. Within the public sector, several key institutions were particularly active in providing wheat seed varieties: together the University of Minnesota and University of California at Davis provided 56 percent of the seed varieties for hard red spring wheat in 1980; Purdue University provided 65 percent of the seed varieties for soft red winter wheat; and Kansas State University and University of Nebraska provided a combined 60 percent of the seed varieties for hard red winter wheat. In the private sector, Northrup-King provided 14 percent of the seed varieties for hard red spring wheat in 1980. The total share for the private firms was 18 percent. Coker provided 7 percent of the market for soft red winter wheat, and North American Plant Breeders supplied 5 percent of the market for hard red winter wheat, with smaller firms providing the rest (Butler and Marion, 1985, p. 93).

The Effects of Concentration

The increase in seed industry concentration has raised concerns about its potential impact on market power.[10] However, concentration may result in trade-

[10] For example, it was reported that in 1999, after learning that the U.S. Department of Justice intended to sue over concerns about the anticompetitive effects in the cotton seed market, Monsanto abandoned its proposed acquisition of Delta & Pine Land Co., which could have combined the Nation's two largest cotton-seed firms (Ross, 2001).

Table 20—Share of cotton varieties planted in the United States, by firm or institution

Firm / Institution	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
								Percent							
Public:															
Arkansas AES (Rex variety)	1	1	2	1	--	--	--	--	--	--	--	*	*	*	*
Mississippi FAES[1] (Dixie King & DES varieties)	2	2	2	1	1	1	1	1	--	--	1	--	1	1	1
Oklahoma AES (Westburn variety)	--	--	--	--	---	--	--	1	2	1	1	1	1	--	--
Texas AES (Blightmaster & Tamcot varieties)	1	1	--	2	2	2	6	6	7	8	8	10	9	10	8
University of New Mexico AES (Acala variety)	15	11	11	15	14	10	10	10	13	13	10	13	14	13	11
Private:															
All-Tex	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Brownfield Seed & Delinting (Quapaw variety)	*	*	*	*	*	*	1	1	1	2	1	2	1	1	1
California Planting Cotton Seed Distributors (CPCSD)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Coker Pedigreed Seed	6	8	8	6	8	5	6	4	3	4	3	3	3	3	3
Custom Agricultural Service (Cascot variety)	*	*	*	*	*	*	*	*	1	2	2	2	2	4	3
Delta & Pine Land[2] (DES, Lankart, Paymaster & Sure-Grow varieties)	28	26	29	24	23	17	20	18	18	15	14	16	16	13	16
Dunn Seed Farms	1	1	--	--	2	2	1	1	2	2	2	3	2	4	4
G & P Seed Company	*	*	*	*	*	*	*	*	*	1	1	1	2	1	2
Germain's (Acala variety)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Growers Seed Association (GSA)	*	*	*	*	*	1	3	4	7	7	7	7	2	5	6
Hyperformer	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Lankart	10	9	8	10	12	14	12	12	14	13	10	10	10	9	6
Lockett	2	2	2	2	3	4	2	1	2	2	2	2	1	1	--
McNair	1	1	--	1	--	1	1	1	1	1	1	1	2	1	3
Monsanto Company[3]	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Paymaster	6	5	2	5	6	8	8	9	7	8	7	9	8	9	10
Pioneer (PR 80, Rosebud 80 varieties)	*	*	*	*	*	*	*	*	*	*	*	*	*	1	
Rilcot Seed Company (Stripper & Rilcot varieties)	2	4	3	2	5	6	4	4	2	2	2	1	1	--	--
Stoneville Pedigreed[4] (Stoneville, Coker & McNair varieties)	21	21	25	24	19	19	23	23	18	15	15	16	18	16	16
Summit (Deltapine variety)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Sure-Grow[5]	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
All other	4	8	8	7	5	10	2	4	2	4	13	3	7	8	10
Largest 8 firms[6]	90	86	88	88	90	83	89	86	87	83	74	84	80	79	77
Largest 4 firms	74	67	73	73	68	60	65	63	63	56	49	55	58	52	53
Herfindahl Index	0.1648	0.1474	0.1778	0.158	0.139	0.1152	0.1345	0.1278	0.1197	0.1014	0.0982	0.105	0.1104	0.0992	0.0762

See footnotes at end of table.

--Continued

Table 20—Share of cotton varieties planted in the United States, by firm or institution–Continued

Firm / Institution	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
								Percent							
Public:															
Arkansas AES (Rex variety)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Mississippi AFES[1] (Dixie King & DES varieties)	--	1	1	2	3	3	--	--	--	--	--	--	--	--	--
Oklahoma AES (Westburn variety)	--	--	*	*	*	*	*	*	*	*	*	*	*	*	*
Texas AES (Blightmaster & Tamcot varieties)	9	7	6	5	7	3	4	1	1	1	1	1	1	1	1
University of New Mexico AES (Acala variety)	10	8	7	5	6	5	3	--	--	--	--	--	--	--	--
Private:															
All-Tex	--	--	1	1	3	1	2	1	1	2	2	3	2	2	2
Brownfield Seed & Delinting (Quapaw variety)	1	1	--	--	*	*	*	*	*	*	*	*	*	*	*
California Planting Cotton Seed Distributors (CPCSD)	*	*	*	*	*	*	*	5	7	6	5	7	6	5	5
Coker Pedigreed Seed	5	3	1	2	1	1	--	--	--	--	--	--	--	--	--
Custom Agricultural Service (Cascot variety)	2	2	3	2	1	1	--	1	--	--	--	--	--	--	--
Delta & Pine Land[2] (DES, Lankart, Paymaster & Sure-Grow varieties)	23	27	24	30	33	38	43	54	40	71	61	71	73	72	76
Dunn Seed Farms	4	2	2	1	1	1	--	--	--	--	--	--	--	--	--
G & P Seed Company	2	1	2	1	1	1	--	--	--	--	--	--	--	--	--
Germain's (Acala variety)	2	4	4	5	5	5	4	3	1	1	1	1	--	--	--
Growers Seed Association (GSA)	4	4	3	3	1	1	1	*	*	*	*	*	*	*	*
Hyperformer	*	*	*	*	*	*	1	2	2	2	2	2	1	--	--
Lankart	7	8	4	4	4	3	--	--	--	--	--	--	--	--	--
Lockett	--	*	*	*	*	*	*	*	*	*	*	*	*	*	*
McNair	3	2	1	1	1	1	*	*	*	*	*	*	*	*	*
Monsanto Company[3]	*	*	*	*	*	*	*	*	*	*	*	*	11	16	*
Paymaster	9	11	13	14	12	16	22	16	29	**	**	**	**	**	**
Pioneer (PR 80, Rosebud 80 varieties)		1	1	2	1	1	1	1	1	--	1	*	*	*	*
Rilcot Seed Company (Stripper & Rilcot varieties)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Stoneville Pedigreed[4] (Stoneville, Coker & McNair varieties)	18	16	13	11	9	7	6	8	8	8	9	9	**	**	13
Summit (Delta Pine & Land variety)	*	*	4	3	3	2	*	*	*	*	*	*	*	*	*
Sure-Grow[5]	*	*	*	*	*	--	--	--	1	2	8	**	**	**	**
All other	1	2	10	8	8	10	13	8	9	7	10	6	6	4	3
Largest 8 firms[6]	85	85	74	77	79	80	86	90	89	93	89	95	96	98	100
Largest 4 firms	60	62	57	60	61	66	75	83	84	87	83	90	92	95	96
Herfindahl Index	0.1244	0.1342	0.1272	0.141	0.1538	0.192	0.2564	0.3328	0.2628	0.5288	0.3984	0.5212	0.551	0.5476	0.5978

* indicates that a company left the cotton seed industry or prior to that had presumably not been involved in the industry.
** indicates company was acquired by another company.
-- indicates less than a 0.5-percent market share.
AES Stands for Agricultural Experiment Station. These are public research facilities that also release seed varieties.
[1] Mississippi Agricultural and Forestry Experiment Station.
[2] Delta Pine & Land acquired Paymaster varieties in 1994.
[3] Monsanto's bid for Delta Pine & Land in 1998 fell through in December 1999 when Monsanto called off the merger.
[4] Stoneville was acquired by Monsanto in 1997 when Monsanto purchased Stoneville's parent company, Calgene. However, Stoneville was then sold by Monsanto in 1999.
[5] Sure-Grow varieties were purchased by Delta & Pine Land in 1996.
[6] For 1994, 1998, and 1999, there were only seven companies listed with more than 0.5-percent share of the cotton seed market.

Sources: USDA, AMS (2000); USDA, ARS (2000).

Table 21—Share of wheat seed sales by principal private and public breeders in the United States, 1980-81

Sector, institution/ company	Hard red spring	Soft red winter	Hard red winter
	Percentage of total sales		
Public sector:			
University of Minnesota	34		
University of California (Davis)	22		
North Dakota University	16		
Purdue University		65	
Ohio State University		5	
University of Missouri		5	
University of Arkansas		5	
Kansas State University			35
University of Nebraska			25
Texas A&M University			10
Colorado University			10
Oklahoma State University			5
Subtotal	72	80	85
Private sector:			
Northrup-King/McNair (Sandoz)	14	2	
North American Plant Breeders (Shell/Olin)		4	5
Pioneer Hi-Bred		3	1
Coker (KWS)		7	
Agrigenetics			1
Western Plant Breeders	1		
World Seeds	2		
Subtotal	18	16	7
Other seeds	10	4	8
Total	100	100	100

Source: Butler and Marion (1985), p. 93.

offs between increased market power and the economies resulting from the increased concentration (arising from mergers or other combinations) (Williamson, 1968). In the case of the seed industry, if market power dominates, concentration may raise industry profits and margins, and farmers may pay higher-than-competitive prices for seeds. On the other hand, if the efficiency (or cost-reducing) effects outweigh the market power effects, concentration may be beneficial to society.

Table 22—U.S. wheat market shares, public and private varieties, 1981 and 1997

	Unknown	Public sector varieties	Private sector varieties
	Percent of area planted		
Hard red winter wheat:			
1981	36	58	6
1997		85	15
Hard red spring wheat:			
1981	37	57	7
1997		85	15
Soft red spring wheat:			
1981	37	63	
1997		35	65

Source: Heisey (1999a).

A growing body of literature presents model-based estimates of the degree of noncompetitive behavior in other industries (Appelbaum, 1979, 1982; Iwata, 1974; Gollop and Roberts, 1979; Azzam and Schroeter, 1995; Azzam, 1997). ERS examined the effects of industry concentration on market power and costs (including R&D) in the U.S. cottonseed and corn seed industries, using an econometric model to measure the relative strengths of these effects over the past 30 years (Fernandez-Cornejo et al., 2002; Fernandez-Cornejo and Spielman, 2002). The model assumes that the profit-maximizing seed firm buys its inputs, including the material input—seed purchased from contract growers—in a competitive market, and sells the seed to cotton (or corn) growers in a noncompetitive market. Most data were collected from USDA and other government sources for the period covering 1970-98. Preliminary empirical results for U.S. cotton and corn seed industries over the past 30 years suggest that increased concentration resulted in a cost-reducing effect that prevailed over the effect of enhanced market power.

Roles of Private and Public Sector R&D in Crop Seed Have Shifted

A prominent change in the seed industry over the last century has been the increasing role of private sector efforts in R&D. Not only have private R&D expenditures increased dramatically in absolute levels, but they have also increased relative to public levels. As private sector R&D expenditures have risen, the types of R&D activity pursued and the choice of crops for research have also changed. With the shift of more R&D activity to the private sector, the process by which the seed industry changes has itself transformed.

Returns to R&D Spending on Plant Breeding

Annual returns to R&D spending on plant breeding exceed 30 percent according to most estimates, although estimates vary widely. Griliches (1958) estimates the returns to public agricultural research for hybrid corn to be 35-40 percent during the period 1940-55. Sundquist et al. (1981) estimate those returns to be 115 percent in 1977. Griliches also finds returns to R&D on hybrid sorghum to be 20 percent during 1940-57. Other studies show returns to cash grains range from 31 to 85 percent (Fuglie et al., pp. 30-31). However, Huffman and Evenson (1993, pp. 245-46) report that returns to public sector crop research (45-62 percent) during 1950-82 are lower than returns to private sector research (90 percent) (table 23).

These estimates of returns to R&D investment may fail to incorporate the positive externalities generated by plant breeding research among and between countries. Foreign research in plant breeding benefits from positive spillovers arising from U.S. agricultural research just as U.S. researchers benefit from transfers of genetically diverse materials from research institutions and firms abroad. As a result, consumers in the United States and foreign countries frequently benefit from the increased quality and lower prices offered by new varieties cultivated, imported, or exported in the international economy (Fuglie et al., 1996, p. 28; Fernandez-Cornejo and Shumway, 1997; Maredia and Byerlee, 1999; Schimmelpfennig and Thirtle, 1999; Schimmelpfennig et al., 2000).

Public R&D

Historically in the United States, the public sector has maintained a central role in agricultural R&D. The establishment of the U.S. Department of Agriculture (1862) and the passage of key legislation, such as the Morill Land-Grant College Act (1862), the Hatch Act (1887), and the Smith-Lever Act (1914), expanded this role. The Morill Act established colleges and universities in U.S. States and territories that were dedicated to instruction in agriculture and engineering sciences, and, in 1890, were given further support with Federal funding under the second Morill Act. The Hatch Act provided further support to State-level research by establishing State agricultural experiment stations (SAES) to collaborate with land-grant institutions and to strengthen scientific research in agriculture. The

Table 23—Estimated returns to crop research in U.S. agriculture, various years

Commodity	Period	Annual return	Study
		Percent	
Hybrid corn	1940-55	35-40	Griliches, 1958
Hybrid sorghum	1940-57	20	Griliches, 1958
Cash grains	1969	47	Bredahl and Peterson, 1976
Crops	1959-64	110	Huffman, 1977
Crops	1964	55	Evenson and Welch, 1979
Cash grains	1969	31-57	Norton, 1981
Cash grains	1974	44-85	Norton, 1981
Maize	1977	115	Sundquist, Cheng, and Norton, 1981
Wheat	1977	97	Sundquist, Cheng, and Norton, 1981
Soybeans	1977	118	Sundquist, Cheng, and Norton, 1981
Crops - public sector, applied R&D	1950-82	45	Huffman and Evenson, 1993
Crops - public sector, pre-tech R&D	1950-82	62	Huffman and Evenson, 1993
Crops - private sector R&D	1950-82	90	Huffman and Evenson, 1993

Sources: Huffman and Evenson (1993), pp. 245-246; Fuglie et al. (1996), p. 30; Alston and Pardey (1996), pp. 204-206.

Smith-Lever Act extended this collaboration to include Federal, State, and county agencies through the establishment of the Cooperative Agricultural Extension Service (Fuglie et al., 1996, p. 2). Combined with resources from the USDA and other cooperating government agencies, these legislative acts supported a wide range of public initiatives in agricultural R&D.

One rationale for public investment in agricultural R&D is to address specific market failures. R&D can enhance yields, lower costs, and provide other benefits to both producers and consumers. The incentive for firms to undertake R&D arises from the ability of firms to capture some of the value created from successful innovation. However, the ease of replicating successful R&D undermines the ability of firms to appropriate the returns to their R&D investments (King, 2001). When a competitor can replicate R&D results without incurring the R&D costs, the competitive advantage to firms investing in R&D is not sustainable. The inability of firms to appropriate the returns to their R&D investments results in a market failure, in that productivity- and wealth-enhancing improvements are not attempted.

Other market failures include negative externalities and risk aversion or financial market failures (Beach and Fernandez-Cornejo, 1994). Negative externalities may arise where the social marginal costs of agricultural R&D exceed the private marginal benefits; for instance, when the broad social desire to improve a certain agricultural process is greater than firms' ability to generate such improvements profitably, resulting in underproduction and deadweight losses to society. Risk aversion and financial market failures may occur when private returns from R&D investments over the long term are discounted by investors at a rate higher than the desirable social rate of return.

Modern agricultural R&D includes large amounts of investment from both the public and private sectors (Alston and Pardey, 1996, pp. 29-30). Total public sector expenditure on agricultural R&D, which includes both Federal and State spending, was $3.1 billion in 1996 (table 24). Private sector R&D exceeded $4 billion in the same period (table 25).

Private Sector R&D

The development of commercially viable hybrid corn in the 1930s, the PVPA and subsequent rulings, and other forms of property rights protection led to significant changes in research expenditure patterns and played a key role in the development of new plant varieties. These technological and institutional changes over the past century improved appropriability, increasing incentives for private investment in agricultural R&D, resulting in a larger role in research for private firms.

