

5.2 Agricultural Research and Development

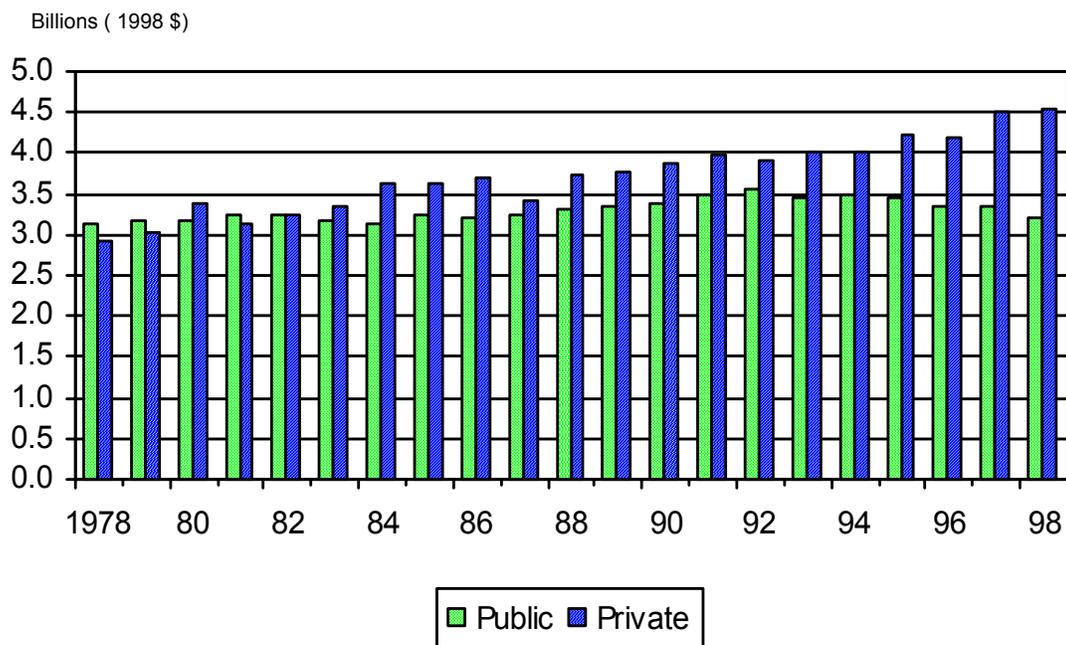
Public and private efforts in research and technology development have been the foundation of impressive productivity gains in the agricultural sector. Over the past few decades, there have been many changes affecting the research system. Advances in the biological sciences, such as recombinant DNA technology, have expanded the opportunities to develop new technology for both the public and private sectors. Legislation that strengthened intellectual property protection for biological inventions and allowed the patenting and licensing of public-sector innovations has further changed the research landscape. These new institutional arrangements have fostered public and private collaboration in research. (Note: The use of commercial or trade names does not imply approval by USDA or ERS.)

<i>Contents</i>	<i>Page</i>
<i>Public Sector Research and Development</i>	<i>4</i>
<i>Private Industry Research and Development</i>	<i>8</i>
<i>Biological Innovations and Crop Development</i>	<i>9</i>
<i>Role of Intellectual Property Rights</i>	<i>12</i>
<i>Globalization of Markets</i>	<i>16</i>
<i>Public and Private Collaboration in Agricultural Research</i>	<i>16</i>
<i>Technology Transfer Mechanisms</i>	<i>17</i>
<i>Research Consortium Model of Technology Transfer</i>	<i>19</i>
<i>Cooperative Efforts in Plant Genomics</i>	<i>20</i>
<i>Changing Industry Structure and R&D</i>	<i>21</i>
<i>References</i>	<i>24</i>

Unprecedented growth in agricultural productivity over the past century can be attributed largely to investments in agricultural research and technology development (see chapter 5.1, [Agricultural Productivity](#)). Many developments, including genetic improvements in crops, more efficient agricultural machinery, agricultural chemicals and fertilizers, and changes in farm management techniques, have transformed the agricultural production system. These developments have translated into an abundant and affordable food supply for consumers. Most early productivity gains can be traced directly to economic conditions that induced technology development to substitute increasingly expensive resources with relatively less expensive ones. One example is the development of farm machinery to offset increasing labor costs. Currently, changing societal demands are driving the development of new technology. These include technologies that provide safer, healthier, and more convenient foods; conserve natural resources and protect the environment; and consider ethics such as animal welfare and social justice (Fuglie et al., 1996)

Two forces guide technological development. The first is “demand-pull,” where the needs of the marketplace and the public create the demand for a product or technology. Government policies such as environmental regulation can also boost demand-pull forces to encourage the development of environmentally benign technologies, for example. Both public- and private-sector scientists, inventors, and entrepreneurs often seek to meet this demand. The second force is “supply-push.” Here, the impetus for development comes from scientists and inventors who find a new and valuable technology. This technology can then be introduced into the marketplace. Government policies can also foster supply-push forces for desirable technologies. These policies include supporting research and development and technology transfer activities. Both forces (singly and together) produce important and useful technologies.

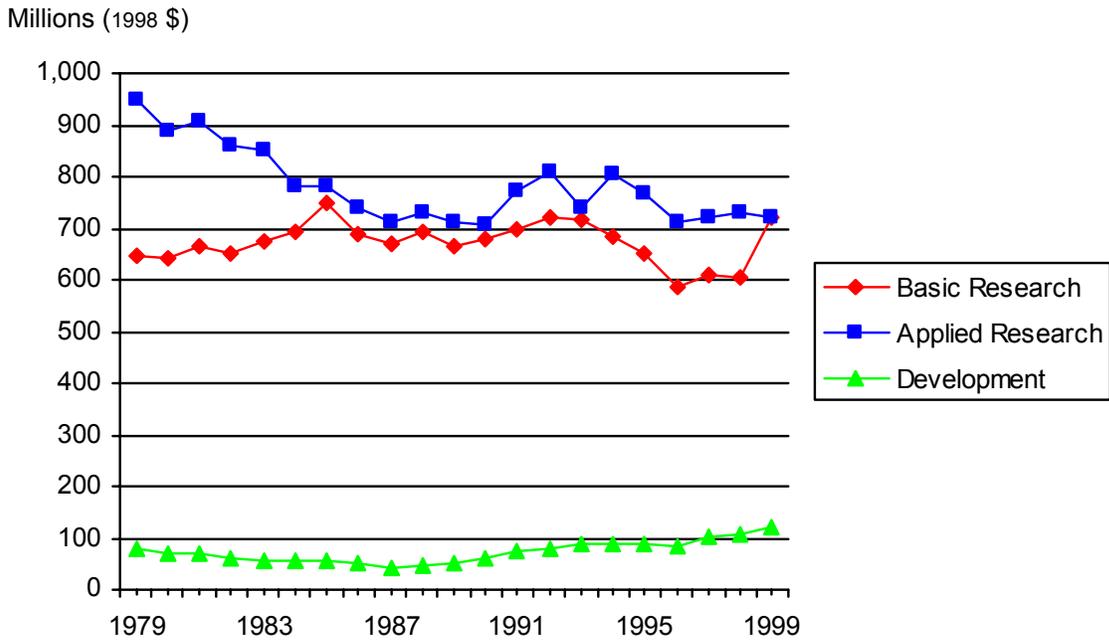
Figure 5.2.1-Agricultural research funding, 1978-1998