Real private sector expenditure in agricultural R&D increased by 224 percent from 1960 to 1996 (table 25). Over the same period, real public sector agricultural R&D increased by 97 percent. In addition to the higher relative increase, annual private sector R&D expenditures have exceeded public expenditures every year since 1982. Whereas private sector efforts accounted for slightly less than half of total R&D expenditures from 1960 to 1970, they accounted for 58.7 percent of the total in 1996.

Expenditures on plant breeding and agricultural chemicals were the main areas of increased private sector R&D. From 1960 to 1995, real plant breeding expenditures increased by $514 million (1996 dollars), while R&D on agricultural chemicals increased by $1.392 billion. The growth of R&D in agricultural chemicals primarily reflects the increasing use of herbicides (USDA, 1997, p. 117) and compliance with regulations (Ollinger and Fernandez-Cornejo, 1995).

The dramatic increase in private sector plant breeding R&D expenditures came while public expenditure in that area changed very little in real terms. On the whole, private spending on plant breeding has steadily increased since 1960 as the seed industry increased in size and extent of commercialization. Private sector R&D expenditure has shifted over this period, in percentage terms, from farm machinery and food and kindred products to agricultural chemicals and plant breeding research.[11] These changes in expenditures have been accompanied by structural change in the industry. First, intense merger and acquisition activity in the last three decades led to the formation of large seed conglomerates that allowed once smaller, individually owned, seed companies to take advantage of the strategic R&D relationships and economies of scale of their parent companies. Second, new entrants into the seed industry between 1982 and 1994 increased the

[11] It is worth noting that that the increasing proportion of expenditure on agricultural chemicals greatly exceeds the increase in plant breeding, as shown in table 25. This is attributed to the fact that research in agricultural chemicals has long been dominated by the private sector, while plant breeding was traditionally the domain of public sector investment and only beginning to attract private investment during the earlier years of this period (Heisey, 1999, p. 19).

Table 24—Public agricultural research and development

Year	Biological efficiency expenditure					Non-commodity biotech & biometry expenditure					Pesticides & herbicides expenditure				
	USDA[1]	SAES[1]	Total	Total	Share of public R&D expenditure	USDA[2]	SAES[2]	Total	Total	Share of public R&D expenditure	USDA[3]	SAES[3]	Total	Total	Share of public R&D expenditure
	Million current dollars			*Mil. 1996 dollar*	*Percent*	*Million current dollars*			*Mil.1996 dollar*	*Percent*	*Million current dollars*			*Mil.1996 dollar*	*Percent*
1960	4.79	29.14	33.93	228.17	14.30	NA	NA	NA	NA	NA	11.60	16.43	28.02	188.43	11.81
1961	5.22	30.99	36.21	236.44	14.32	NA	NA	NA	NA	NA	12.84	17.26	30.10	196.57	11.91
1962	5.69	32.95	38.64	242.75	14.46	NA	NA	NA	NA	NA	13.40	18.96	32.37	203.33	12.11
1963	6.20	35.04	41.24	248.68	14.49	NA	NA	NA	NA	NA	14.42	20.45	34.87	210.27	12.25
1964	6.76	37.27	44.02	255.85	13.67	NA	NA	NA	NA	NA	16.72	23.14	39.86	231.63	12.38
1965	7.37	39.63	47.00	262.28	13.15	NA	NA	NA	NA	NA	19.60	25.82	45.42	253.49	12.71
1966	8.03	42.14	50.17	266.73	12.85	NA	NA	NA	NA	NA	20.25	30.26	50.51	268.53	12.94
1967	8.75	44.82	53.57	269.43	13.13	NA	NA	NA	NA	NA	20.98	32.92	53.90	271.10	13.21
1968	9.77	46.29	56.06	266.00	12.95	NA	NA	NA	NA	NA	20.42	38.44	58.87	279.32	13.60
1969	10.26	49.96	60.21	267.74	13.18	NA	NA	NA	NA	NA	22.17	40.68	62.85	279.46	13.75
1970	9.69	46.55	56.24	232.26	11.41	6.44	19.70	26.14	107.96	5.30	19.95	37.91	57.86	238.96	11.74
1971	9.74	49.81	59.55	232.37	11.19	7.08	20.41	27.48	107.25	5.16	22.35	40.48	62.83	245.18	11.81
1972	12.69	52.16	64.86	241.62	10.34	9.43	22.67	32.10	119.59	5.12	31.12	43.15	74.27	276.69	11.84
1973	13.64	54.46	68.10	239.10	10.15	10.93	25.27	36.19	127.07	5.40	30.68	48.82	79.51	279.14	11.85
1974	13.96	59.66	73.62	238.94	10.10	11.07	26.70	37.77	122.58	5.18	31.85	56.27	88.12	285.97	12.08
1975	15.60	68.89	84.50	254.80	10.26	12.35	27.74	40.09	120.90	4.87	33.96	63.67	97.62	294.40	11.85
1976	23.85	88.10	111.95	317.96	12.46	18.90	39.66	58.56	166.31	6.52	51.69	89.93	141.62	402.23	15.76
1977	20.96	89.55	110.51	301.77	10.71	17.96	35.59	53.54	146.21	5.19	47.40	79.40	126.80	346.24	12.29
1978	24.44	96.01	120.45	310.43	10.41	27.78	39.23	67.01	172.70	5.79	56.30	88.29	144.58	372.63	12.50
1979	27.49	101.70	129.19	309.61	10.36	26.71	43.20	69.91	167.55	5.61	62.41	98.60	161.01	385.87	12.91
1980	26.58	117.05	143.62	316.38	10.50	33.69	50.75	84.43	186.00	6.18	65.84	114.72	180.56	397.74	13.21
1981	34.02	126.34	160.35	323.09	10.49	37.91	55.45	93.36	188.10	6.11	75.56	132.95	208.50	420.10	13.64
1982	33.38	135.83	169.20	316.40	10.31	36.59	62.36	98.94	185.02	6.03	76.10	144.74	220.84	412.96	13.45
1983	36.68	138.96	175.64	310.66	10.31	39.84	70.64	110.48	195.40	6.48	79.20	150.41	229.61	406.11	13.48
1984	36.64	142.75	179.40	300.50	10.14	38.52	75.53	114.05	191.04	6.45	76.11	161.24	237.36	397.58	13.42
1985	44.55	153.05	197.61	314.03	10.25	47.72	90.03	137.75	218.90	7.14	88.12	173.12	261.24	415.16	13.55
1986	52.14	163.19	215.33	324.88	10.69	43.75	100.43	144.18	217.54	7.16	87.57	184.78	272.34	410.91	13.52
1987	56.84	164.75	221.59	315.19	10.26	38.29	105.58	143.87	204.65	6.66	94.82	193.81	288.63	410.56	13.36
1988	66.92	168.89	235.81	322.90	10.25	44.01	114.17	158.18	216.59	6.87	103.43	201.83	305.26	418.00	13.27
1989	70.58	180.00	250.58	325.41	10.25	33.81	122.18	155.99	202.58	6.38	105.63	216.56	322.19	418.40	13.17
1990	69.98	194.07	264.05	325.71	10.16	24.12	126.96	151.08	186.36	5.81	115.21	228.54	343.75	424.03	13.23
1991	75.70	199.36	275.06	325.74	9.89	27.26	132.69	159.95	189.42	5.75	131.05	244.63	375.68	444.90	13.51
1992	79.26	201.85	281.11	322.47	9.65	24.35	133.00	157.34	180.50	5.40	134.57	259.73	394.30	452.32	13.54
1993	80.16	205.83	286.00	313.97	9.63	25.39	137.58	162.97	178.91	5.49	135.03	270.47	405.50	445.16	13.65
1994	79.98	210.68	290.66	308.87	9.34	25.63	145.42	171.05	181.77	5.50	138.99	277.58	416.56	442.67	13.39
1995	74.21	211.50	285.71	294.59	9.02	22.71	142.47	165.18	170.32	5.21	143.71	295.96	439.67	453.34	13.87
1996	69.09	198.10	267.20	267.20	8.49	16.14	139.05	155.19	155.19	4.93	141.52	303.91	445.42	445.42	14.15

See footnotes at end of table.

--Continued

Table 24—Public agricultural research and development--Continued

Year	Production mechanization expenditures					Total public agri. R&D expenditures		
	USDA[4]	SAES[4]	Total	Total	Share of public R&D expenditure	Total[5]	Total[5]	Agric. R&D deflator[6]
	Million current dollars			*Mil. 1996 dollars*	*Percent*	*Million current dollars*	*Mil. 1996 dollars*	
1960	NA	NA	NA	NA	NA	237.3	1,595.7	0.1487
1961	NA	NA	NA	NA	NA	252.8	1,650.6	0.1531
1962	NA	NA	NA	NA	NA	267.3	1,679.3	0.1592
1963	NA	NA	NA	NA	NA	284.7	1,716.6	0.1658
1964	NA	NA	NA	NA	NA	322.0	1,871.5	0.1721
1965	NA	NA	NA	NA	NA	357.3	1,994.4	0.1792
1966	NA	NA	NA	NA	NA	390.5	2,075.9	0.1881
1967	NA	NA	NA	NA	NA	408.1	2,052.4	0.1988
1968	2.37	3.76	6.13	29.09	1.42	432.7	2,053.3	0.2107
1969	2.72	4.33	7.05	31.34	1.54	457.0	2,032.0	0.2249
1970	1.85	4.40	6.24	25.78	1.27	492.8	2,035.3	0.2421
1971	2.97	4.65	7.63	29.76	1.43	532.2	2,076.8	0.2562
1972	3.62	4.47	8.09	30.13	1.29	627.1	2,336.2	0.2684
1973	3.86	4.95	8.81	30.93	1.31	670.7	2,354.9	0.2848
1974	3.93	5.39	9.32	30.26	1.28	729.2	2,366.7	0.3081
1975	4.06	5.67	9.72	29.32	1.18	823.5	2,483.4	0.3316
1976	5.74	7.62	13.36	37.95	1.49	898.4	2,551.6	0.3521
1977	4.82	6.30	11.13	30.38	1.08	1,031.7	2,817.2	0.3662
1978	5.25	7.00	12.25	31.56	1.06	1,157.1	2,982.1	0.3880
1979	5.02	7.27	12.29	29.46	0.99	1,247.2	2,989.1	0.4173
1980	5.48	7.91	13.39	29.49	0.98	1,367.2	3,011.8	0.4540
1981	6.21	7.36	13.57	27.33	0.89	1,528.6	3,079.8	0.4963
1982	5.63	7.97	13.61	25.44	0.83	1,641.6	3,069.6	0.5348
1983	6.22	8.12	14.34	25.36	0.84	1,703.6	3,013.1	0.5654
1984	6.10	7.79	13.89	23.27	0.79	1,769.0	2,963.1	0.5970
1985	6.50	8.96	15.46	24.57	0.80	1,928.0	3,063.9	0.6293
1986	4.32	8.67	12.99	19.60	0.64	2,014.8	3,039.9	0.6628
1987	3.32	9.19	12.51	17.80	0.58	2,160.5	3,073.2	0.7030
1988	3.22	9.77	12.99	17.78	0.56	2,301.2	3,151.0	0.7303
1989	2.67	10.37	13.04	16.93	0.53	2,445.8	3,176.2	0.7700
1990	3.08	10.26	13.35	16.46	0.51	2,598.3	3,205.1	0.8107
1991	3.40	9.56	12.96	15.35	0.47	2,780.5	3,292.8	0.8444
1992	3.24	8.99	12.23	14.03	0.42	2,913.2	3,341.8	0.8717
1993	3.36	9.32	12.68	13.92	0.43	2,970.9	3,261.5	0.9109
1994	3.46	9.98	13.44	14.28	0.43	3,111.5	3,306.6	0.9410
1995	3.24	9.64	12.88	13.28	0.41	3,168.8	3,267.3	0.9698
1996	2.88	9.03	11.91	11.91	0.38	3,148.0	3,148.0	1.0000

NA = not available. SAES = State Agricultural Experiment Station.

[1] Research problem area code 304 and 307 in CRIS (USDA, CSREES, CRIS, 1993). Source: "Inventory of Agricultural Research" for fiscal years 1968-96 (USDA, CSREES, CRIS, various years). For 1960-67, total public expenditures on biological efficiency and pesticides/pest management estimated by linear interpolation.

[2] Research problem area code 318 in CRIS (USDA, CSREES, CRIS, 1993). Source: "Inventory of Agricultural Research" for fiscal years 1968-96 (USDA, CSREES, CRIS, various years). For 1960-67, total public expenditures on biological efficiency and pesticides/pest management are estimated by linear interpolation.

[3] Research problem area codes 204-209 in CRIS (USDA, CSREES, CRIS, 1993). Source: 1960-67: USDA and SAES expenditure on pesticides and herbicides are linear interpolations of data based on total SAES R&D expenditure derived from the rate of growth of total SAES R&D expenditure assumed to be consistent with the annual rate of growth in Alston and Pardey (1996, Table 2-A3, 76); 1968-96: "Inventory of Agricultural Research" for fiscal years 1968-96 (USDA, CSREES, CRIS, various years).

[4] Research problem area code 305 and 308 in CRIS (USDA, CSREES, CRIS, 1993). Source: "Inventory of Agricultural Research" for fiscal years 1968-96 (USDA, CSREES, CRIS, various years). For 1960-67, total public expenditures on biological efficiency and pesticides/pest management are estimated by linear interpolation.

[5] Total agri. R&D expenditures are not the sum of the four categories of R&D presented, and includes other categories not shown here. Source: 1960-69: data are based on rates of change from Alston and Pardey (1986, p. 76), and Huffman & Evenson (1993, pp. 95-96); 1970-96: "Inventory of Agricultural Research" for fiscal years 1970-96 (USDA, CSREES, CRIS, various years).

[6] Source: Klotz-Ingram (2000).

Table 25—Private agricultural research and development

Year	Plant breeding expenditure			Agricultural chemicals expenditure			Farm machinery expenditure			Food & kindred products expenditure			Veterinary pharmaceuticals expenditure			Total private agric. R&D expenditure		
	Total[1]	Total	Share of private R&D	Total[1]	Total	Share of private R&D expenditure	Total[1]	Total	Share of private R&D expenditure	Total[1]	Total	Share of private R&D expenditure	Total[1]	Total	Percent of private R&D expenditure	Total[1]	Total	Agric. R&D deflator[2]
	Million current $	*Mil. 1996 dollars*	*Percent*	*Million current $*	*Mil. 1996 dollars*	*Percent*	*Million current $*	*Mil. 1996 dollars*	*Percent*	*Million current $*	*Mil. 1996 dollars*	*Percent*	*Million current $*	*Mil. 1996 dollars*	*Percent*	*Million current $*	*Mil. 1996 dollars*	
1960	6.00	40.35	2.91	27.00	181.56	13.11	75.00	504.34	36.41	92.00	618.66	44.66	6.00	40.35	2.91	206.00	1,385.26	0.1487
1961	6.00	39.18	2.83	38.00	248.14	17.92	65.00	424.45	30.66	92.00	600.76	43.40	11.00	71.83	5.19	212.00	1,384.36	0.1531
1962	6.00	37.69	2.61	42.00	263.84	18.26	70.00	439.73	30.43	98.00	615.62	42.61	14.00	87.95	6.09	230.00	1,444.82	0.1592
1963	7.00	42.21	2.86	45.00	271.33	18.37	76.00	458.25	31.02	102.00	615.02	41.63	15.00	90.44	6.12	245.00	1,477.24	0.1658
1964	8.00	46.49	2.93	48.00	278.96	17.58	79.00	459.12	28.94	118.00	685.77	43.22	20.00	116.23	7.33	273.00	1,586.57	0.1721
1965	9.00	50.23	2.79	64.00	357.19	19.81	96.00	535.78	29.72	131.00	731.12	40.56	23.00	128.36	7.12	323.00	1,802.68	0.1792
1966	11.00	58.48	3.18	77.00	409.36	22.25	100.00	531.63	28.90	130.00	691.13	37.57	28.00	148.86	8.09	346.00	1,839.46	0.1881
1967	12.00	60.36	3.38	72.00	362.14	20.28	102.00	513.04	28.73	134.00	673.99	37.75	35.00	176.04	9.86	355.00	1,785.57	0.1988
1968	17.00	80.67	4.34	78.00	370.12	19.90	96.00	455.53	24.49	165.00	782.94	42.09	36.00	170.82	9.18	392.00	1,860.07	0.2107
1969	22.00	97.82	5.21	85.00	377.96	20.14	99.00	440.21	23.46	182.00	809.27	43.13	34.00	151.18	8.06	422.00	1,876.44	0.2249
1970	26.00	107.38	5.60	98.00	404.72	21.12	89.00	367.55	19.18	206.00	850.74	44.40	45.00	185.84	9.70	464.00	1,916.23	0.2421
1971	29.00	113.17	5.95	109.00	425.37	22.38	90.00	351.22	18.48	211.00	823.42	43.33	48.00	187.32	9.86	487.00	1,900.49	0.2562
1972	32.00	119.21	6.30	104.00	387.44	20.47	93.00	346.46	18.31	227.00	845.67	44.69	52.00	193.72	10.24	508.00	1,892.51	0.2684
1973	39.00	136.92	6.76	113.00	396.73	19.58	120.00	421.31	20.80	243.00	853.14	42.11	62.00	217.67	10.75	577.00	2,025.78	0.2848
1974	45.00	146.05	6.73	136.00	441.38	20.33	131.00	425.16	19.58	283.00	918.47	42.30	74.00	240.16	11.06	669.00	2,171.22	0.3081
1975	50.00	150.78	7.05	169.00	509.64	23.84	138.00	416.15	19.46	273.00	823.26	38.50	79.00	238.23	11.14	709.00	2,138.06	0.3316
1976	55.00	156.21	6.72	200.00	568.05	24.45	168.00	477.16	20.54	308.00	874.80	37.65	87.00	247.10	10.64	818.00	2,323.32	0.3521
1977	58.00	158.38	6.08	243.00	663.55	25.47	221.00	603.47	23.17	348.00	950.27	36.48	84.00	229.37	8.81	954.00	2,605.04	0.3662
1978	69.00	177.83	6.39	290.00	747.40	26.88	249.00	641.73	23.08	385.00	992.24	35.68	86.00	221.64	7.97	1,079.00	2,780.85	0.3880
1979	81.00	194.13	6.73	312.00	747.74	25.91	295.00	707.00	24.50	420.00	1,006.58	34.88	96.00	230.08	7.97	1,204.00	2,885.53	0.4173
1980	97.00	213.68	6.67	395.00	870.14	27.17	363.00	799.65	24.97	488.00	1,075.01	33.56	111.00	244.52	7.63	1,454.00	3,202.99	0.4540
1981	105.00	211.56	7.15	469.00	944.95	31.93	278.00	560.12	18.92	492.00	991.29	33.49	125.00	251.85	8.51	1,469.00	2,959.78	0.4963
1982	118.00	220.65	7.15	527.00	985.45	31.92	281.00	525.45	17.02	596.00	1,114.47	36.10	129.00	241.22	7.81	1,651.00	3,087.24	0.5348
1983	138.00	244.08	7.69	584.00	1,032.93	32.53	290.00	512.93	16.16	636.00	1,124.90	35.43	147.00	260.00	8.19	1,795.00	3,174.85	0.5654
1984	154.00	257.96	7.53	624.00	1,045.22	30.50	311.00	520.94	15.20	803.00	1,345.05	39.25	154.00	257.96	7.53	2,046.00	3,427.13	0.5970
1985	179.00	284.47	8.26	683.00	1,085.42	31.52	304.00	483.11	14.03	842.00	1,338.10	38.86	159.00	252.68	7.34	2,167.00	3,443.78	0.6293
1986	204.00	307.79	8.79	691.00	1,042.57	29.77	307.00	463.20	13.23	940.00	1,418.25	40.50	179.00	270.07	7.71	2,321.00	3,501.88	0.6628
1987	222.00	315.78	9.75	682.00	970.10	29.94	292.00	415.35	12.82	891.00	1,267.39	39.11	191.00	271.69	8.38	2,278.00	3,240.31	0.7030
1988	245.00	335.48	9.53	938.00	1,284.41	36.48	295.00	403.95	11.47	871.00	1,192.67	33.88	221.00	302.62	8.60	2,571.00	3,520.50	0.7303
1989	283.00	367.51	10.31	979.00	1,271.36	35.65	320.00	415.56	11.65	921.00	1,196.04	33.54	243.00	315.57	8.85	2,746.00	3,566.05	0.7700
1990	314.00	387.33	10.57	1,127.00	1,390.21	37.93	360.00	444.08	12.12	925.00	1,141.03	31.13	245.00	302.22	8.25	2,971.00	3,664.86	0.8107
1991	342.00	405.01	10.78	1,228.00	1,454.25	38.69	382.00	452.38	12.04	946.00	1,120.30	29.80	276.00	326.85	8.70	3,174.00	3,758.80	0.8444
1992	400.00	458.86	12.47	1,062.00	1,218.28	33.10	394.00	451.98	12.28	1021.00	1,171.24	31.83	331.00	379.71	10.32	3,208.00	3,680.07	0.8717
1993	453.00	497.31	13.04	1,389.00	1,524.86	39.99	369.00	405.09	10.62	995.00	1,092.32	28.65	267.00	293.12	7.69	3,473.00	3,812.71	0.9109
1994	470.00	499.46	13.10	1,356.00	1,440.99	37.80	377.00	400.63	10.51	1084.00	1,151.94	30.22	300.00	318.80	8.36	3,587.00	3,811.82	0.9410
1995	524.00	540.29	13.64	1,419.00	1,463.12	36.94	436.00	449.56	11.35	1146.00	1,181.63	29.84	316.00	325.82	8.23	3,841.00	3,960.41	0.9698
1996	554.00	554.00	12.35	NA	NA	NA	487.00	487.00	10.86	NA	NA	NA	359.00	359.00	8.00	4,486.00	4,486.00	1.0000

NA = not available.

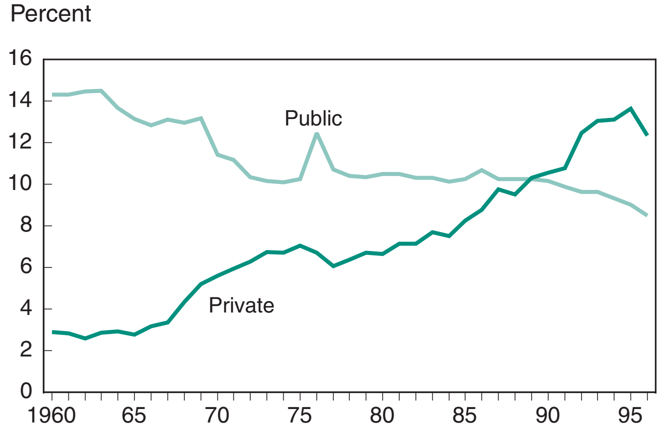
[1] Source: 1960-92: Klotz, Fuglie, and Pray (1995, p. 26); 1993-1997: Klotz, Fuglie and Pray (1995, updated July 1998). [2] Klotz-Ingram, Private Communication (2000).

number of firms engaged in private plant breeding throughout the United States from 269 to 329 (table 26). This trend in the private sector resulted in a 1,300-percent real increase in private R&D plant breeding expenditures between 1960 and 1996.

As the emphasis of R&D shifted, the share of public sector R&D expenditures on plant breeding research remained relatively unchanged at about 10 percent between 1970 and 1990, but the share declined in the 1990s (fig. 13). Public spending on biological efficiency (used as a proxy for public spending on plant breeding) decreased as a share of total public agricultural R&D expenditures, reaching 9 percent ($291 million) of total public sector agricultural R&D in 1994 (figs. 13-14).[12] This decrease occurred despite evidence suggesting that the rate of return on public research remains positive, and that such areas as precommercial agricultural research continue to require government support (Fuglie et al., 1996, pp. 29-31). On the other hand, the share of private sector research spent on plant breeding increased, reaching 13 percent ($470 million) of total expenditures on private agricultural R&D in 1994 (table 25) (Klotz et al.).

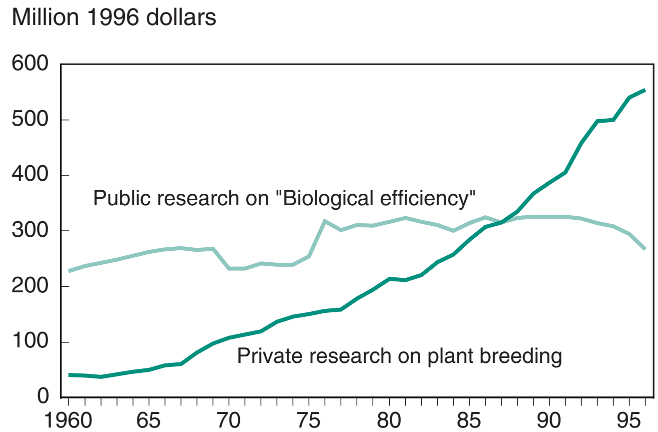
[12] We approximate public sector spending on plant breeding with USDA and SAES expenditures on improving biological efficiency for fruits and vegetables and field crops. Improvement of biological efficiency research is described in research problem areas 304 and 307 of the *Manual of Classification of Agricultural and Forestry Research*, as research on "the ability of agriculture to meet the feed, food, and fiber needs of the American people and provide vital amounts of these commodities for exports" (USDA, 1993, p. 71). The specific areas of research contained in this category of the *Manual* relevant to plant breeding are (i) the identification of superior germplasm and breeding and selection of improved varieties, and (ii) the genetic and biological determinants of biological efficiency. These research areas are adequate to examine trends in public sector expenditure on plant breeding, and to make comparisons with private sector expenditures.

Figure 13
Plant breeding as a share of total agricultural R&D expenditures



Source: Data source provided in tables 24 and 25.

Figure 14
Public and private research expenditures on plant breeding



"Biological efficiency" includes breeding and selection of improved plant varieties.

Source: Data source provided in tables 24 and 25.

Table 26—Private sector firms engaged in plant breeding, major field crops

Crop	1982		1989		1994	
	Number of companies	Share of companies	Number of companies	Share of companies	Number of companies	Share of companies
		Percent		*Percent*		*Percent*
Corn	66	24.5	75	27.6	91	27.7
Soybeans	26	9.7	34	12.5	38	11.6
Cotton	13	4.8	11	4.0	35	10.6
Wheat	21	7.8	11	4.0	27	8.2
Others	143	53.2	141	51.8	138	41.9
Total	269	100.0	272	100.0	329	100.0

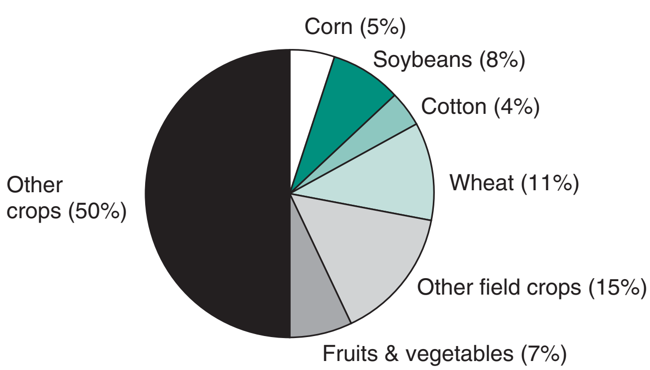
Source: Companies and expenditures for 1994: Frey (1996, p.19); companies and expenditures for 1982 and 1989: Kalton et al. (1990, p. 24).

Private and public research do not always emphasize the same areas. The emphasis of the private sector on pure line field crops (fig. 15, table 26) suggests that one role for the public sector is to carry out research in otherwise neglected crops. Private sector research has expanded to include cultivar development on hybrid crops and pre-breeding activities; meanwhile, public plant breeding research has focused on basic germplasm and applied plant genetics. (Heisey et al., 2001). So even as private firms engage in R&D that once was performed mostly by the public sector, important roles still exist for both public and private R&D.

A breakdown of expenditures on plant breeding R&D by specific private firms provides additional insight into the magnitude and growth of private sector research (table 27). Large firms, such as ICI, Sandoz, and Pioneer, each spent between $38 million and $57 million on plant breeding in 1988. As a share of seed sales, these figures range from 6.3 percent (Pioneer) to 23.2 percent (ICI). The seed industry considers 5 to 7 percent of sales to be the minimum requisite investment in R&D to maintain competitiveness (James, 1997, p. 6). Other large firms, such as Ciba-Geigy, DeKalb, Limagrain, KWS, and Upjohn, spent between $16 million and $27 million each on plant breeding R&D in 1988, and, when measured as a share of sales, each of these firms also exceeded the minimum requisite investment levels in R&D. By 1996, after new rounds of mergers and acquisitions, the upper bounds of R&D expenditures by large firms had increased significantly: Pioneer spent $133 million on seed R&D, a 2.5-fold increase relative to 1988, followed closely by Novartis with $122 million. Even Cargill, a smaller player in the market in terms of annual seed revenue, spent $37 million on seed R&D in 1996. As a share of sales, these expenditure levels again exceeded the industry estimates of minimum spending necessary to sustain competitiveness in the seed market.

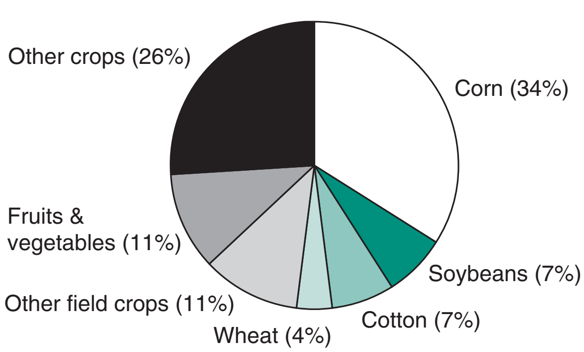
Figure 15
Research effort by crop, 1994

A--Public sector research effort (staff years) in biological efficiency



Source: Calculated from the number of SY given in table 32 first column.

B--Private industry research effort (staff years) in plant breeding



Source: Data source provided in table 31.

Plant Breeding Research Patterns by Crop

The changing focus of public and private sector R&D expenditures in plant breeding has also been associated with changes in research expenditure on specific crops. Historically, public sector expenditures on plant breeding have been allocated to basic and applied research on new varieties of field crops, while private sector expenditures have focused on the development of new plant varieties for home garden and horticultural crops (Fuglie et al., 1996, p. 53).

With the development of commercially viable hybrids in the 1930s, corn was the first crop subject to the rapid shift from public to private R&D sector expenditures in plant breeding. Private seed companies accounted for 40 percent of total R&D spent on corn in 1960 and more than 60 percent in 1984 (table 28). The shift of R&D expenditures from the public to the private sector occurred more recently with soybeans, and may be partly credited to the PVPA (Fuglie et al., 1996, p. 53). In 1960, less than 1 percent of R&D expenditures on soybean improvement came from the private sector (table 29). By 1984, this share had risen to almost a quarter of the total (public and private) R&D spent on soybeans. Among private R&D expen-

Table 27—Plant breeding R&D expenditures by company

Company	1986 Plant breeding			1988-89 Plant breeding					1996 Seed		
	Conventional breeding R&D	Plant biotechnology R&D	Total plant breeding R&D	Conventional breeding R&D	Plant biotechnology R&D	Total plant breeding R&D	Seed sales (fiscal 1989)	R&D as share of seed sales	Seed R&D	Annual revenue	R&D as share of revenue
	Million current dollars			*Million current dollars*				*Percent*	*Mil. current dollars*		*Percent*
Aventis Cropscience											
Rhone-Poulenc	2	3	5				125				
AgrEvo											
Novartis									122	970	12.6
Zeneca											
Advanta									53	470	11.3
ICI	11	15	26	21	17	38	164	23.2			
Sandoz	16	7	23	41	16	57	473	12.1			
Ciba-Geigy	9	13	22	9	17	26	125	20.8			
DowElanco											
Dow AgroSciences											
DuPont				0	20	20					
Pioneer	30	5	35	46	7	53	840	6.3	133	1,600	8.3
Monsanto	1	15	16	1	15	16					
DeKalb/Pfizer	19	6	25	16	6	22	205	10.7	41	387	10.6
Cargill[1]							250		37	250	14.8
Limagrain				22	5	27	335	8.1	60	660	9.1
KWS				18	5	23	151	15.2	47	350	13.4
Enimont				0	15	15					
Seminis									47	380	12.4
Shell	9	3	12	19	3	22					
Upjohn				24	3	27	270	10.0			

[1] Cargill's international seed business was purchased by Monsanto, while its U.S. seed business was purchased by AgrEvo.

Sources: 1986: Grossman et al. (1988, p. 13), 1988-89: Fox (1990, p. 42-43), 1996: James (1997, p. 6).

ditures on major crops, the share of R&D spent on soybeans by the 14 largest seed firms grew the fastest, from 1 percent in 1970 to 11 percent in 1980 (table 30). Public varieties of wheat and, to a lesser degree, cotton have been important sources of new seed for farmers. In addition, the public sector has continued to be the primary source of R&D investment and variety development for many small grains, such as oats, barley, and other minor field crops (Fuglie et al., 1996, pp. 53-55; Heisey, 1999, p. 19).