The public sector and private industry are the primary contributors to agricultural research, but their respective roles in research have undergone significant changes. Until recently, the public sector was the primary supporter and conductor of agricultural research. Now, the private sector plays a more significant role in terms of funding the development of new agricultural technologies. Private-sector spending for food and agricultural research now exceeds agricultural research expenditures by the public sector (Fuglie et al., 1996; Huffman and Evenson, 1993; Klotz et al., 1995; and Pray, 1993). Private-sector agricultural research expenditures are estimated to have increased from \$2.9 billion in 1978 to almost \$4.6 billion in 1998 (figure 5.2.1) (Klotz et al., 1995). Public-sector expenditures have remained largely stagnant and were about \$3.2 billion in both 1978 and 1998.

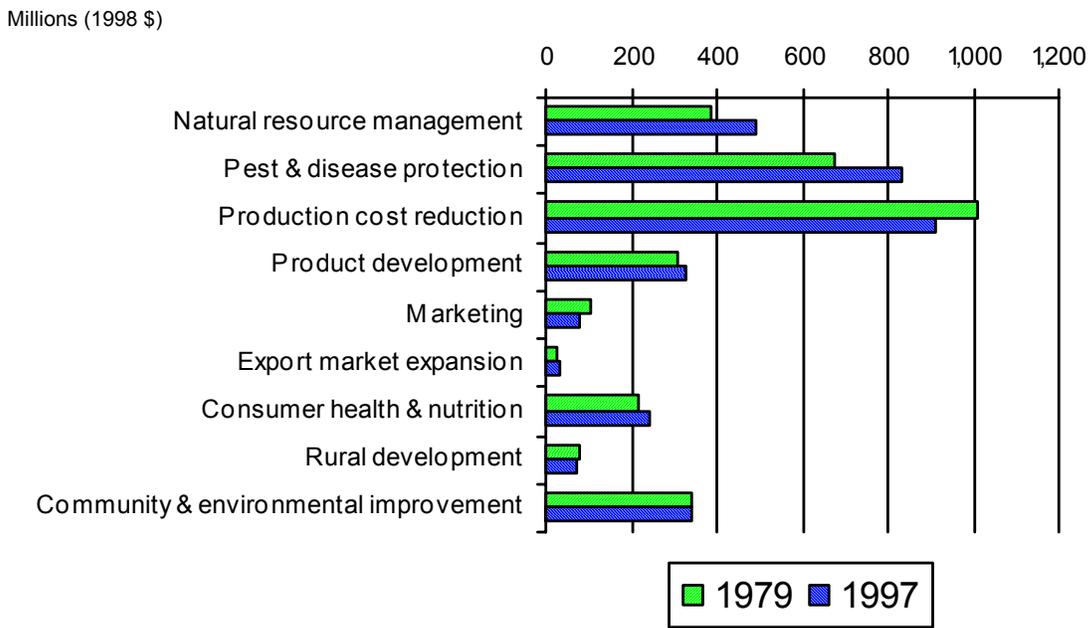
Public-sector and private industry research also differ in focus. Public scientists tend to conduct more basic or fundamental research, which seeks a fuller understanding of phenomena without specific applications to products or processes. This basic research is the foundation for all other research efforts and outcomes. Approximately 44 percent of USDA research funds were allocated to basic research in 1999 (figure 5.2.2), which is estimated to have a higher social rate of return than applied research. While the payoff to society of investing in basic research is high, the results of such research generally cannot be appropriated. The gains benefit society as whole, and therefore the private sector has little market incentive to conduct basic or pre-technology research. Over the last 20 years, USDA funds devoted to basic research have increased, perhaps in response to expanding private-sector investments. The private sector tends to conduct more applied research and to undertake more developmental efforts than the public sector, focusing more on bringing products to the marketplace. One study by the Agricultural Research Institute (1985), while a bit dated, found that only 15 percent of private-sector funds were allocated to basic research. This probably has changed given recent developments in the biological sciences (e.g., in the area of genomics, an area generally considered to be basic research). Much depends on the how basic research is defined. Traditionally, any research with commercial

Figure 5.2.2--Federal Obligations for Agricultural R&D



Source: USDA, ERS, based on data from the National Science Foundation.

Figure 5.2.3--Allocation of public funds for agricultural research, 1979 and 1997



Source: USDA, Current Research Information System.

application was not considered to be basic, but the divisions between basic and applied research are increasingly blurred. Nonetheless, there are believed to be some increases in private-sector involvement in more long-term, “basic” research with an application in mind.