Table 28—Research expenditures on crop improvement for corn, public and private

Expenditure type sector/type	1960	1965	1970	1975	1979	1984
	Million 1984 dollars					
Research expenditures - breeding:						
Private sector	11.0	13.4	18.8	28.9	43.6	59.2
Public sector	16.5	18.5	21.2	26.0	27.5	36.8
Total public and private	27.5	31.9	40	54.9	71.1	96
	Percent					
Share of total:						
Private	40.0	42.0	47.0	52.6	61.3	61.7
Public	60.0	58.0	53.0	47.4	38.7	38.3

Source: Huffman and Evenson (1993, p. 159).

Table 29—Research expenditures on crop improvement for soybeans, public and private

Expenditure type sector/type	1960	1965	1970	1975	1979	1984
	Million 1984 dollars					
Research expenditures - breeding:						
Private sector	0.01	0.2	1.0	5.9	9.5	13.2
Public sector	9.79	10.9	14.7	23.9	40.6	41.9
Total public and private	9.80	11.1	15.7	29.8	50.1	55.1
	Percent					
Share of total:						
Private	0.10	1.8	6.4	19.8	19.0	24.0
Public	99.90	98.2	93.6	80.2	81.0	76.0

Source: Huffman and Evenson (1993, p. 165).

Research Patterns in Terms of Scientist Years

Measuring the number of scientist years (SY) and funding per scientist (holding Ph.D. or M.S. degrees) allocated to specific areas of research offers additional insights into the public and private R&D effort on plant breeding. Across all crop varieties, the number of SY engaged in private plant breeding of major crops increased by 114 percent (from 701 to 1,498) between 1982 and 1994, while funding per scientist year had an apparent increase of 38 percent from $164,000 to $226,000 in current dollars over the same period (table 31), a 28-percent decrease in real terms. The distribution of SY between different crops has closely followed the allocation of R&D expenditures in dollar terms for both the public and private sectors (fig. 15). For instance, the private sector provided 94 percent of the total 545 SY allocated to corn breeding research in 1994, a fact that reflects the private sector's dominance in corn research. For such crops as cotton and soybeans, for which the public sector still plays a role in plant breeding and germplasm research, the private sector provided 77 percent (cotton) and 65 percent (soybeans) of the total SY allocated to plant breeding research in 1994 (table 32). Private sector research on wheat is even more limited: 41 percent of the total SY allocated to wheat breeding research came from the private sector in 1994.

A cost comparison of public and private R&D on plant breeding per scientist year for 1994 shows that, on average, expenditures in plant breeding were higher in the public sector ($286,840 per SY) than in the private sector ($225,898 per SY) (table 33). However, public R&D expenditures were lower than expenditures of the larger private firms ($290,000 per SY), likely due to

Table 30—Private research and development expenditures of the 14 largest seed firms, by year and crop

Year	Expenditures	Corn	Soybeans	Alfalfa	Wheat	Cotton
	Million current dollars	*Percent*				
1970	3.40	79	1	9	7	4
1972	3.94	77	2	8	9	5
1974	5.59	75	6	7	8	4
1976	8.39	73	7	6	11	3
1978	10.26	71	10	6	9	4
1980	12.13	71	11	7	9	3

Source: Butler and Marion (1985), p. 31.

the more complex nature of plant breeding R&D (including the use of biotechnology techniques, which is expensive, Kalton el al., 1989) carried out by both public sector and large firms. Overall, the private sector employed more than twice as many SY as the public sector (1,498 versus 743), and total private sector expenditures in plant breeding ($338 million) exceeded those of the public sector ($213 million) in 1994.

Table 31—Number of firms and scientist years (SY) engaged in private plant breeding for major field crops

	1982				1989*				1994			
Crop	Number of firms	Share of firms	Scientist years	Share of SY	Number of firms	Share of firms	Scientist years	Share of SY	Number of firms	Share of firms	Scientist years	Share of SY
		Percent		*Percent*		*Percent*		*Percent*		*Percent*		*Percent*
Corn	66	24.54	255	36.38	75	27.57	371	34.77	91	27.66	510	34.05
Soybeans	26	9.67	52	7.42	34	12.50	86	8.06	38	11.55	101	6.74
Cotton	13	4.83	28	3.99	11	4.04	17	1.59	35	10.64	103	6.88
Wheat	21	7.81	42	5.99	11	4.04	47	4.40	27	8.21	54	3.60
Others	143	53.16	324	46.22	141	51.84	546	51.17	138	41.95	730	48.73
Total	269		701		272		1,067		329		1,498	
Dollars ($Mil.)	114.95				272				338.462			
Dollars ($)/SY	163,980				306,306				225,898			

* 1989 figures for million dollars per SY are based on the average of figures for 1988 and 1990.

Source: Companies and Expenditures for 1994: Frey (1996), p. 19; SY by crop, Frey (1996), pp. 36-38; Companies and expenditures for 1982 and 1989: Kalton et al. (1990), p. 24.

Table 32—Number of scientist years (SY) devoted to plant breeding, public and private, by crop, 1994

	Public sector		Private sector		Total	
Crop/Crop category	Number of SY employed	Share of total for the crop	Number of SY employed	Share of total for the crop	Number of SY employed	Share of total SY
		Percent		*Percent*		*Percent*
Corn	35	6.48	510	93.52	545	24.72
Soybeans	55	35.01	101	64.99	156	7.07
Cotton	31	22.94	103	77.06	134	6.09
Wheat	76	58.63	54	41.37	130	5.91
Other cereal crops	77	35.48	139	64.06	217	9.84
Other grain legumes	26	50.98	25	49.02	51	2.31
Other fiber crops	2	100.00	0	0.00	2	0.09
Forage	71	58.20	51	41.80	122	5.53
Fruit vegetable	46	21.60	167	78.40	213	9.66
Other crops	287	45.27	348	54.89	634	28.75
Total	706		1,499		2,205	

Source: Frey (1996), pp. 6-11.

Table 33—Public and private research in plant breeding, scientist years (SY), and cost, 1994

Sector/Institution	Number of companies	Total number of SY	Cost per SY	Dollar input per sector/institution
			Dollars	*Million current dollars*
Private	329	1,498	225,898	338.5
Public	NA	743	286,840	213.2
ARS/USDA	NA	177	300,000	53.1
SAES	NA	530	293,500	155.5
Plant materials center	NA	36	125,000	4.5
Total	NA	2,241		551.6

* Average cost. Cost varies with company size, ranging from $148,000 for the smallest firm size category to $290,000 for the larger firms (Frey, 1996, p.19)
NA = not available. SAES = State Agricultural Experiment Station.

Source: Frey (1996, p. 19).

Introductions and Trials of New Varieties Are Increasing Over Time

The emergence of the private sector marks a significant shift in agricultural R&D. Decisions about R&D made in a competitive environment are likely to differ from those made in a public sector setting, where most R&D traditionally has taken place. Therefore, the amount of R&D, the emphasis of research, and other aspects of R&D are likely to change. In addition, public research priorities may change in response to R&D efforts undertaken by private firms: Public institutions may pursue initiatives that complement private efforts as well as research areas that the private sector neglects. Measures of plant breeding research output further highlight the shift in emphasis from public to private R&D.

PVP Certificates

Plant variety protection certificates approved by USDA's PVPO are similar to patents issued for crop varieties. PVP certificates are intended to benefit both consumers and producers of improved crop varieties. Individual and corporate consumers benefit from the improved quality of agricultural goods that they use directly for consumption purposes or as inputs to the production of goods, such as livestock and medicine. And to the extent that new varieties increase productivity and supply, consumers also stand to gain from decreases in price. Seed producers, on the other hand, benefit from the exclusive rights they secure over the purity, breeding, marketing, distribution, and sales of improved varieties, allowing them to obtain a return on their investment of research and development resources (USDA, AMS, 2000).

Estimates of the time involved in producing new varieties in a breeding program range from 10 to 15 years to produce a marketable product (tables 34-35).[13] On an annual basis, a small breeding program was estimated to cost approximately $250,000 in the late 1980s, a sum adequate to cover the costs of a chief breeder, a staff of three or four, equipment, facilities and land (McMullen, 1987, p. 58). Even where larger firms realize economies of scale and scope in producing multiple varieties, the estimated development costs of a new variety range between $2.0 million and $2.5 million for the same period (McMullen, 1987, pp. 58-60). Given the magnitude of these investments, it is unlikely that plant breeders would have made this type of R&D investment without property rights protection.

The number of PVP certificates issued by the PVPO provides a useful indicator of the results of plant breeding research efforts. Research findings differ in showing the PVPA's effect on creating private sector incentives in research. Butler and Marion (1985, p. 79) conclude that during the 1970s, the PVPA resulted in "modest private and public benefits at modest private and public costs." Perrin et al. (1983), on the other hand, conclude that the act led to increased private investment in plant breeding for soybeans and other nonhybrid seed crops. These competing conclusions highlight the significance of time lags between R&D investment and the release of a new variety. For many varieties, this lag is often more than 10 years (table 35), implying that the economic returns to new R&D investments in plant breeding made in the 1970s were

[13] Amount of time depends on availability of source germplasm. Time can also be reduced when breeders can use more than one cycle per year (e.g., through Southern Hemisphere shuttle breeding).

Table 34—Stages and time required in plant breeding

Stage	Hybrid	Open-pollinated
	Years	
Recognition	0	0
Parent-line preparation	4-5	0-2
Initial crosses	5-6	0-3
Progeny selection	6-10	3-11
Crop evaluation	7-12	5-12
Testing the variety	7-15	6-15
Determination of a new variety	8-12	7-13
Market evaluation	8-13	8-14
Application for plan variety protetection	8-14	9-14
Multiplication from individual plants or ears	9-14	9-15
Certification	9-14	9-15
Market introduction	10-15	10-17
Market acceptance	12-18	12-19
Market growth	13-19	13-20
Obsolescence	20-25	20-25

Source: McMullen (1987b), p. 58.

Table 35—Research time required for developing new seed varieties, major field crops

Crop	Time required			Number of varieties[1]	
	From date of cross to date of determination	From date of determination to application date	Total	Cross to date of determination	Date of determination to application
	Years				
Corn	5.5	2.0	7.5	4	6
Soybean	6.2	3.0	9.2	64	75
Cotton	8.0	4.2	12.2	27	57
Wheat	8.0	2.8	10.8	36	56
Rice	6.0	2.8	8.8	5	12
Average/total[2]	7.9	3.2	11.1	253	391

[1] Applicants are required to list the date of variety determination and date of application when submitting protection applications but they are not required to list the date the cross was made. For this reason, there are fewer varieties listed in the "Cross to date of determination" column.

[2] Average and total include other field crops and vegetables not shown here.

Source: McMullen (1987), p. 60, using data from Asgrow Seed Company.

not fully captured in the studies by Butler and Marion and Perrin et al. (Fuglie et al., 1996, p. 38).

The number of PVP certificates issued by the PVPO has grown rapidly since the 1970 PVPA after accounting for the time lag in plant breeding R&D (tables 36-37). This growth indicates the PVPA's positive effect on generating private sector incentives for plant breeding R&D. The increases were most marked for soybeans and corn, which together account for more than half of all certificates issued for field crops. By the end of 2002, 2,584 certificates were issued for varieties of U.S. origin for the four major field crops, including 1,078 for soybeans, 648 for corn, 568 for wheat, and 290 for cotton (table 37).

The majority of PVP certificates—about 84 percent—are held by the private sector. Among PVPs for major crops, the private sector owns close to 100 percent of corn certificates, 87 percent of cotton certificates, 84 percent of soybean certificates, and 68 percent of wheat certificates. Figure 16 captures the growth in PVP certificates issued for U.S. private and public entities for corn, soybeans, cotton, and wheat between 1970 and 2002.

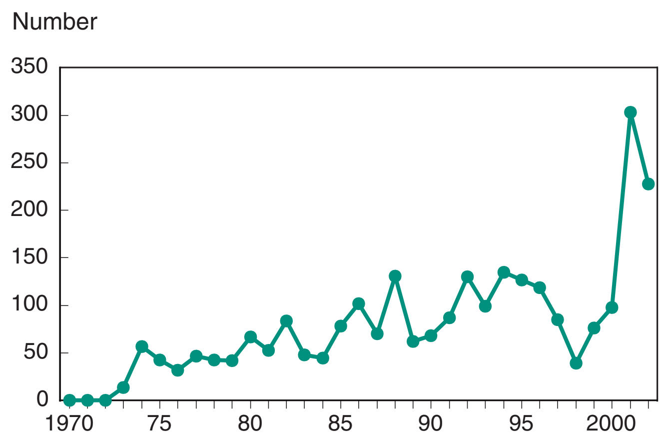
Agricultural Biotechnology R&D

A driving force behind some of the increase in private sector R&D has been the introduction of modern biotechnology to agriculture. Biotechnology, broadly defined, is the application of biological science to affect living things. Under this broad definition, the entire endeavor of agricultural experimentation over thousands of years of human history might be considered "biotechnology." But the 20th century discovery of DNA and subsequent scientific advances have ushered in a new period of biological research. The application of genetic science to plants and animals in light of these discoveries is the sense in which this report employs the word "biotechnology."

The emergence of modern biotechnology is consistent with the more recent focus on plant breeding in private sector agricultural R&D (tables 25-26; figs. 13-14). In addition to techniques of modern biotechnology, the creation of new plant varieties with useful agronomic properties requires significant knowledge of plant breeding. In this sense, plant breeding and biotechnology are complementary. Moreover, the commercial success of GE crop varieties typically requires that biotechnology-derived trait enhancements are incorpo-

Figure 16

Number of PVP certificates issued for corn, soybeans, cotton, and wheat



Source: Data source provided in table 37.

Table 36—Plant variety protection certificates issued for new crop varieties, field crops

Crop	Number of certificates issued							Share of certificate ownership	
	1971-74	1975-78	1979-82	1983-86	1987-90	1991-94	Total	Private	Public
								Percent	
Soybeans	34	69	132	150	114	162	661	0.84	0.16
Corn	0	1	6	50	104	161	322	1.00	0.00
Wheat	12	52	59	30	74	87	314	0.68	0.32
Cotton[1]	24	35	41	38	34	39	211	0.87	0.13
Subtotal for major crops	70	157	238	268	326	449	1,508	0.85	0.15
Barley	0	12	2	22	6	35	77	0.82	0.18
Beans, field	0	1	5	18	10	28	62	0.77	0.23
Oats	0	10	6	0	9	8	33	0.36	0.64
Rice	0	8	4	2	5	15	34	1.00	0.00
Sorghum	0	0	0	0	2	31	33	1.00	0.00
Canola	0	0	0	2	8	15	25	0.72	0.28
Safflower	0	3	2	1	5	6	17	0.88	0.12
Other field crops	0	16	15	13	18	13	75	0.85	0.15
Subtotal for other crops	0	50	34	58	63	151	356	0.80	0.20
Total field crops	70	207	272	326	389	600	1,864	0.84	0.16

[1] Figures for PVP certificates issued for cotton varieties given here may vary from figures presented elsewhere in this report due to PVPO revisions and updates to PVP certificate listings.

Source: Fuglie (1996), p. 38.

rated into successful cultivars. Acquisition of firms with established varieties by companies with the ability to improve varieties using biotechnology is one possible rationale for recent consolidation in the U.S. seed industry.

The rapid commercial success of GE varieties provides a preliminary measure of the technical success of the R&D efforts.[14] The number of field releases of plant varieties for testing purposes provides an ex-ante measure of R&D output.[15]

Field Releases

The process by which new GE varieties of organisms are released into the environment is regulated and monitored by USDA's Animal and Plant Health Inspection Service (APHIS). Private companies and public institutions proposing tests of such organisms in the environment either notify APHIS of their intent, in accordance with APHIS's field release notification procedures, or submit an application for a field release permit (referred to here as an application). If an APHIS review of the application (notification or permit application) establishes that there are no significant environmental risks associated with a release, a notification is acknowledged or a field permit is issued (referred to here as an "approval"), thereby allowing the breeder to pursue testing. Between 1987 and June 2001, APHIS received over 7,600 applications for field releases of GE varieties. Of these applications, APHIS approved the field release of more than 6,700 new varieties (table 38). Also significant is the annual growth of field release applications during this period: applications received annually by APHIS increased from just 9 in 1987 to a high of 1,206 in 1998 (fig. 17). Although some applications were denied or withdrawn, a significant majority—almost 90 percent—were approved by APHIS (table 39, fig. 18).

The majority of applications for field releases received from private companies and public institutions are for testing improved varieties of major crops. By mid-2001, applications received included more

[14] Ex-ante, two important factors suggested a profitable market, justifying the time and expense of improving seed through biotechnology R&D. First, the seed market for U.S. field crops is very large. Second, genetically engineered seeds, selling at a price premium over conventional seeds, are not substantially more expensive to produce after R&D and regulatory approval are complete.

[15] Another measure of research output is the number of patents, which can also provide an indication of concentration of research assets (Brennan et al., 2000). Considering the two major crops, corn and soybeans, the three top firms, DuPont/Pioneer, Monsanto/DeKalb and Novartis/Syngenta, held 46 percent of the biotech patents or patent applications as of 1996-97 (table 51).

Table 37—PVP certificates issued for major field crops[1]

Calendar year issued	Corn: Private origin	Corn: Public origin	Corn: Total U.S.	Corn: Foreign origin	Corn: Total	Soybeans: Private origin	Soybeans: Public origin	Soybeans: Total U.S.	Soybeans: Foreign origin	Soybeans: Total	Cotton: Total U.S.	Wheat: Total U.S.	All major field crops: Total
	Number												
1970	0	0	0	0	0	0	0	0	0	0	0	0	0
1971	0	0	0	0	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	0	0	0	0	0	0	0	0	0
1973	0	0	0	0	0	10	3	13	0	13	0	1	14
1974	0	0	0	0	0	21	1	22	0	22	24	11	57
1975	0	0	0	0	0	8	5	13	0	13	14	16	43
1976	0	0	0	0	0	14	0	14	0	14	7	11	32
1977	3	0	3	0	3	21	1	22	0	22	5	17	47
1978	0	0	0	0	0	20	2	22	0	22	9	12	43
1979	0	0	0	0	0	19	2	21	0	21	11	10	42
1980	6	0	6	0	6	30	13	43	0	43	12	6	67
1981	1	0	1	0	1	30	2	32	0	32	10	10	53
1982	2	0	2	0	2	32	7	39	0	39	10	33	84
1983	3	0	3	0	3	33	1	34	0	34	11	0	48
1984	11	0	11	0	11	23	4	27	0	27	7	0	45
1985	8	0	8	0	8	37	11	48	0	48	8	14	78
1986	29	0	29	0	29	42	2	44	0	44	13	16	102
1987	15	0	15	1	16	36	5	41	0	41	11	2	70
1988	33	0	33	0	33	34	14	48	0	48	8	42	131
1989	19	0	19	0	19	12	3	15	0	15	0	28	62
1990	37	0	37	0	37	10	0	10	0	10	15	6	68
1991	35	0	35	0	35	33	4	37	0	37	14	1	87
1992	54	0	54	1	55	47	17	64	1	65	1	9	130
1993	36	0	36	5	41	6	0	6	0	6	4	48	99
1994	29	0	29	0	29	42	12	54	0	54	20	32	135
1995	22	0	22	0	22	58	15	73	0	73	6	26	127
1996	35	0	35	5	40	33	5	38	0	38	7	34	119
1997	30	0	30	10	40	24	4	28	0	28	4	13	85
1998	22	0	22	0	22	13	1	14	0	14	0	3	39
1999	26	0	26	0	26	16	4	20	0	20	0	30	76
2000	18	1	19	0	19	43	9	52	0	52	0	27	98
2001	88	4	92	3	95	124	10	134	0	134	10	64	303
2002	79	2	81	0	81	43	7	50	2	52	49	46	228
Total	641	7	648	25	673	914	164	1,078	3	1,081	290	568	2,612

[1] Figures for PVP certificates issued may vary from figures presented elsewhere due to PVPO revisions and updates to PVP listings.

Source: Strachan (2003).

Table 38—Applications for field releases received by APHIS, by crop and year[1]

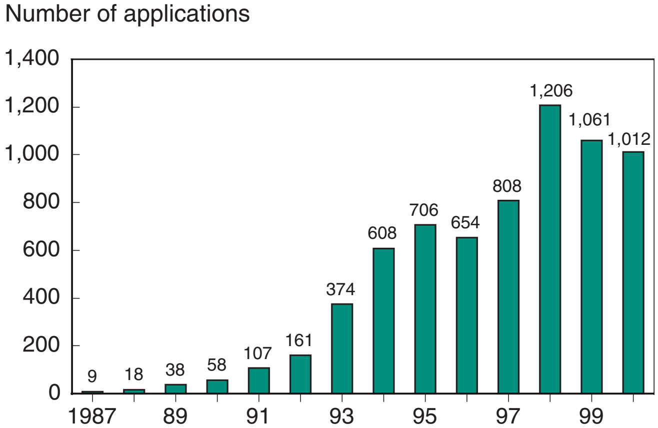
Crop	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total (1987-2001)[1]
	Number															
Corn	0	0	0	3	15	44	134	262	348	279	406	563	385	420	468	3,327
Soybeans	0	0	4	5	6	36	68	69	62	52	55	85	68	51	40	601
Cotton	0	1	5	11	17	4	23	43	63	33	50	47	53	79	52	481
Wheat	0	0	0	0	0	0	0	3	4	12	16	20	39	65	50	209
Other	9	17	29	39	69	77	149	231	229	278	281	491	516	397	246	3,058
Total	9	18	38	58	107	161	374	608	706	654	808	1,206	1,061	1,012	856	7,676

[1] Includes field release notifications received by APHIS, and field release permits either issued, withdrawn, or denied by APHIS, between June 16, 1987, and July 9, 2001.

Source: Virginia Polytechnic Institute (2001).

Figure 17

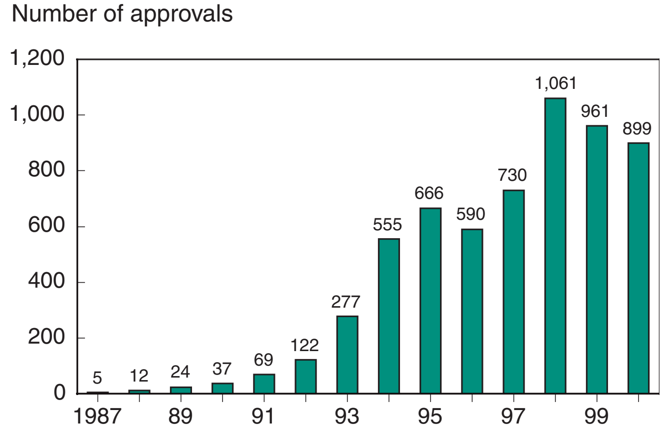
Total number of field release applications, by year



Source: Data source provided in table 38.

Figure 18

Total number of field release approvals, by year



Source: Data source provided in table 39.

than 3,327 for corn varieties, 761 for potatoes, 601 for soybeans, 532 for tomatoes, 481 for cotton, and 209 for wheat (table 40). APHIS classifies each variety according to the variety's unique genetic characteristic, or phenotype, which distinguishes it from other varieties. Field release applications received by APHIS between 1987 and 2000 included varieties with such characteristics as herbicide tolerance (27 percent), insect resistance (25 percent), product quality usually associated with added value output traits (17 percent), virus resistance (9 percent), and agronomic properties (6 percent) (table 41). A small share of the applications for field releases also contain multiple or "stacked" traits, such as herbicide tolerance and insect resistance.

The breakdown of the number of applications for field releases by company is provided in table 42. Much more detail, by year and for each of the major crops —corn, soybeans, cotton, and wheat—is shown in tables 43-47.

Table 39—Status of field release notifications and permits[1]

Year	Received	Approved	Delayed approval	Denied	Withdrawn	Void	Pending	Total
				Number				
1987	9	5	4	0	0	0	0	18
1988	18	12	6	0	0	0	0	36
1989	38	24	14	0	0	0	0	76
1990	58	37	21	0	0	0	0	116
1991	107	69	38	0	0	0	0	214
1992	161	122	28	0	11	0	0	322
1993	374	277	29	0	68	0	0	748
1994	608	555	38	6	9	0	0	1,216
1995	706	666	14	2	18	5	0	1,411
1996	654	590	35	8	20	0	0	1,307
1997	808	730	13	33	28	3	0	1,615
1998	1,206	1,061	25	108	10	2	0	2,412
1999	1,061	961	25	46	22	6	0	2,121
2000	1,012	899	36	57	16	1	2	2,023
2001	856	777	0	25	13	1	39	1,711
Total[2]	7,676	6,785	326	285	215	18	41	15,346

[1] From June 16, 1987, to July 9, 2001.

[2] The total number of field releases approved by APHIS includes 961 permits issued and 6,156 notifications acknowledged. Acknowledgments are given under the APHIS notification procedure, while issued refers to release permits issued by APHIS. For most purposes, there is no difference in these two categories, and together, they equal the number of field releases approved by APHIS.

Source: Virginia Polytechnic Institute (2001).

Table 40—Number of applications for field releases, by crop[1]

Crop	2000		1987-2001	
	Number	*Percent*	*Number*	*Percent*
Corn	420	41.5	3,327	43.3
Potatoes	70	6.9	761	9.9
Soybeans	51	5.0	601	7.8
Tomatoes	25	2.5	532	6.9
Cotton	79	7.8	481	6.3
Wheat	65	6.4	209	2.7
Tobacco	15	1.5	202	2.6
Rapeseed	16	1.6	177	2.3
Rice	19	1.9	134	1.7
Beet	22	2.2	121	1.6
Melons	13	1.3	140	1.8
Other	217	21.4	991	12.9
Total	1,012	100.0	7,676	100.0

[1] From June 16, 1987, to July 9, 2001. Includes field release notifications received by APHIS, and field release permits either issued, withdrawn, or denied by APHIS between June 16, 1987, and July 9, 2001.

Source: Virginia Polytechnic Institute (2001).

Table 41—Share of applications for field releases received by APHIS, by trait

Trait	2000	1987-2001[1]
	Percent	
Agronomic properties	6.5	6.0
Bacterial resistance	1.3	1.2
Fungal resistance	5.5	5.5
Herbicide tolerance	30.1	27.4
Insect resistance	26.0	25.3
Marker gene	5.4	3.8
Nematode resistance	0.2	0.2
Product quality	11.5	17.3
Virus resistance	6.1	9.1
Other	7.3	4.4
Total[1]	100.0	100.0

[1] From June 16, 1987, to June 25, 2001. Note that certain products contain multiple or "stacked" traits and are thus included separately under each appropriate trait.

Source: Virginia Polytechnic Institute (2001).

Table 42—Status of notifications and field release permits by company, 1987-2001[1]

Company/ institution	Acknowledged[2]	Issued[2]	Pending	Denied	Withdrawn	Void	Total
				Number			
Monsanto	2,142	155	11	68	47	6	2,429
Pioneer	535	55	2	31	22	1	646
AgrEvo	312	14		14	4		344
DuPont	305	15			1		321
ARS	130	42	1	12	8	3	196
DeKalb	172	9		8	3		192
Calgene	90	74		2	8	1	175
Semnis Vegetable Seed	144	18	2	3	1		168
DNA Plant Tech	74	15			2		91
Northrup-King	69	11		3	5		88
University of Idaho	66	14		6	1	1	88
Upjohn	10	63			12		85
Aventis	72	4	1		8		85
Iowa State University	69	5		7	2		83
Asgrow	49	26		1	5		81
Novartis Seeds	74	3		2			79
ProdiGene	50	22	2	1	1		76
Stine Biotechnology	71			4			75
Rutgers University	59	12		4			75
Cargill	54	11		1	5		71
Dow	56	2	4				62
Agracetus	57	3		1			61
Agritope	47	6		6	1		60
Zeneca	47	2	1	7	1		58
Frito Lay	36	18		2	2		58
Other	1,366	362	17	102	76	6	1,929
Total	6,156	961	41	285	215	18	7,676

[1] From June 16, 1987, to July 9, 2001.

[2] Acknowledgments are given under the APHIS notification procedure, while issued refers to release permits issued by APHIS. For most purposes, there is no difference in these two categories, and together, they equal the number of field releases approved by APHIS.

Source: Virginia Polytechnic Institute (2001).

Table 43—Field release approvals for corn, by company[1]

Crop	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
								Number							
Monsanto					1	7	47	72	63	32	105	94	147	248	816
Pioneer					4	11	20	45	57	78	106	114	54	5	494
DuPont							12	67	63	14	17	19	7		199
AgrEvo							2	2	12		5	131	26		178
DeKalb				2	1	6	6	27	29	41	26	33	1		172
Northrup-King						3	6	10	42	10					71
ProdiGene											2	6	24	24	56
Novartis Seeds											12	22	7	12	53
Iowa State University									1	1	4	15	16	14	51
Stine Biotechnology											3	9	21	14	47
Plant Genetic Systems										4	42				46
Cargill					1	2	3	2	10	6	7	8	2		41
Holdens					2	4	3	5	14	7	2				37
Ciba-Geigy					2	3	4	5	10	12					36
Stanford University											7	4	12	13	36
Garst/ICI					1	2	2	4	3	5	5	8	3		33
Mycogen							1	2	1	1	6	8	11		30
Dow							1	1	2		1		6	18	29
Limagrain								1		10	6	6	1	4	28
Asgrow							1	4	6	3	3				17
Agracetus								1	5	5	3		1		15
NC+Hybrids									3	6	3	3			15
University of Minnesota									1	2	3	4	5		15
University of Arizona										1	1	5	3	4	14
Aventis														13	13
Golden Harvest Seeds									2	5	1	3	2		13
Rogers/Rogers NK							1	4	2	6					13
Rhone-Poulenc											1	3	6		10
Wyffels Hybrids										6	4				10
Southern Illinois Univ.										2	2	1	3	1	9
Upjohn					2	3	2								7
Zeneca											1	2	3	1	7
Other				1	1	2	3	6	11	16	5	9	5	15	74
Total	0	0	0	3	15	43	114	258	337	273	383	507	366	386	2,685

[1] From June 16, 1987, to December 31, 2000. Field release approvals are either categorized as notifications acknowledged by APHIS under its notification procedure, or field release permits issued by APHIS. For most purposes, there is no difference in the two categories, and together, they equal the number of field releases approved by APHIS.

Source: Virginia Polytechnic Institute (2001).

Table 44—Field release approvals for soybeans, by company[1]

Crop	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
								Number							
Monsanto			4	4	3	22	13	12		1	6	20	38	21	144
DuPont							3	15	28	4	19	18	2	2	91
AgrEvo								6	16	16	8	13			59
Pioneer					1	4	11	16	5	3	7	7	2	2	58
Agracetus							1	4	9	13	2				29
Asgrow							1	6	2	9	5	6			29
Upjohn				1	2	5	7								15
Rhone-Poulenc											2	2	10		14
Aventis														10	10
DeKalb							2	1		2	1	3			9
Stine Biotechnology						1							1	6	8
Dairyland Seeds							2	3	1			1			7
Limagrain										1	1	3	1		6
University of Kentucky									1				2	2	5
AgriPro						1	2	1							4
Northrup-King						1	2	1							4
University of Illinois										2		2			4
Calgene												3			3
Iowa State University												1	1	1	3
Jacob Hartz							1	2							3
University of Georgia											1	1	1		3
University of Nebraska												1		2	3
FFR Cooperative							1	1							2
Ohio State University													2		2
Other							4					1			5
Total	0	0	4	5	6	34	50	68	62	51	52	82	60	46	520

[1] From June 16, 1987, to December 31, 2000. Field release approvals are either categorized as notifications acknowledged by APHIS under its notification procedure, or field release permits issued by APHIS. For most purposes, there is no difference in the two categories, and together, they equal the number of field releases approved by APHIS.

Source: Virginia Polytechnic Institute (2001).

Table 45—Field release approvals for cotton, by company[1]

Crop	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
								Number							
Monsanto			2	6	6		9	11	26	12	14	26	39	54	205
Calgene			2	4	9	4	4	4	4	5	11	1			48
Delta & Pine Land							2	11	13	6	4				36
AgrEvo											12	10	4		26
Dupont				1	2		2	8	7						20
Agracetus		1						1	5	7	1				15
Mycogen									2	1	2	4	3		12
Texas Tech University												5	3	4	12
Aventis														9	9
Dow														8	8
All-Tex								2							2
ARS										1			1		2
Boswell										1	1				2
Jacob Hartz									2						2
Novartis Seeds														2	2
United Agri Products								1	1						2
American Cyanamid							1								1
Bowdoin College														1	1
Brownfield								1							1
Chembred								1							1
Dunn								1							1
Miles							1								1
Northrup-King			1												1
SeedCo								1							1
Williams Seed								1							1
Other															0
Total	0	1	5	11	17	4	19	43	60	33	45	46	50	78	412

[1] From June 16, 1987, to December 31, 2000. Field release approvals are either categorized as notifications acknowledged by APHIS under its notification procedure, or field release permits issued by APHIS. For most purposes, there is no difference in the two categories, and together, they equal the number of field releases approved by APHIS.

Source: Virginia Polytechnic Institute (2001).