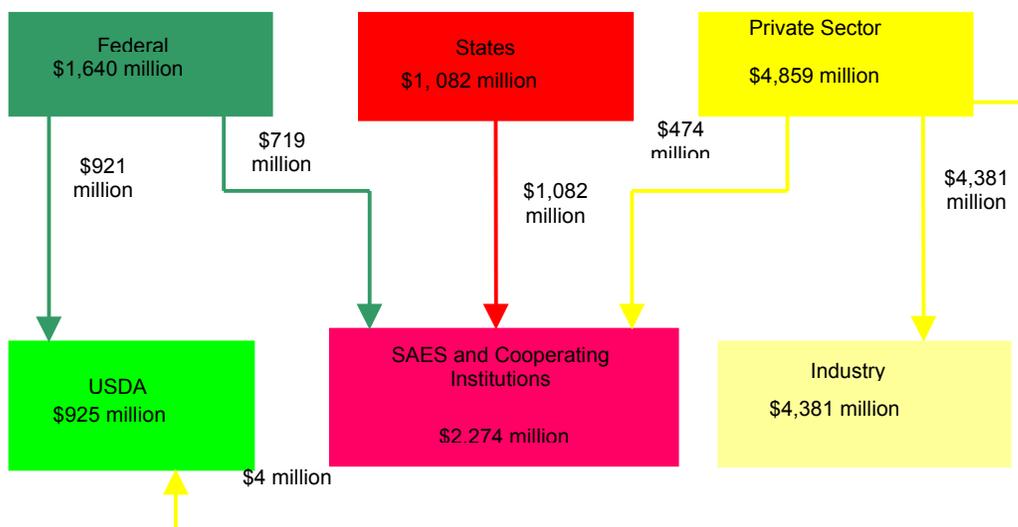
Differences between research focus (basic versus applied) in the public and private sectors are observed specifically in agricultural inputs research, such as plant breeding. A comprehensive survey of public and private plant breeding research found that USDA’s Agricultural Research Service (ARS) concentrates most of its research on long-term pre-breeding activities, while the private sector devotes most of its resources to short-term varietal development (Frey, 1996). About 80 percent of private-sector plant breeding funds were allocated to cultivar development. ARS has terminated much of its research on variety development, preferring to concentrate on areas of research not pursued as intensely by the private sector. ARS does, however, remain active in the development of “minor crops,” such as vegetables, berries, stone fruits, catfish, and regional crops such as forage soybeans. These crops often lack adequate private breeding because they have relatively small sales volumes and do not justify private-sector investment.

There is also limited incentive for the private sector to conduct research that improves government or consumer decisionmaking, such as the relationship of agriculture to natural resources, global climate change, ecosystem loss, human nutrition and diet, and food safety (for the distribution of public-sector research, see [figure 5.2.3](#)). Private research focuses on bringing products to market, and generally must contribute to the overall profitability of the firm. More than 40 percent of private agricultural R&D expenditures are for product development research (Agricultural Research Institute, 1985). Again, although this study is fairly old, it does give an indication of the differences between the public and private sectors. In contrast, about 7 percent of USDA R&D expenditures are applied to product development activities (National Science Foundation, 2000). Therefore, a combination of public- and private-sector research is important in developing new agricultural technologies.

Public-Sector Research and Development

Public agricultural research involves a unique partnership between the Federal Government (chiefly USDA) and the States. USDA, the State Agricultural Experiment Stations (SAES), and cooperating institutions together conduct over \$3 billion worth of research (USDA Current Research Information System, 2000). USDA conducts about \$925 million worth of research in-house through its research agencies, primarily the Agricultural Research Service, the Forest Service, and the Economic Research Service. The SAES and cooperating institutions conduct about \$2.3 billion worth of research, giving them the largest share of agricultural research in the public sector. The Federal Government pays for about \$1.6 billion worth of total public research and the States about \$1 billion, with additional funds supplied by the private sector ([figure 5.2.4](#)). Historically, USDA has used several funding instruments to provide research money to States. One instrument is *formula funds*, allocated in block form to States based on rural population and number of farms. Research administrators have numerous options in how they distribute formula funds. *National Research Initiative (NRI) competitive grants* are allotted by peer review panels. *Special grants* are specifically awarded by Congress, whereas other USDA *contracts, grants, and cooperative agreements* are awarded at the discretion of USDA research agencies to carry out their work. (See Fuglie et al., 1996, for a more detailed description of these mechanisms.) Between 1983 and 1997, competitive and special grants have grown in importance as funding sources by 16 percent and 14 percent, respectively. While certain data for 1998, 1999, and 2000 are available, data for 1997 are used because they are the most recent year to include Forest Service expenditures, and the most recent year that can be readily

Figure 5.2.4 - Funding sources and flows for agricultural research, 1997



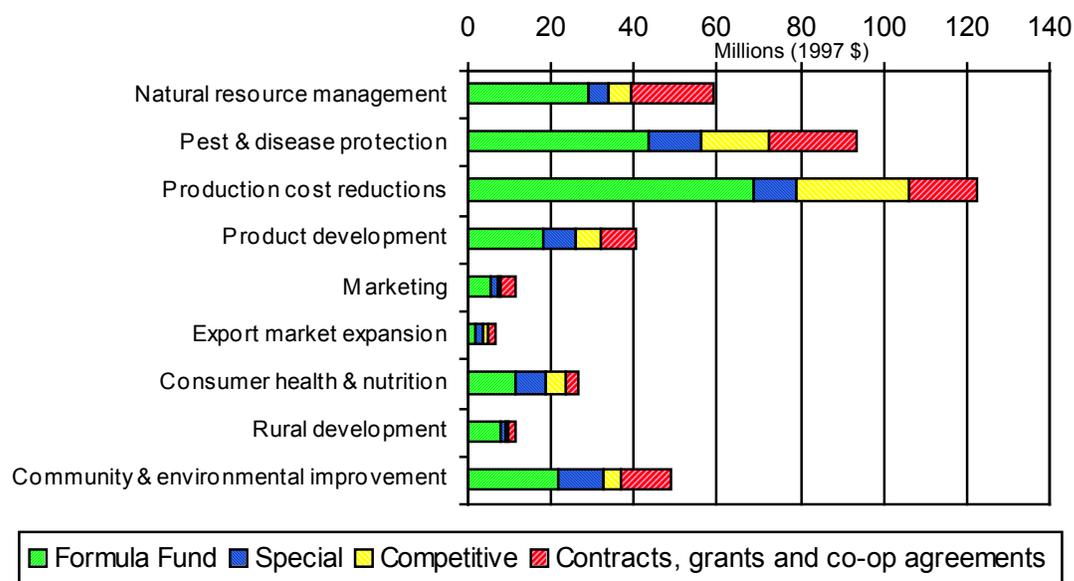
Source: ERS, USDA based on USDA CRIS and Klotz et al. (1995)

compared with research expenditures prior to 1993. Formula funds declined from 74 percent of USDA funds (granted to the States through the above four instruments) in 1983 to about 49 percent in 1997. Funds for cooperative agreements increased to around 21 percent.