Table 46—Field release approvals for wheat, by company[1]

Crop	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
								Number							
Monsanto								2	3	7	6	13	27	52	110
University of Idaho										1	3	3	3	3	13
Montana State Univ.												1	4	3	8
Novartis Seeds											2	1	3	1	7
ARS									1	2		1		1	5
Applied Phytologics														2	2
AgrEvo								1							1
Syngenta														1	1
Cargill														1	1
Other															0
Total	0	0	0	0	0	0	0	3	4	10	11	19	37	64	148

[1] From June 16, 1987, to December 31, 2000. Field release approvals are either categorized as notifications acknowledged by APHIS under its notification procedure, or field release permits issued by APHIS. For most purposes, there is no difference in the two categories, and together, they equal the number of field releases approved by APHIS.

Source: Virginia Polytechnic Institute (2001).

Table 47—Field release approvals for corn, soybeans, cotton, and wheat, by company, 1987-2000[1]

Corn		Soybeans		Cotton		Wheat	
Company	No.	Company	No.	Company	No.	Company	No.
Monsanto	816	Monsanto	144	Monsanto	205	Monsanto	110
Pioneer	494	DuPont	91	Calgene	48	University of Idaho	13
DuPont	199	AgrEvo	59	Delta & Pine Land	36	Montana State Univ.	8
AgrEvo	178	Pioneer	58	AgrEvo	26	Novartis Seeds	7
DeKalb	172	Agracetus	29	DuPont	20	ARS	5
Northrup-King	71	Asgrow	29	Agracetus	15	Applied Phytologics	2
ProdiGene	56	Upjohn	15	Mycogen	12	AgrEvo	1
Novartis Seeds	53	Rhone-Poulenc	14	Texas Tech University	12	Syngenta	1
Iowa State University	51	Aventis	10	Aventis	9	Cargill	1
Stine Biotechnology	47	DeKalb	9	Dow	8	Other	0
Plant Genetic Systems	46	Stine Biotechnology	8	All-Tex	2		
Cargill	41	Dairyland Seeds	7	ARS	2		
Holdens	37	Limagrain	6	Boswell	2		
Ciba-Geigy	36	University of Kentucky	5	Jacob Hartz	2		
Stanford University	36	AgriPro	4	Novartis Seeds	2		
Garst/ICI	33	Northrup-King	4	United Agri Products	2		
Mycogen	30	University of Illinois	4	American Cyanamid	1		
Dow	29	Calgene	3	Bowdoin College	1		
Limagrain	28	Iowa State University	3	Brownfield	1		
Asgrow	17	Jacob Hartz	3	Chembred	1		
Agracetus	15	University of Georgia	3	Dunn	1		
NC+Hybrids	15	University of Nebraska	3	Miles	1		
University of Minnesota	15	FFR Cooperative	2	Northrup-King	1		
University of Arizona	14	Ohio State University	2	SeedCo	1		
Aventis	13	Other	5	Williams Seed	1		
Golden Harvest Seeds	13	Delta Pine & Land	1	Other	0		
Rogers/Rogers NK	13	Michigan State University	1				
Rhone-Poulenc	10	Midwest Oilseeds	1				
WyFFels Hybrids	10	Land O' Lakes	1				
Southern Illinois University	9	Other					
Upjohn	7						
Zeneca	7						
Other	74						
Total	2,685	Total	524	Total	412	Total	148

[1] From June 16, 1987, to December 31, 2000. Field release approvals are either categorized as notifications acknowledged by APHIS under its notification procedure, or field release permits issued by APHIS. For most purposes, there is no difference in the two categories, and together, they equal the number of field releases approved by APHIS.

Source: Virginia Polytechnic Institute (2001).

Determination of Nonregulated Status

In the United States, once new varieties are successfully field tested and the research is fully documented, breeders may apply for a "determination of nonregulated status" from APHIS. This determination, once approved, allows the variety to be produced and sold commercially (USDA, APHIS, 2000). Out of the thousands of plant varieties approved for field release, APHIS had received 79 petitions for deregulation status as of mid-2001 (table 48). Of these 79 petitions, APHIS granted nonregulated status to a total of 53. These new varieties no longer fall under Federal regulation and can be planted freely throughout the United States.

Of the varieties granted nonregulated status by APHIS, 18 are corn varieties, 12 are tomatoes, 5 are soybeans, and 5 are cotton. Thirty-six of percent of these nonregulated varieties have herbicide-tolerance traits, 20 percent have insect-resistance traits, and 19 percent have traits to improve product quality (table 49).

Adoption of Crop Biotechnology Products

Successful transfer of a targeted trait to an elite strain may take plant breeders many crop generations. Superior hybrid corn varieties, for example, were introduced in the early 1930s after more than 25 years of research. Once development is complete, adoption of these crops takes time as well. The share of corn acreage planted with hybrid corn in the U.S. grew from about 1 percent of total corn planted in 1933 to more than 95 percent by 1960 (fig. 2). The speed of adoption might depend on the success of marketing efforts, the ability of growers to adapt farming practices to take advantage of the new varieties, and the superiority of the new varieties to existing varieties. The speed of adoption of corn hybrids differed by region because plant breeders had to produce varieties compatible with local growing conditions (Griliches, 1957).

By comparison, both the development and the adoption of genetically engineered field crop varieties were even more rapid than the adoption of hybrid corn varieties. The relative speed with which new varieties can be developed using modern biotechnology gives biotechnology an advantage over other techniques. Notwithstanding, first-generation biotechnology products were commercially available for farmers in the mid-1990s after about 15 years of research and development. Following their release in 1996, U.S. farmers rapidly adopted GE crops with herbicide-tolerant and insect-resistant traits (fig. 3).

Table 48—Crops no longer regulated by USDA, 1987-2001[1]

Crop	Petitions submitted	Petitions approved	Share of petitions approved
	Number	*Number*	*Percent*
Corn	23	18	33.96
Tomato	23	12	22.64
Potato	23	5	9.43
Soybeans	23	5	9.43
Cotton	23	5	9.43
Other	23	8	15.09
Total	79	53	100.00

[1] From June 16, 1987, to June 25, 2001.

Source: Virginia Polytechnic Institute (2001).

Table 49—Crops no longer regulated by USDA, by trait, 1987-2001[1]

Trait	Petitioned	Approved	Share approved
	Number	*Number*	*Percent*
All crops:			
Agronomic properties (AP)	8	6	9.38
Herbicide tolerance (HT)	29	23	35.94
Insect resistance (IR)	22	13	20.31
Stacked (HT, IR)	5	4	6.25
Product quality (PQ)	18	12	18.75
Virus resistance (VR)	9	6	9.38
Total	91	64	100.00
Corn:			
Agronomic properties (AP)	3	3	16.67
Herbicide tolerance (HT)	8	7	38.89
Insect resistance (IR)	10	5	27.78
Stacked (HT, IR)	5	3	16.67
Total	26	18	100.00
Soybeans:			
Herbicide tolerance (HT)	5	4	80.00
Product quality (PQ)	2	1	20.00
Total	7	5	100.00
Cotton:			
Herbicide tolerance (HT)	3	3	60.00
Insect resistance (IR)	3	1	20.00
Stacked (HT, IR)	1	1	20.00
Total	7	5	100.00

[1] From June 16, 1987, to June 25, 2001.

Source: Virginia Polytechnic Institute (2001).

Concentration and Private Sector R&D

A relatively small number of firms are active in the field of crop biotechnology, particularly with respect to major field crops (tables 43-46). Only a few firms have secured approval for unregulated release of genetically modified crops, a number likely affected by recent merger and acquisition activity.

As Fulton and Giannakas (2002) observe, the relevant measure of market concentration is not always based on output markets (sales). To assess the impact of mergers focusing on innovative activity, the Federal Trade Commission is using innovation competition.

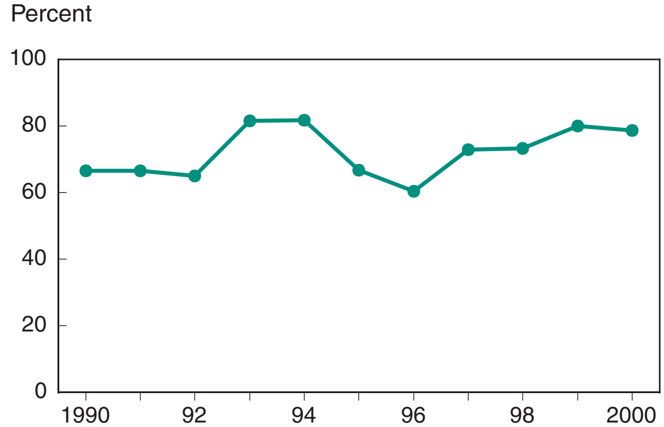
To construct a measure of concentration in innovation activity for the case of crop biotechnology, this report uses the regulatory approvals of GE varieties. In particular, this section adapts the CR4 measure used to quantify concentration in seed sales. Figures 19-21 show the percentage of field releases obtained by the leading four firms during 1988-2000. The top four firms control well over 50 percent of these approvals, suggesting concentration in R&D as well as potential barriers to entry for potential competitors. Note that much of the concentration reflects mergers and acquisitions among firms listed individually in the tables.

Based on the four-firm concentration ratio of approvals, corn seed remains the least concentrated industry relative to the other three crops. This finding is fairly consistent with earlier findings presented on the four-firm concentration ratio of corn in terms of sales. Moreover, the level of corn seed R&D concentration has remained relatively constant, at around 72 percent since 1990, which is also consistent with earlier findings. Soybean seed R&D remains highly concentrated in terms of field release approvals, although this concentration generally follows a downward trend. Again, this is fairly consistent with trends for the four-firm concentration ratio when measured in more conventional terms earlier. Cottonseed R&D, on the other hand, shows a trend toward increasing concentration, from 89 percent in 1993 to 96 percent in 2000, a finding also consistent with earlier market concentration measures.[16] Finally, the wheat seed industry remains highly concentrated, although this

[16] Note, however, that few firms dominated cotton field release approvals by APHIS during the first 5 years (1988-92). Hence, the four-firm concentration ratio during this period was 100 percent. New firms entered the market and pursued R&D in subsequent years.

Figure 19

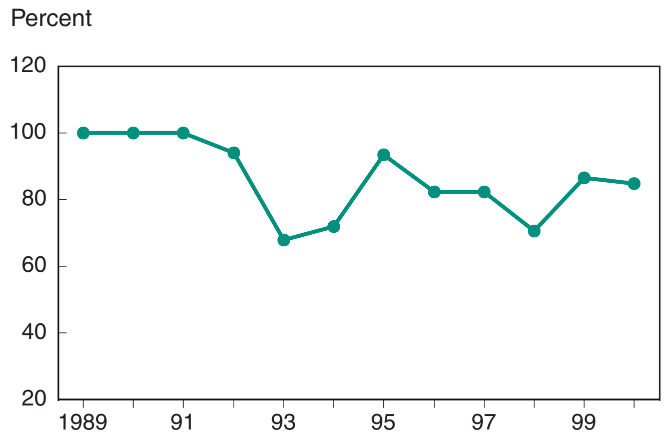
Four-firm concentration ratio in APHIS field release approvals for corn



Source: Data source provided in table 43.

Figure 20

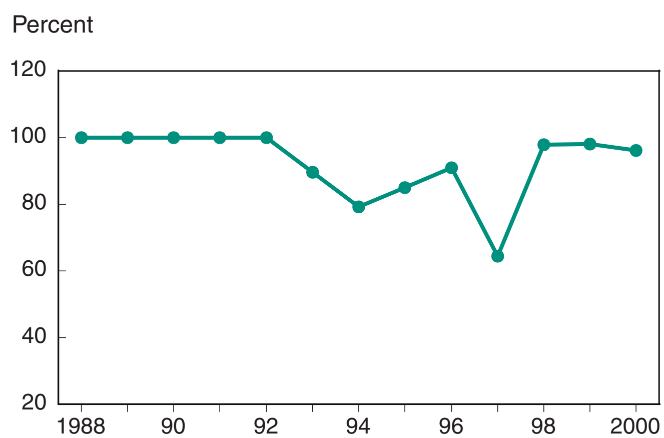
Four-firm concentration ratio in APHIS field release approvals for soybeans



Source: Data source provided in table 44.

Figure 21

Four-firm concentration ratio in APHIS field release approvals for cotton



Source: Data source provided in table 45.

may be due to the limited number of private firms operating in the sector; only two of the largest four institutions were private firms.

Between 1988 and 2000, Monsanto received approvals for over 1,200 new varieties of corn, soybeans, cotton, and wheat, making it the leader in product development, followed by other large companies such as DuPont/ Pioneer, and AgrEvo. The majority of the permits issued to leading companies have been for testing of new corn varieties, followed by soybeans and cotton (table 47). Similarly, out of the 53 approvals for nonregulated status given by APHIS, 28 were for varieties developed by Monsanto/ Calgene/Asgrow/DeKalb, 10 were for AgrEvo, and 3 were for DuPont/Pioneer (table 50). Thus, the largest two firms hold 70 percent of the nonregulated varieties.

Patent ownership shows a pattern of concentration similar to that evident in other R&D measures. Most of the biotech patents awarded to private sector firms are held by a small number of large companies. As of 1996/97, DuPont/Pioneer held the largest number of patents for corn and soybeans, followed by Monsanto (table 51) (Brennan et al., 1999, p. 167).

As with regulatory approvals, the leading firms in the sector have received intellectual property rights not only through their R&D investment but also through recent mergers and acquisitions.

Table 51—Biotech patent ownership for corn and soybeans, by company

	Corn (1982-96)	Soybeans (up to 1997)	Corn and soybeans
	Number of patents held		
Aventis/Rhone-Poulenc-Agrochem	3	4	7
AgrEvo /PGS	4	3	7
Novartis/Syngenta	17	2	19
Zeneca	0	3	3
Dow Chemical/Mycogen	3	4	7
DuPont/Pioneer	28[1]	42[2]	70
Monsanto DeKalb	11[3]	23	34
Cyanamid	3	0	3
Others	69	49	118
Total	138	130	268

[1] Includes 21 from Pioneer.
[2] Includes 27 from Pioneer.
[3] Includes 4 from DeKalb.

Source: Derwent Biotechnology Abstracts, as reported in *GRAIN* (1996, 1997) and in Brennan et al. (2000).

Table 50—Status of petitions for deregulation, by company, 1987-2001[1]

Company/institution	Approved	Incomplete	Pending	Withdrawn	Void	Total
			Number			
Monsanto	16		2	8		26
AgrEvo	10			3		13
Calgene	9				1	10
DeKalb	2			1		3
DuPont	2			1		3
DNA Plant Tech	1			1		2
Agritope	1			1		2
Bejo	1			1		2
Zeneca		1		1		2
Cornell University	1			1		2
Asgrow	1					1
Aventis				1		1
Ciba-Geigy	1					1
Dow	1					1
Upjohn	1					1
Syngenta				1		1
University of Saskatchewan	1					1
Zeneca & Petoseed	1					1
Mycogen				1		1
Northrup King	1					1
Novartis Seeds	1					1
Pioneer	1					1
Plant Genetic Systems	1					1
Vector Tobacco			1			1
Total	53	1	3	21	1	79

[1] From June 16, 1987, to June 25, 2001.

Source: Virginia Polytechnic Institute (2001).

References

Abrahams, P. "ICI To Split and Shed 9,000 Jobs Worldwide: Investment in Petrochemicals Halted, Pounds 384m Pre-Tax Loss Reported." *Financial Times*. February 26, 1993, p. 1.

Advanta, Facts and Figures. Accessed at URL: *http://www.advantaseeds.com/show?id=11882&langid=96*

AgBiotech Reporter. "Banner Year at D&PL." January 2000, p. 4. AgrEvo. Accessed at URL: *http://www.archive.hoechst.com/english/life_sciences/ernaehrung/lw_zahlenfakten.html*

Agrawal, P.K., B.D. Agrawal, P. Venkat Rao, and Jai Singh. "Seed Multiplication, Conditioning and Storage." In Morris, Michael L., *Maize Seed Industries in Developing Countries*. Boulder, CO: CIMMYT, 1998, pp. 103-24.

Airy, John M., L.A. Tatum, and J.W. Sorenson, Jr. "Producing Seed of Hybrid Corn and Grain Sorghum. In *Seeds: The Yearbook of Agriculture, 1961*. U.S. Department of Agriculture, 1961, pp. 145-53.

Alston, J.M., and P.G. Pardey. *Making Science Pay: The Economics of Agricultural R&D Policy*. Washington, DC: AEI Press, 1996.

Alston, J.M., and R.J. Venner. "The Effects of the U.S. Plant Variety Protection Act on Wheat Genetic Improvement." *Research Policy* 31(2002): 527-42.

Appelbaum, E. "The Estimation of the Degree of Oligopoly Power." *Journal of Econometrics* 19(1982): 287-99.

Appelbaum, E. "Testing Price Taking Behavior." *Journal of Econometrics* 9(1979): 283-94.

Asgrow Seed Company. "History." Accessed at URL: *http://www.asgrow.com/corporate/History.html*, June 5, 2000.