Because State-level research is the primary form of public R&D, there is considerable discussion about whether research should be funded with formula funds (or “block” grants) or on a project-specific basis (such as with special grants, competitive grants, or cooperative agreements that specify the research to be funded). Another issue is the process by which grants are allocated. Some funds (particularly formula funds) are allocated primarily by research administrators, others by Congress, and yet others competitively, through peer review. Traditionally, State-level research was funded through formula funds. Generally, State-level institutions have used a decentralized research approach that focused on geographically specific applied research. In the early 1970s, some critics contended that agricultural research had become too applied, moving too far from basic biological research (National Research Council, 1972). These critics called for greater peer review and competition for research funds, as well as a shift to more basic biological research and away from commodity-specific applied research. This shift included moving from formula funding to competitive grants (National Research Council, 1972). Behind these recommendations was the belief that biotechnological breakthroughs based on basic biological research were needed to maintain historical rates of agricultural productivity growth. Continuing to rely on formula funds, which fostered geographically specific commodity research, might not generate the needed breakthroughs.

These recommendations have themselves met with criticism. Buttel (1986) warned that the shift toward competitive grants might narrow the focus of agricultural research in two ways. First, the research problem areas might be narrowed and public-sector research would then be redirected toward the profit-maximizing goals of private biotechnology firms. The public sector would move away from emphasizing research on public goods,

Figure 5.2.5-USDA funds to SAES and other institutions, 1997



Source: USDA, ERS, based on Current Research Information System data.

which would reduce the value of public research to society as a whole. While some types of applied research, such as natural resource and environmental research, have a high value to society, they seldom are profit-maximizing. Second, declines in formula funding could possibly skew the geographic distribution of USDA research funds granted to individual States. States with strong programs in molecular and cellular biology would fare well under the new system, but Experiment Stations further from the frontier of biological research might be starved for funds and unable to address regional problems.

Different instruments generally have focused on different research goals (figure 5.2.5). For example, competitive grants initially centered on two goals—control of pests/diseases and reduced production costs. While the NRI competitive grants program has evolved and broadened somewhat over time, these still remain the top research priorities. Special grants and cooperative agreements are used to fund a greater portion of research on natural resource, environmental, and rural development issues. Special grants also focus more resources on human health and nutrition. Formula funds are spread most evenly across the categories.

The different funding instruments also have different degrees of concentration among the various States. Because environmental protection and resource management are often site-specific, using instruments that concentrate funding among fewer States may leave certain States without adequate funds to conduct research effectively and meet their needs. However, concentrating funds in States with strong research programs could increase the likelihood of finding solutions to various resource and environmental problems. In evaluating the degree to which funding instruments affect the geographic distribution of funds across States, Day-Rubenstein et al. (2000) showed that (1) formula funds are the most evenly distributed across States, (2) competitive grants are the most unevenly distributed, and (3) special grants and cooperative agreements lie somewhere in between.

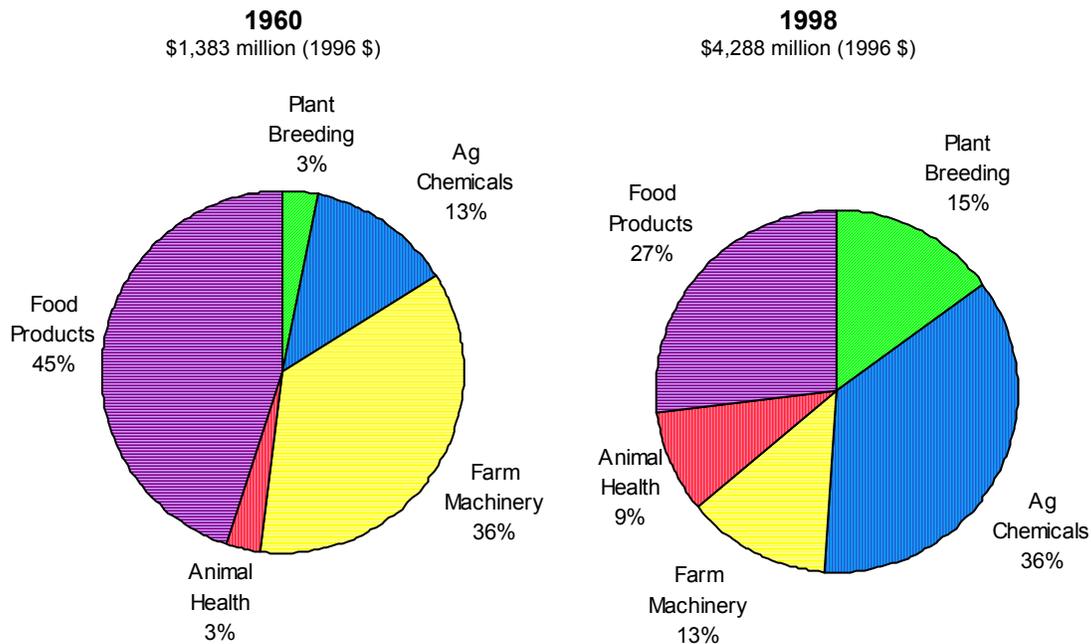
Therefore, competitive grants (as predicted by Buttel) are concentrated among fewer SAES and are used to fund a narrower set of research objectives than other instruments. However, the emphasis on competitive grants has

not significantly shifted the geographical or topical distribution of total USDA funding of SAES. Distributional curves for overall funds indicate little change from 1983 to 1997. Furthermore, while the distribution of research funds among research categories is different for formula funds and competitive grants, total USDA funding closely matches that of formula funds. There are two reasons for this. First, competitive grants comprise only 16 percent of USDA funds to SAES and cooperating institutions (USDA, CRIS, 1998). Second, special grants and cooperative agreements counterbalance the effect of competitive grants (which themselves have become somewhat less concentrated among research goals, as noted earlier). Therefore, shifts in funding methods appear not to have greatly affected natural resource and environmental research at SAES and cooperating institutions thus far. However, a significant shift toward competitive grants has the potential to limit the traditional sources of funding for this research, unless allocation processes increase the priority of resource and environmental research.