Aventis Agriculture. "Introducing Aventis." Accessed at URL: *http://www2.aventis.com/introduce/agro.htm*, June 5, 2000.

Azzam, A. "Measuring Market Power and Cost-Efficiency Effects of Industrial Concentration." *Journal of Industrial Economics* 45(4)(1997): 377-86.

Azzam, A., and E. Pagoulatos. "Testing Oligopolistic and Oligopsonistic Behavior: An Application to the U.S. Meat Packing Industry." *Journal of Agricultural Economics* 41(1990): 362-70.

Azzam, A., and J.R. Schroeter. "The Tradeoff Between Oligopsony Power and Cost Efficiency in Horizontal Consolidation: An Example From Beef Packing." *American Journal of Agricultural Economics* 77(1995): 825-36.

Bayer CropScience. "Bayer CropScience Launch." Accessed at URL: *http://www.bayercropscience.co.uk/home,* September 27, 2002.

Beach, D.E., and J. Fernandez-Cornejo. "Setting Research Priorities in the Public Sector: A Suggested Framework for the AARC Center." *Journal of Agricultural Economics Research* 45 (Summer 1994): 3-16.

Begemann, B.D. "Competitive Strategies of Biotechnology Firms: Implications for U.S. Agriculture." *Journal of Agricultural and Applied Economics* 29 (June 1997): 117-22.

Bjornson, B. "Capital Market Values of Agricultural Biotechnology: How High and Why?" *AgBioForum*, 1(2)(1998): 69-73. Accessed at URL: *http://www.agbioforum.missouri.edu*, September 22, 1999.

Blonigen, B.A., and Ch.T. Taylor. "R&D Intensity and Acquisitions in High-Technology Industries: Evidence From the U.S. Electronic and Electrical Equipment Industries." *Journal of Industrial Economics* 48(1) (March 2000): 47-70.

Boswell, V.R. "The Importance of Seeds." In *Seeds: The Yearbook of Agriculture, 1961*. U.S. Department of Agriculture, 1961, pp. 1-10.

Brennan, M.F., C.E. Pray, and A. Courtmanche. "Impact of Industry Concentration on Innovation in the U.S. Plant Biotech Industry." In Lesser, William H., ed., *Transitions in Agbiotech: Economics of Strategy and Policy. Proceedings of NE-165 Conference, June 24-25, 1999*, Washington, DC. Connecticut: University of Connecticut, 2000.

Butler, L.J., and B.W. Marion. *The Impacts of Patent Protection on the U.S. Seed Industry and Public Plant Breeding*. North Central Region Research Publication 304, North Central Project 117, Monograph 16. Madison, WI: Research Division, College of Agricultural and Life Sciences, University of Wisconsin, September 1985.

Carlton, D.W., and J.M. Perloff, *Modern Industrial Organization*, 2nd edition. Reading, MA: Addison-Wesley, 1994.

Chen, Z., and R. Lent. "Supply Analysis in an Oligopsony Model." *American Journal of Agricultural Economics* 74(1992): 973-79.

Clark, A. "Zeneca Spends Pound 46m on Dutch Genetic Engineer." *Daily Telegraph*. May 14, 1997, p. 29.

Cohen, W.M., and R.C. Levin, "Empirical Studies of Innovation and Market Structure." In Schmalensee, R., and R.D. Willig, *Handbook of Industrial Organization*, Vol. II. Amsterdam: Elsevier, 1989.

Cosun. "Advanta Seed Technology." Accessed at URL: *http://www.cosun.com/advantagb.htm*, June 5, 2000.

Cotton USA. Accessed at URL: *http://www.cottonus.org/NewsResources/SouthMid.htm; http://www.cottonus.org/NewsResources/West.htm*, no date.

Cowling, K.G., and M. Waterson. "Price-Cost Margins and Market Structure." *Economica* 43(1976): 267-74.

Daily Telegraph. "Zeneca's Seeds Business Merges." August 13, 1996, p. 25.

Day-Rubenstein, K., and P. Heisey. "Agricultural Resources and Environmental Indicators: Crop Genetic Resources." Chapter 3.2 of *ERS Agricultural Resources and Environmental Indicators,* Agricultural Handbook No. AH722. April 2001. Accessed at URL: *http://www.ers.usda.gov/publications/arei/arei2001/arei3_2/AREI3_2geneticresources.pdf*

Dow AgroSciences. "Company." Accessed at URL: *http://www.dowagro.com/main/company/default.htm*, August 7, 2000.

Dow AgroSciences, News Release. "Dow AgroSciences To Reorganize, Eliminate 500 Positions Globally." September 19, 2002. Accessed at URL: *http://www.dowagro.com/newsroom/news/091902.htm*, September 27, 2002.

Duvick, D.N. "Genetic Contributions to Yield Gains of U.S. Hybrid Maize, 1930 to 1980." In Fehr, W.R., ed., *Genetic Contributions to Yield Gains of Five Major Crop Plants*. Madison, WI: CSSA, 1984, pp. 15-48.

Duvick, D.N. "Genetic Rate of Gain in Hybrid Maize Yields During the Past 40 Years." *Maydica* 22(1977):187-96.

Duvick, D.N. Plant Breeding: Past Achievements and Expectations for the Future. *Economic Botany*, 40 (1992): 289-97.

Duvick, D.N. "United States." In Morris, M.L., ed., *Maize Seed Industries in Developing Countries*. Boulder, CO: CIMMYT, 1998, pp. 193-211.

Emsweller, S.L., "Fundamental Procedures in Breeding Crops." In *Seeds: The Yearbook of Agriculture, 1961*. U.S. Department of Agriculture, 1961, pp. 127-33.

Falck-Zepeda, J., and G. Traxler. "The Role of Federal, State, and Private Institutions in Seed Technology Generation." Greg Traxler and José Falck-Zepeda. In Fuglie, K.O., and D.E. Schimmelpfennig, eds., *Public-Private Collaboration in Agricultural Research: New Institutional Arrangements and Economic Implications*. Ames, IA: Iowa State University Press, 2000.

Fernandez-Cornejo, J. "Adoption of Genetically Engineered Crops in the U.S." Data product. U.S. Department of Agriculture, Economic Research Service, November 2003. Accessed at URL: *http://www.ers.usda.gov/data/BiotechCrops*

Fernandez-Cornejo, J., and C.R. Shumway. "Research and Productivity in Mexican Agriculture." *American Journal of Agricultural Economics* 79(1997): 738-53.

Fernandez-Cornejo, J., and D. Spielman. *Concentration, Market Power, and Cost Efficiency in the Corn Seed Industry*. Selected paper presented at the 2002 AAEA meetings, Long Beach CA, July 28-31, 2002.

Fernandez-Cornejo, J., and W.D. McBride. *Genetically Engineered Crops for Pest Management in U.S. Agriculture: Farm Level Effects*. Agricultural Economic Report 786. U.S. Department of Agriculture, Economic Research Service, April 2000.

Fernandez-Cornejo, J., and W.D. McBride. *The Adoption of Bioengineered Crops*. Agricultural Economic

Report 810. U.S. Department of Agriculture, Economic Research Service, May 2002.

Fernandez-Cornejo, J., and W.D. McBride. "Genetically Engineered Crops: U.S. Adoption and Impacts." *Agricultural Outlook*, No. 294, September 2002a, pp. 24-27.

Fernandez-Cornejo, J., D. Spielman, and J. Keller. *Concentration, Market Power, and Cost Efficiency in the Cotton Seed Industry.* Selected paper presented at the 2002 SAEA meetings, Orlando, FL, Feb. 4-6, 2002.

Fernandez-Cornejo, J., M. Caswell, and C. Klotz-Ingram. "Seeds of Change: From Hybrids to Genetically Modified Foods." *Choices* (4th quarter 1999): 18-22.

FIS/ASSINSEL (The International Seed Trade Federation / The International Association of Plant Breeders for the Protection of Plant Varieties). *Statistics*. Accessed at URL: *http://www.worldseed.org/statistics.html*, April 14, 2000.

Food and Agriculture Organization (FAO). "Agreement Reached on Protecting Plant Genetic Resources," July 16, 2001. Accessed at URL: *http://www.fao.org/news/2001/010703-e.htm*, July 30, 2001.

Fox, Patrick. *Biotechnology and the Seed Industry*. UK: PJB Publications, June 1990.

Frey, Kenneth. J. *National Plant Breeding Study-1: Human and Financial Resources Devoted to Plant Breeding Research and Development in the United States in 1994*. Special Report 98. Ames, IA: Iowa Agriculture and Home Economics Experiment Station, Iowa State University, 1996.

Frisvold, G., Sullivan, J., and Raneses, A. Who Gains From Genetic Improvements in U.S. Crops? *AgBio-Forum* 2 (3 & 4)(1999): 237-46. Accessed at URL: *http://www.agbio.forum.org*, July 17, 2000.

Fuglie, K., N. Ballenger, K. Day, C. Klotz, M. Ollinger, J. Reilly, U. Vasavada, and J. Yee. *Agricultural Research and Development*. Acricultural Economic Report 735. U.S. Department of Agriculture, Economic Research Service, May 1996.

Fulton, M., and K. Giannakas. "Agricultural Biotechnology and Industry Structure." *AgBioForum*. 4(2):137-51. Accessed at URL: *http://www.agbioforum.com.*

Garst Seed Company. "Mike Muston Named Vice President for Advanta, Americas." Accessed at URL: *http://www.garstseed.com/articles/pres990313-muston.htm*, June 6, 2000.

Gollop, F.M., and M.J. Roberts. "Firm Interdependence in Oligopolistic Markets." *Journal of Econometrics* 10(1979): 313-31.

Gould, F. "Genetics of Plant Herbivore Systems: Interactions Between Applied and Basic Study." In Denno, R.F., and M.S. McClure, eds, *Variable Plants and Herbivores in Natural and Managed Systems*. New York: Academic Press, 1983.

Graff, G.D., G.C. Rausser, and A.A. Small. "Agricultural Biotechnology's Complementary Intellectual Assets." *Review of Economics and Statistics*, Forthcoming.

Grain. "The Biotech Battle Over the Golden Crop." *Seedling* 13(3) (October 1996). Accessed at URL: *http://www.grain.org/publications/oct964-en-p.htm*.

Grain. "Soybean: The Hidden Commodity." *Seedling* 14(2) (June 1997). Accessed at URL: *http://www.grain.org/publications/oct973-en-p.htm*.

Groosman, A., A. Linnemann, and H. Wierma. *The International Dimension of Seed Industry Development: Draft Final Report of the Project*. Paper prepared for the seminar on "Technology Development and Changing Seed Supply Systems." Tilburg, 1988.

Hansen, L., and M. Knudson. "Property Right Protection of Reproducible Genetic Material." *Review of Agricultural Economics* 18(1996): 403-14.

Hayenga, M.L. "Structural Change in the Biotech Seed and Chemical Industrial Complex." *AgBioForum*, 1(2)(1998): 43-55. Accessed at URL: *http://www.agbioforum.missouri.edu*, September 22, 1999.

Heisey, Paul, W. *Public Sector Agricultural Research in an Era of Rapidly Expanding Private Sector Investment.* Paper prepared for the Western Economic Association International, Huntington Beach, CA, July 10, 1999.

Heisey, Paul, W. Private communication, September 23, 1999a.

Heisey, P.W., C.S. Srinivasan, and C. Thirtle. *Public Sector Breeding in a Privatizing World*. Agricultural

Economic Report 772. U.S. Department of Agriculture, Economic Research Service, August 2001.

Hoechst Schering AgrEvo. "Agriculture." Accessed at URL: *http://www.archive.hoechst.com/english/life_sciences/ernaehrung/lw_agrevo.html* and *http://www.archive.hoechst.com/english/life_sciences/ernaehrung/lw_kooperationen.html*, August 7, 2000.

Huffman, W.E., and R.E. Evenson. *Science for Agriculture*. Ames, IA: Iowa State University Press, 1993.

International Union for the Protection of New Varieties of Plants (UPOV). *UPOV Convention (1991 Act)*. Accessed at: URL: *http://www.upov.int/eng/convntns/1991/w_up910_.htm#_1*, July 24, 2001.

_________. "States Party to the International Convention and Addresses of Plant Variety Protection Offices." Accessed at URL: *http://www.upov.int/eng/ratif/index.htm*, July 30, 2001a.

_________. "The UPOV System of Plant Variety Protection." Accessed at URL: *http://www.upov.int/en/about/upov_system.htm*, on July 9, 2003.

Iwata, G. "Measurement of Conjectural Variations in Oligopoly. *Econometrica* 42(1974): 947-66.

James, C. "Progressing Public-Private Sector Partnerships in International Agricultural Research and Development." *ISAAA Briefs* 4(1997).

James, C., and A.F. Krattiger. "Global Review of the Field Testing and Commercialization of Transgenic Plants: 1986-1995: The First Decade of Crop Biotechnology." *ISAA Briefs* 1(1996).

Jenkins, M.T. "Corn Improvement." In *Yearbook of Agriculture, 1962*. U.S. Department of Agriculture, 1936, pp. 455-522.

Jewett, T.O. "Thomas Jefferson: Father of Invention." *The Early America Review*, Vol. III, n. 1. (Winter 2000). Anna Maria, Florida. Downloaded from *http://www.earlyamerica.com* on December 17, 2001.

Joly, Pierre-Benoit, and S. Lemarie "Industry Consolidation, Public Attitude and the Future of Plant Biotechnology in Europe." *AgBioForum* 1(2)(1998): 85-90. Accessed at URL: *http://www.agbioforum.missouri.edu*, September 22, 1999

Just, R.E., and D.L. Hueth. "Multimarket Exploitation: The Case of Biotechnology and Chemicals." *American Journal of Agricultural Economics* 75(4)(1993): 936-45.

Kalaitzandonakes, N. "Mycogen: Building a Seed Company for the Twenty-First Century." *Review of Agricultural Economics* 19(2)(1997): 156-66.

Kalaitzandonakes, N., and B. Bjornson. "Vertical and Horizontal Coordination in the Agrobiotechnology Industry: Evidence and Implications." *Journal of Agricultural and Applied Economic*s 29(4)(1997): 129-139.

Kalaitzandonakes, N. and M.L Hayenga. *Structural Change in the Biotechnology and Seed Industrial Complex: Theory and Evidence.* Paper presented at the Transitions in AgBiotech: Economics of Strategy and Policy Conference, Washington, DC, June 24-25, 1999.

Kalton, R.R., P.A. Richardson, and N.M. Frey. "Inputs in Private Sector Plant Breeding and Biotechnology Research Programs in the USA." *Diversity* 5(1990): 22-25.

Kidd, George H. (L. William Teweles and Co.). *Ag Biotech* (statement). Proceedings of the Conference held in Arlington, VA, March 28-30, 1989.

Kimle, K. and M.L. Hayenga. "Structural Change Among Agricultural Input Industries." *Agribusiness* 9(1)(1993): 15-27.

Kimle, K., and M.L. Hayenga. *Agricultural Inputs and Processing Industries*. Ames, IA: Iowa State University, 1992.

King, John L. *Concentration and Technology in Agricultural Input Industries*. U.S. Department of Agriculture, Economic Research Service, Agriculture Information Bulletin 763, March 2001.

Klotz, Cassandra, K. Fuglie, and C. Pray. *Private-Sector Agricultural Research Expenditures in the United States, 1960-1992.* NRED-9525. U.S. Department of Agriculture, Economic Research Service, October 1995. Update for 1993-1997 released in July 1998.

Klotz-Ingram, C. Private communication. July 24, 2000.

Kloppenburg, J.R. *First the Seed: A Social History of Plant Breeding and the Seed Industry in the United States*. Ph. D. dissertation, Cornell University, January 1985.

Knudson, M.K. "The Role of the Public Sector in Applied Breeding R&D: The Case of Wheat in the U.S.A." *Food Policy* 15(3)(1990): 209-217.

Knudson, M.K. and C. E. Pray. "Plant Variety Protection, Private Funding, and Public Sector Research Priorities." *American Journal of Agricultural Economics*, 73:3 (August 1991): 882-86.

Knudson, M. K. and L. Hansen, *Intellectual Property Rights and the Private Seed Industry*. Agricultural Economic Report 654. U.S. Department of Agriculture, Economic Research Service, November 1991.

Krull, D.F., J.M. Prescott, and C.W. Crum. "Seed Marketing and Distribution." In Morris, Michael, L., *Maize Seed Industries in Developing Countries*. Boulder, CO: CIMMYT, 1998, pp. 125-41.

Leibenluft, R.F. *Competition in Farm Inputs: An Examination of Four Industries*. Federal Trade Commission, Office of Policy Planning, February 1981.