In the past few years, new mechanisms have been emerging for funding agricultural research that may change some of these dynamics, such as the integrated research, education, and extension competitive grants program. One mechanism that is gaining rapidly in terms of funding is the Initiative for Future Agriculture and Food Systems (IFAFS). This mechanism is not unlike the NRI Competitive Grants, as grants are awarded competitively within specific areas. However, IFAFS grants are not limited to research. Extension and education activities are included, and multidisciplinary, multi-institution, and integrative projects are given priority. IFAFS addresses six mission areas: 1) genomics; 2) food safety, technology and nutrition; 3) new and alternative uses of agricultural products; 4) agricultural biotechnology; 5) natural resource management, including precision agriculture; and 6) farm efficiency and competitiveness. The IFAFS program is so new that comparisons to the traditional funding mechanisms are not possible. The incorporation of education and extension activities also complicates comparisons. A few general observations can be made, though. First, these grants tend to be much larger, and are awarded to fewer recipients than NRI grants. Second, the food safety/nutrition and natural resource mission areas suggest that competitive grants can be used to fund these areas. However, it is too soon to assess the impact of such changes, or even the types of research being funded within these mission areas.

Natural resource and environmental issues remain a particular concern for research administrators, because they have both national and local dimensions. Certain issues, such as water quality and use, have critical regional aspects (see [AREI chapter 2](#)). Likewise, management of agricultural nutrients can vary greatly by region and industry. Yet, some technologies, for example certain new manure management techniques, could be used by producers around the country. Overall, research on natural resources and the environment accounted for about 21 percent of total public agricultural funds in 1997. For 2000, the most recent year for which data are available, natural resources and environmental research accounted for about 18 percent of total public agricultural spending. However, this does not include Forest Service expenditures, biasing the results downward. The share of research resources devoted to natural resources and the environment is slightly higher among Federal-level scientists, about 27 percent of all scientist-years, than among non-Federal scientists, who devote 20 percent of all scientist-years (USDA, 1997). We note that using a different definition of natural resources research can alter results somewhat, particularly including certain types of forestry research. Definitional issues are also important because many types of research that can benefit the environment may not be considered “natural resource and environmental research” by some scientists who classify their work. For example, plant breeders may produce resistant varieties that require less agricultural chemicals, which in turn improves water quality, but the research is not classified as “environmental.” Likewise, mechanical structures that reduce nutrient runoff are often regarded primarily as engineering or equipment research. Yet, this research can have significant benefits for the

Figure 5.2.6-Private agricultural research by industry, 1960 and 1998



Source: USDA, ERS, based on Klotz, Fuglie, and Pray, 1995.

environment. Ideally, resource protection is a goal for scientists working in all related areas. As USDA moves towards this goal, difficulties documenting such improvements should not be taken as an indication that progress is lacking.

Private Industry Research and Development

Private industry has been playing a more important role in agricultural research, not only boosting research investments but also expanding into new areas of research. Private industry expenditures on agricultural research increased 50 percent in real terms between 1978 and 1998 (figure 5.2.1). Furthermore, the proportion of total private-sector investments focusing on biological and chemical technologies, such as agricultural chemicals, plant breeding, and animal health, has increased in recent years. In 1998, 60 percent of private-sector agricultural research expenditures were allocated to these technologies, compared with only 19 percent in 1960 (figure 5.2.6). In earlier years, the public sector conducted more yield-increasing agricultural research, especially in plant breeding, whereas the private sector focused more on agricultural machinery and “downstream” technologies, such as food processing. The proportion of funds allocated to agricultural machinery and food and kindred products decreased by half from 81 percent in 1960 to 40 percent in 1998.

Changing private-sector efforts in technology development have been stimulated by several factors, including new technological opportunities motivated by advances in the biological sciences, expanded intellectual property rights (IPRs) protection for biological innovations, new legislation fostering collaboration with the public sector, and the globalization of markets.

Biological Innovations and Crop Development

Public investments in basic research created new technological opportunities for private research. Scientific breakthroughs, such as the development of biotechnology applications, help facilitate agricultural research. For example, gene transfer technologies enable researchers to tailor crops for specific uses, such as crops resistant to disease, pests, herbicides, or harsh environmental conditions, and crops with increased nutrition or improved food processing traits. Furthermore, biotechnology has blurred the distinction between basic and applied research and the respective roles of the public and private sectors. The private sector is conducting more research that would have been considered basic in the past, especially in genomics (i.e., the identification and mapping of genes, as well as determining gene function in living organisms), although some would argue that private efforts in genomics have an applied focus.

Many technological milestones, beginning with Mendel's theories explaining the inheritance of biological characteristics in plants, led to genetic improvements in crops that contributed to agricultural productivity growth. One milestone was the development and rapid adoption of hybrid crops in the United States in the 1930s, especially corn. Hybridization refers to the process of crossing two unrelated inbred lines to create a seed variety with greater yield potential than either of the parental varieties. The adoption of hybrid crops had a dramatic impact on the development of new plant varieties, especially in the private sector. Hybrid crops provide an inherent form of intellectual property protection because the yield potential of progeny diminishes with each succeeding generation of seed. Another technological advancement, which spurred the Green Revolution of the 1960s and 1970s, was the development and introduction of high-yielding crop varieties, predominantly wheat and rice, in developing countries. These modern grain varieties were highly responsive to fertilizers and boosted world agricultural productivity.

More recently, scientific breakthroughs in the biological sciences have allowed scientists to make more precise changes at the molecular level, thereby expanding the opportunities to develop crops with desirable traits (Shoemaker, 2001). Modern biotechnology embodies a variety of techniques to achieve changes in plants, including *cell culture* and *genetic engineering*. Tissue *cell culture* helps to facilitate conventional plant breeding by reducing the time required to identify valuable traits. *Genetic engineering* is used to modify organisms by either enhancing or suppressing the performance of existing genes or transferring genetic information from one organism into a host organism.

Biotechnology has made it more profitable for private industry to develop new crop varieties, expanding the production opportunities for farmers. Crops are being developed with improved production (input) or quality (output) traits. The first wave of new crop varieties available commercially were those with input traits, such as pest- or herbicide-resistant crops. Crops with these input traits offer certain farmers, who experience significant pest pressures, increased flexibility in managing pests. Also, farmers are able to use more effective herbicides and can reduce pesticide applications, thereby potentially increasing yields and reducing agricultural pesticide costs. The most common genetically modified crops available to farmers are herbicide-tolerant corn, cotton, and soybeans (mostly resistant to the glyphosate-based herbicide RoundupTM), and Bt corn and cotton. Crops carrying herbicide-tolerant genes were developed to survive certain herbicides that previously would have destroyed the crop along with the targeted weeds, allowing farmers to use a broader variety of herbicides to control weeds. Bt crops contain a gene from the soil bacterium *Bacillus thuringiensis*. Bt is toxic when ingested by certain insects. Crops expressing the Bt gene are able to produce this toxin, thereby providing protection throughout the entire plant. Bt cotton is primarily effective in controlling the tobacco budworm, the bollworm, and the pink bollworm. Bt corn primarily provides protection against the European corn borer.

New crop varieties with herbicide-tolerant and Bt traits are being adopted at an astonishing rate. Since commercial introduction of these varieties only a few years ago, adoption of corn varieties with these traits has increased dramatically from around 4 percent of planted corn acres in 1996 to slightly over 26 percent in 2001 (table 5.2.1). Likewise, the adoption of herbicide-tolerant and Bt cotton has increased from 17 percent of cotton acres to 69 percent during those years. Finally, adoption of herbicide-tolerant soybeans increased from 7.4 percent of soybean acres in 1996 to about 54 percent in 2000.

The next generation of new crop varieties heading to the marketplace is expected to have quality-enhanced traits. Plants are being developed with increased nutritional and health properties (e.g., increased vitamin content, oils with less saturated fats, and increased protein) and increased feed and food processing qualities (e.g., altered oil profiles, increased solids and protein content). Crops containing several traits stacked in a single variety will become more common. Already, crops are being planted with both the herbicide-tolerant and Bt toxin traits. Crops of the future may also be engineered to contain medicinal properties or to produce pharmaceuticals.

Table 5.2.1—Percent of crop acres planted to herbicide-tolerant and Bt crop varieties, 1996-2001

	1996	1997	1998	1999	2000	2001
Corn: ¹						
Bt corn	1.4	7.6	19.1	25.9	18	18
Herbicide-tolerant corn ²	3	4.3	9	8	6	7
Stacked	0	na	na	na	1	1
Soybeans:						
Herbicide-tolerant soybeans	7.4	17	44.2	55.8	54	64
Cotton: ¹						
Bt cotton	14.6	15	16.8	32.3	15	13
Herbicide-tolerant cotton	2.2	10.5	26.2	42.1	26	32
Stacked	0	na	na	na	20	24

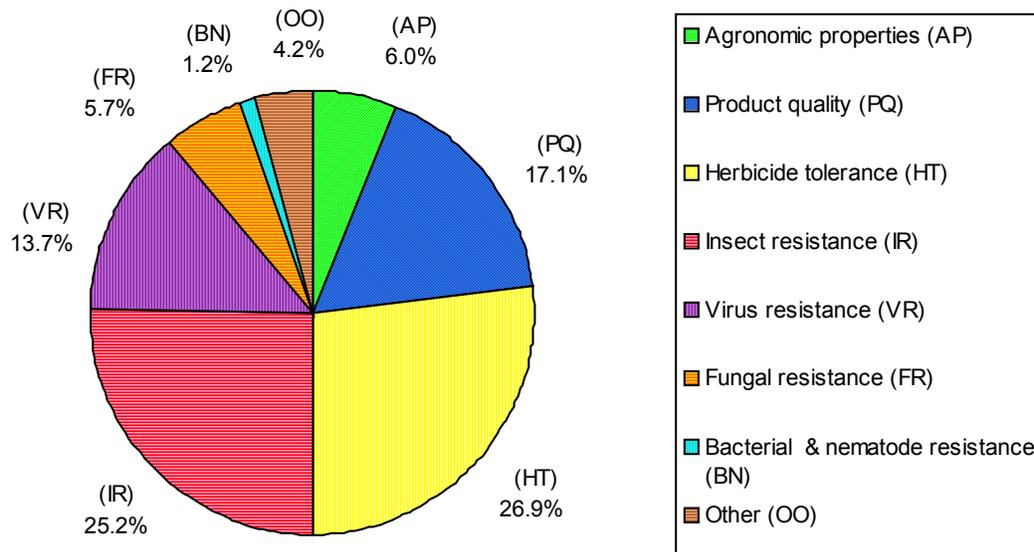
¹ Estimates for herbicide-tolerant and Bt corn and cotton for the years 1997 to 1999 includes stacked varieties (crops containing both Bt and herbicide-tolerant genes). This suggests that for those years the percent of acres devoted to stacked varieties is included in both the Bt and herbicide-tolerant crop estimates. For the years 2000 and 2001, the percent of acres in stacked varieties was known.

² Includes seeds obtained by traditional breeding, but developed using biotechnology techniques that were used to identify the herbicide-tolerant genes.

na = Not available.

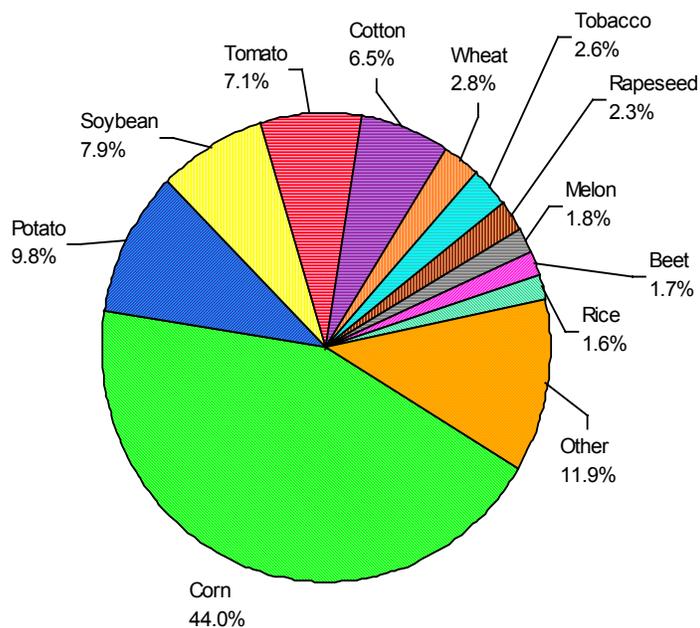
Source: ERS, USDA; based on ERS and NASS data.

Figure 5.2.7--APHIS environmental release permits by phenotype, 1987-2001¹



Source: USDA, ERS, based on Animal and Plant Health Inspection Service data.
¹ Through May 2001.

Figure 5.2.8--APHIS environmental release permits by crop or organism, 1987-2001¹



Source: USDA, ERS, based on Animal and Plant Health Inspection Service data.
¹ Through May 2001.