Lerch, V.D. "The Plant Variety Protection Act: A Current Look." *Seed World*. U.S. Department of Agriculture, Agricultural Marketing Service, Plant Variety Protection Office, 1989.

Lesser, W. "Intellectual Property Rights and Concentration in Agricultural Biotechnology." *AgBioForum* 1(2) (Fall 1998): 56-61. Accessed at URL: *http://www.agbioforum.missouri.edu*, August 21, 2001.

Lucier, G., A. Chesley, and M. Ahearn. *Farm Income Data: A Historical Perspective*. Statistical Bulletin 740. U.S. Department of Agriculture, Economic Research Service, 1986.

Maredia, M.K., and D. Byerlee. "Toward Efficiency Allocation of Research Resources in the Presence of Spillovers: Lessons From Wheat Iimprovement Research." In Maredia, M.K, and D.Byerlee, eds., *Global Wheat Improvement System: Prospects for Enhancing Efficiency in the Presence of Spillovers*. Mexico, DF (Mexico): CIMMYT. 1999. pp. 118-26.

Maredia, M.K., and R. Ward. "Wheat Breeding Environments: A Conceptual and Empirical Analysis." In Maredia, M.K, and D. Byerlee, eds., *The Global Wheat Improvement System: Prospects for Enhancing Efficiency in the Presence of Spillovers*. Mexico, DF (Mexico): CIMMYT. 1999, pp. 12-21.

McKay, John W. "How Seeds Are Formed." In *Seeds: The Yearbook of Agriculture, 1961*. U.S. Department of Agriculture, 1961, pp. 11-17.

McMullen, N. *An Introduction to Seed Production.* NPA Report Series No 227. National Planning Association, 1987a.

McMullen, N. *Seeds and World Agricultural Progress*. National Planning Association, 1987b.

Meredith, W.R., Jr., and R.R. Bridge. "Genetic Contributions to Yield Changes in Upland Cotton." In Fehr, W.R., ed., *Genetic Contributions to Yield Gains of Five Major Crop Plants*. Madison, WI: CSSA, 1984, pp. 75-87.

Merrill Lynch. *Ag. Biotech Update: Franken-Potato Revisted.* Merrill Lynch, Global Securities Research & Economics Group, Global Fundamental Equity Research Department, February 1, 1999.

_________. *Global Chemical Benchmark: The New Ag Products Industry, Chemicals.* Merrill Lynch, Global Securities Research & Economics Group, Global Fundamental Equity Research Department, July 7, 2000.

Monsanto Company. "About Monsanto." Accessed at URL: *http://www.monsanto.com/monsanto/about/past/index5.htm*, June 2, 2000.

Morris, M.L., ed. *Maize Seed Industries in Developing Countries*. Boulder, CO: CIMMYT, 1998.

Morse, L. "Dow Chemical Buys Out Partner." *Financial Times*, May 16, 1997, p. 33.

Mycogen Corporation. "Dow Subsidiary Purchases Mycogen Shares in Tender Offer." October 5, 1998. Accessed at URL: *http://www.mycogen.com/pressrelease.asp?ID=11*, August 24, 2001.

_________. "Dow to Acquire All Outstanding Mycogen Shares." August 31, 1998. Accessed at URL: *http://www.mycogen.com/pressrelease.asp?ID=14*, August 24, 2001.

National Research Council, Board on Agriculture and Natural Resources, Committee on Genetically Modified Pest-Protected Plants. *Genetically Modified Pest-Protected Plants: Science and Regulation*. Washington, DC: National Academy Press, 2000.

Northrup-King Co. "Northrup-King Co. History." Accessed at URL: *http://www.nk.com/helper/1998/12_28_history_northrupking.html*, June 9, 2000.

Ollinger, M., and J. Fernandez-Cornejo. *Regulation, Innovation, and Market Structure in the U.S. Pesticide Industry*. Agricultural Economic Report 719. U.S. Department of Agriculture, Economic Research Service, 1995.

Panos. "Greed of Need? Genetically Modified Crops." Panos Media Briefing No. 30. October 1998. Accessed at URL: *http://www.oneworld.org/panos/*

Pharmacia Corporation. "Corporate Facts." Accessed at URL: *http://www.pharmacia.com/facts_monsanto.html*, June 6, 2000.

Pioneer Hi-Bred International, Inc. "75 Years: A Legacy of Values." Accessed at URL: *http://pioneer.com/ 75th/default.htm*, August 24, 2001.

Plant Variety Protection Act. 7 U.S.C. § 2321-2583. 1970.

Pollak, A. "Green Revolution Yields to the Bottom Line." *The New York Times*, May 15, 2001.

Preckel, P.V., T.G. Baker, and J. Eide. "Seed Corn Tournament and Excess Nitrogen Applications." Unpublished manuscript, Purdue University, February 12, 1997.

PR Newswire. "Monsanto Completes Sale of Stoneville to Hicks, Muse, Tate & Furst and Emergent Genetics, Inc." December 29, 1999.

PRNewswire-FirstCall (via COMTEX). "As Pharmacia Completes Monsanto Spinoff, Monsanto CEO Says Company Retains Focus and Strategic Direction, August 13, 2002." Accessed at URL: *http://www.corporate-ir.net/ireye/ir_site.zhtml?ticker=MON&script=410&layout=-6&item_id=325145* Sept 27, 2002.

Rivlin, R. "Monsanto Sells Seeds Business." *Financial Times*, August 7, 1999, p. 19.

Ross, D. "Antitrust Enforcement and Agriculture." Address before the Organization of Competitive Markets. U.S. Department of Justice, Nashville, TN, July 20, 2001, *http://www.usdoj.gov/atr/public/speeches/8661.htm*

Ruttan, V.W. "Biotechnology and Agriculture: A Skeptical Perspective." *AgBioForum* 2(1)(2000): 54-60. Accessed at URL: *http://www.agbioforum.org/vol2no1/ruttan.htm*l.

Schimmelpfennig, D.S., and Thirtle, C. "Research Spillovers Between the European Community and the United States." *Contemporary Economic Policy*, Vol. 19, No. 4, October 1999, pp. 457-68.

Schimmelpfennig, D.S., Thirtle, C., and van Zyl, J. "Short and Long Run Returns to Agricultural R&D in South Africa, or Will the Real Rate of Return Please Stand Up?" *Agricultural Economics*, Vol. 24, No. 1, June 2000, pp.1-15.

Schmalensee, R., and R.D. Willig. *Handbook of Industrial Organization* Vol. II. In Arrow, K.J., and M.D. Intriligator. *Handbooks in Economics*. Amersterdam: Elsevier, 1989.

Schor, J. *The Evolution and Development of Biotechnology: A Revolutionary Force in American Agriculture*. AGES 9424. U.S. Department of Agriculture, Economic Research Service, August 1994.

Schroeter, J.R. 1988. "Estimating the Degree of Market Power in the Beef Packing Industry." *Review of Economics and Statistics* 70(1988): 158-62.

Schroeter, J.R., and A. Azzam. "Marketing Margins, Market Power, and Price Uncertainty." *American Journal of Agricultural Economics* (1991): 990-99.

Sears, E.R. "Genetics and Farming." In *Science of Farming - Yearbook of Agriculture 1943-1947*. U.S. Department of Agriculture, 1947, pp. 245-55.

Seedquest. "AstraZeneca Merger Approved; U.S. Names Senior Management." Accessed at URL: *http://www.seedquest.com/News/releases/europe/Zeneca/N1710.htm*, April 6, 1999.

_________. "Dupont and Pioneer Hi-Bred International, Inc. Merger Completed." Accessed at URL: *http://www.seedquest.com/News/releases/usa/Dupont/n2145.htm*, October 1, 1999.

_________. "KWS and Limagrain Merge Their Corn Activites in North America." Accessed at URL: *http://www.seedquest.com/News/releases/europe/Limagrain/n2406.htm*, January 19, 2000.

_________ "Monsanto Agrees To Purchase Cargill International Seed Operations in Central and Latin America, Europe, Asia, Africa." Accessed at URL: *http://www.seedquest.com/News/Press%20releases/Monsanto/N1119.htm*, June 29, 1998.

_________. "Monsanto and Pharmacia & Upjohn To Merge, Creating Global Leader in Pharmaceuticals With Top-Tier Growth Prospects – Leading Global Agricultural Business To Be Operated as a Separate Entity, With a Partial IPO." Accessed at URL: *http://www.seedquest.com/News/releases/usa/Monsanto/n2331.htm*, December 19, 1999.

Seed World. "Building Business With Seed Treatment," December 1999.

Sexton, R.J. "Imperfect Competition in Agricultural Markets and the Role of Cooperatives: A Spatial

Analysis." *American Journal of Agricultural Economics* (1990): 609-720.

Shields, M. "Novartis and AstraZeneca Mix Agribusiness." *American Seed Trade Association Newsletter*, December 1999. Accessed at URL: *http://www.amseed.com/newsletter/newsletr.htm*, January 19, 2000.

Shimoda, S.M. "Agricultural Biotechnology: Master of the Universe?" *AgBioForum* 1(2) (1998): 62-68. Accessed at URL: *http://www.agbioforum.missouri.edu*, September 22, 1999.

Shoemaker, R., J. Harwood, K. Day-Rubenstein, T. Dunahay, P. Heisey, L. Hoffman, C. Klotz-Ingram, W. Lin, L. Mitchell, W. McBride, and J. Fernandez-Cornejo. *Economic Issues in Agricultural Biotechnology*. Agriculture Information Bulletin 762. U.S. Department of Agriculture, Economic Research Service, February 2001.

Smale, M., and K. Day-Rubenstein. "The Demand for Crop Genetic Resources: International Use of the U.S. National Germplasm System." *World Development* (2002): 1639-55.

Sprague, G.F. "Hybrid Corn." In *After a Hundred Years - Yearbook of Agriculture, 1962*. U.S. Department of Agriculture, 1962, pp. 106-107.

St. Louis Post-Dispatch. "Justice Officials Looking Into Flurry of Cottonseed Mergers." July 20, 1996: p. 1C.

Stoneville Pedigreed Seed Company. "News." Accessed at URL: *http://www.stoneville.com/news.htm*, June 8, 2000.

Storck, W.J. "Pesticide Growth Slows." *Chemical and Engineering News*, November 16, 1987.

Strachan, J.L. Private communication. U.S. Department of Agriculture, Agricultural Marketing Service, Plant Variety Protection Office, 2003.

Strachan, J.M. *Plant Variety Protection: An Alternative to Patents.* U.S. Department of Agriculture, Agricultural Marketing Service, Plant Variety Protection Office, 1992.

Syngenta About Syngenta, Facts and Figures. Accessed at URL: *http://www.syngenta.com/en/about_syngenta/figures.aspx,* May 2003

Teitelbaum, G.L., and A. Figueroa. "Seed Companies, A Review of the Investment Case," Merrill Lynch, 1997.

Tripp, R. "Regulatory Issues: Varietal Registration and Seed Quality Control." In Morris, M.L., *Maize Seed Industries in Developing Countries*. Boulder, CO: CIMMYT, 1998, pp. 159-73.

U.S. Congress, Office of Technology Assessment. *New Developments in Biotechnology Patenting Life—Special Report*. OTA-BA-370, April 1989.

U.S. Congress (USC). *Plant Variety Protection Act*. 7 U.S.C. 1970. § 2321-U.S. Department of Agriculture, Agricultural Marketing Service, Cotton Program, Market News Branch. *Cotton Varieties Planted, Crops of (1970-1997)*. Accessed at URL: *http://www.ams.usda.gov/cotton/cnpubs/htm,* June 14, 2000.

U.S. Department of Agriculture. Agricultural Biotechology. Frequently Asked Questions. What Is Biotechnology? Accessed at URL: *http://www.usda.gov/agencies/biotech/faq/html*, 2003

U.S. Department of Agriculture, Agricultural Marketing Service, Plant Variety Protection Office. "Science and Technology Programs." Accessed at URL: *http://www.ams.usda.gov/science/PVPO/pvp.htm,* August 10, 2000.

U.S. Department of Agriculture, Agricultural Marketing Service. *Plant Variety Protection Act and Regulations and Rules of Practice*. Revised March 2001, 45 pp, *http://www.ams.usda.gov/science/PVPO/PVPO_Act/whole.pdf*

U.S. Department of Agriculture, Agricultural Marketing Service, Plant Variety Protection Office. "Plant Variety Protection Listings." Accessed at URL: *http://www.ars-grin.gov/cgi-bin/npgs/html/pvplist.pl?* May 30, 2001a.

U.S. Department of Agriculture, Agricultural Marketing Service, Plant Variety Protection Office. *Cotton PVP Accessions*. Accessed at URL: *http://www.ars-grin.gov/cgi-bin/npgs/html/pvp.pl?Cotton,* May 30, 2001b.

U.S. Department of Agriculture, Animal and Plant Health Inspection Service. "Regulating Biotechnology in Agriculture." Accessed at URL: *http://www.aphis.usda.gov/oa/biotech.html*, August 14, 2000.

U.S. Department of Agriculture, Cooperative State Research, Education, and Extension Service, Current Research Information System. *Manual of Clas-*

sification of Agricultural and Forestry Research: Classifications used in the Current Research Information System, Revision V. 1993.

_________, Current Research Information System, *Inventory of Agricultural Research*. 1968-1996.

_________, Information Systems for Biotechnology. "Field Tests in the U.S., 1988-2000." Accessed at URL: *http://www.nbiap.vt.edu/cfdocs/fieldtests1.cfm*, July 3, 2000b.

_________, Information Systems for Biotechnology. "Background on the Environmental Release Database." Accessed at URL: *http://www.nbiap.vt.edu/biomon/explain.htm*, August 14, 2000b.

U.S. Department of Agriculture, Economic Research Service. *Agricultural Resources Inputs Situation and Outlook*, AR-13, February 1989.

_________. *Agricultural Resources Inputs Situation and Outlook*, AR-32, October 1993.

_________. *Agricultural Resources and Environmental Indicators, 1996-97*. Agricultural Handbook 712. July 1997.

_________. *AREI Updates 1998*, No. 8, December 1998.

_________. "*Farm Sector Performance – Situation and Outlook*." Accessed at URL: *http://www.ers.usda.gov/briefing/farmincome/s&o.htm*, August 20, 1999.

_________. *Agricultural Resources and Environmental Indicators 2000*, AREI 2000, August 2000.

_________. *Agricultural Resource Management Survey (ARMS): Recommended Data.* Accessed at URL:*http://www.ers.usda.gov/Briefing/ARMS/moredata.htm*, March 28, 2002.

U.S. Department of Agriculture, National Agricultural Statistics Service. *Agricultural Statistics*. Various years.

U.S. Department of Agriculture, National Agricultural Statistics Service. "Published Estimates Data Base." Accessed at URL: *www.nass.usda.gov:81/ipedb/*, accessed May 25, 2001.

U.S. Department of Energy, Energy Information Agency. "Electricity." Accessed at URL: *www.eia.doe.gov/fuelelectric.html*, May 21, 2001.

U.S. Department of Labor, Bureau of Labor Statistics. *Bureau of Labor Statistics Data: Series ID: EES00500049, Seasonally Adjusted, Industry: Total Private Industry, SIC Code: na, Average Hourly Earnings, 1982 Dollars; 2: Series ID: EES30000006, Seasonally Adjusted, Industry: Manufacturing, SIC Code: 20-39, Average Hourly Earnings of Production Workers.* Accessed at: URL: *www.bls.gov*, May 18, 2001

U.S. International Trade Commission. *Industry & Trade Summary: Seeds*. USITC 2859, May 1995.

Van Wijk, Jeroen, J.I. Cohen, and J. Komen. *Intellectual Property Rights for Agricultural Biotechnology: Options and Implications for Developing Countries. A Biotechnology Research Management Study*. ISNAR Research Report No. 3. The Hague: International Service for National Agricultural Research, 1993.

Virginia Polytechnic Institute and State University. "Information Systems for Biotechnology, Environmental Release Database of Field Test Releases in the U.S." Accessed at URL: *www.isb.vt.edu/cfdocs/fieldtests1.cfm*, June 28, 2001.

The Wall Street Journal Interactive Edition. "Monsanto To Expand Internationally With $1.4 Billion Purchase From Cargill," June 29, 1998. Accessed at URL: *http://interactive.wsj.com*, June 29, 1998.

Wann, J.J., and R. J. Sexton. "Imperfect Competition in Multiproduct Food Industries With Application to Pear Processing." *American Journal of Agricultural Economics* (1992): 980-90.

Williamson, O.E. "Economies as an Antitrust Defense: The Welfare Tradeoff. *American Economic Review* (58)(1968):18-36.

Zeneca Agrochemicals. "Plant Biotechnology." Accessed at URL: *http://www.zeneca.com/page.asp?section=research&sub=biotech*, June 6, 2000.