Environmental release (field test) permits from the USDA Animal and Plant Health Inspection Service (APHIS) provide an indication of the types of genetically modified crops that are being developed and may be marketed in the near future. [Figure 5.2.7](#) depicts field tests of the most common phenotypes (characteristics). Almost 73 percent of the environmental release permits were issued for plants with input traits for pest management (that is, herbicide tolerance and insect, virus, fungus and disease resistance). Seventeen percent of the crops tested were developed to enhance product quality. The output traits incorporated into the plants included changes in nitrogen and carbohydrate metabolism, oil profile, amino acid content, protein and nutritional quality, fruit ripening, solids content, fruit sugar composition, and flavor. Slightly more than 10 percent of the crops receiving release permits had changed agronomic properties and other characteristics, such as male sterility, increased yield, environmental tolerance, the addition of marker genes, and the ability to produce novel proteins, antibodies, and pharmaceuticals. [Figure 5.2.8](#) displays the most common crops receiving environmental release permits. As shown, genetically modified corn received the most permits, about 44 percent, followed by potatoes (9.8 percent), soybeans (7.9 percent), and tomatoes (7.1 percent).

Although there may be benefits associated with the adoption of genetically modified crops, there are several environmental and health concerns as well. Environmental and health risks include insect resistance to Bt; the development of “super weeds” if genes from herbicide-tolerant crops are passed on to weedy relatives; the potential outcrossing of traits; the impacts on beneficial insect species; and the unintended introduction of allergens (Shoemaker, 2001). Several Federal agencies are responsible for regulating the environmental release and marketing of genetically modified organisms, including the USDA, the Environmental Protection Agency, and the Food and Drug Administration. Concerns about the environmental and health safety of genetically modified organisms have created controversy, especially with important trading partners such as Europe. Several countries require the segregation and labeling of foods and grains containing genetically modified organisms. As trade in genetically modified organisms is further inhibited, the high adoption rates so far witnessed in the United States may not be sustained in the future.

Role of Intellectual Property Rights

Besides scientific advancements, expanded IPRs for biological inventions and new plant varieties have stimulated private-sector plant breeding efforts over the past 30 years. IPRs have encouraged private research by allowing innovating firms to capture a greater share of the benefits from research.

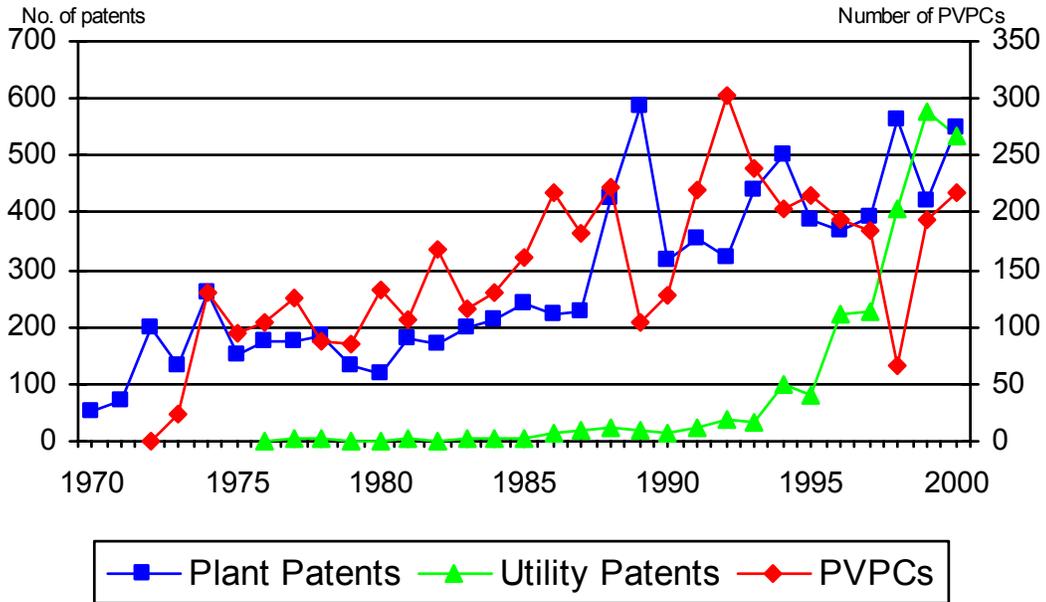
To “promote the progress of science and useful arts,” the Patent Act of 1790 was established and offered property rights protection to encourage inventors to publicly disclose their inventions. The patent system provided manufacturers and inventors incentives to develop new industrial inputs and consumer products. However, the Act's principal contribution to agriculture was the protection offered for mechanical and chemical inventions. Biological inventions were considered products of nature and were not thought to be patentable. Therefore, appropriating the gains from technological advances in plant breeding was difficult. Simply possessing a biological invention generally provided the means to reproduce it. Producers of a new plant or animal could profit from their invention only once, even though it could be used for generations. The development of hybrid seed technologies in the 1920s changed this because hybrid crops reproduce at decreasing yields, requiring farmers to repurchase seed every year. Private-sector plant breeding efforts then focused on hybrid seeds.

The extension of IPRs to new plant varieties and biological inventions, including biotechnologies, has further stimulated private companies to invest in plant breeding. The Plant Patent Act of 1930 and the Plant Variety

Protection Act (PVPA) of 1970 established plant breeders' rights for new plants and plant varieties (see box, "Intellectual Property Rights"). In 1980, a Supreme Court decision (*Diamond v. Chakrabarty*) established the use of Utility Patents for biological inventions, specifically microorganisms. Several recent decisions by the Patent and Trademark Office broadened the use of Utility Patents for plants (in ex parte Hibberd in 1985) and animals (in ex parte Allen in 1987). As a result, in 1998 dollars, private-sector research expenditures for plant breeding increased from about \$40 million in 1960 to \$670 million in 1998 (Klotz et al., 1995). Nearly 70 percent of private-sector plant breeding research expenditures in 1989 was for corn, vegetables, and soybeans (Fuglie et al., 1995).

The number of Plant Patents, Plant Variety Protection Certificates (PVPCs), and Utility Patents issued over the last 30 years has risen (figure 5.2.9). The PVPA stimulated the development of new field crop varieties. By the end of 2000, 4,377 PVPCs had been issued for new crop varieties (figure 5.2.10; table 5.2.2). The number of PVPCs issued for new plant varieties climbed from a total of 153 in 1971-74 to 992 in 1991-94. There was a significant drop to 663 PVPCs issued between 1997 and 2000 (due mostly to administrative processing delays).

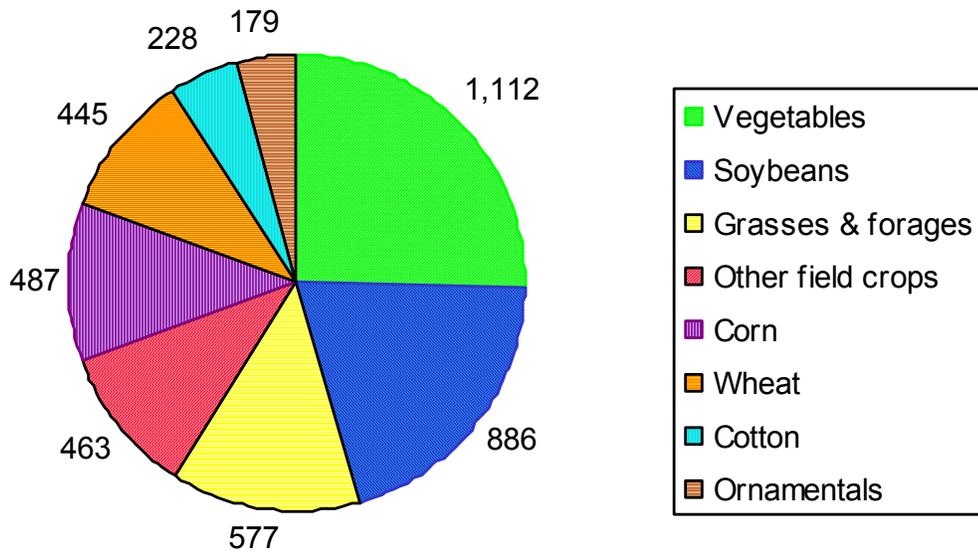
Figure 5.2.9--Intellectual property rights issued for new plant varieties, 1970-2000



Source: USDA, ERS, based on data from the Agricultural Marketing Service and the Patent and Trademark Office.

Figure 5.2.10--Use of plant variety protection certificates issued in 1971-2000 (4,377 in total)

Million acres



Source: USDA, ERS, based on Fuglie et al., 1996, and the Agricultural Marketing Service, USDA, PVPC database.

Intellectual Property Rights for New Plant Varieties and Biological Inventions

Plant Patents

The Plant Patent Act amended the Patent Act of 1970 and provided plant breeders protection for 17 years for asexually reproduced plant varieties. Specifically, these include fruits, nuts, and ornamentals, but exclude tuber crops. As with Utility Patents, the Patent and Trademark Office (PTO) administers Plant Patents.

Plant Variety Protection Certificates (PVPCs)

The Plant Variety Protection Act of 1970 established plant breeders' rights for new plant varieties produced from seed, particularly field crops. PVPCs are awarded for new plant varieties determined to be distinct, uniform, and stable. A 1980 amendment extended coverage to vegetables.

Amendments in 1994 restricted farmer rights to resell protected seed, provided protection for tuber crops, and extended property rights protection from 17 to 20 years. A provision was also added to protect plant breeders from cosmetic infringements or superficial changes in the appearance of protected plant varieties that do not increase yield or value. A 1995 Supreme Court decision, *Asgrow v. Winterboer*, further restricted farmer rights to resell protected seed. USDA administers PVPCs.

Utility Patents

Utility Patents are administered by the PTO of the U.S. Department of Commerce and grant ownership of new inputs and products for 20 years. Biological inventions were not thought to be patentable until 1980 when a decision by the Supreme Court in *Diamond v. Chakrabarty* authorized the use of Utility Patents for microorganisms. In 1985, the PTO's Board of Appeals and Interferences approved the use of Utility Patents for new plants or plant parts, and in 1987, for animals. Although Utility Patents offer owners the strongest form of protection for new plant varieties, they are often more difficult to acquire than other options for obtaining plant breeders' rights.

Source: USDA, ERS, based on Fuglie et al., 1996.

New soybean, corn, and vegetable varieties accounted for 57 percent of total PVPCs awarded. The private sector owns approximately 87 percent of the total PVPCs issued (Fuglie et al., 1995). Utility Patents are the most difficult to obtain and have been awarded primarily for new biotechnology innovations, such as genetically engineered varieties. From 1976 to the end of 2000, 2,760 Utility Patents had been issued for multicellular organisms (Patent and Trademark Office, 2001). Of these, 2,364 were issued for new plants or plant parts and 396 were issued for animals. As with PVPCs, most Utility Patents are awarded to the private sector.

International organizations have attempted to harmonize intellectual property protection among member states to facilitate trade and technology development. The International Union for the Protection of New Varieties of Plants was established in Paris in 1961 (UPOV, 1999). The purpose of UPOV is to promote uniformity in domestic intellectual property laws for new plant varieties among member states. Plant breeders from member states seek intellectual property protection in other member countries, thereby increasing the incentive to develop new crop varieties. The PVPA in the United States conforms to the UPOV agreement. The World Intellectual Property Organization (WIPO) is a United Nations agency based in Geneva, Switzerland. It is responsible for promoting the protection of intellectual property among cooperating states and administering

various multilateral treaties related to intellectual property (WIPO, 1999). WIPO provides a method for

Table 5.2.2—Use of plant variety protection certificates issued in 1971-2000

Crop	1971-94	1995	1996	1997	1998	1999	2000	Total
Number of certificates issued								
Vegetables	885	33	18	61	15	44	56	1,112
Soybeans	661	73	38	28	14	20	52	886
Grasses and forages	418	29	23	13	10	46	38	577
Other field crops	356	24	25	21	2	17	18	463
Corn	322	22	39	38	22	26	18	487
Wheat	314	26	34	11	3	30	27	445
Cotton	211	6	7	4	0	0	0	228
Ornamentals	139	2	9	8	1	11	9	179
Total	3,306	215	193	184	67	194	218	4,377

Source: USDA, ERS, based on Fuglie et al., 1996, and the Agricultural Marketing Service, USDA, PVPC database.

inventors to simultaneously seek patents on an innovation in the United States and selected participating countries. The TRIPs (Trade Related Aspects in Intellectual Property Rights) agreement of the World Trade Organization (WTO) also attempts to harmonize patent laws among member countries to promote free trade (WTO, 1999).

IPRs have encouraged the private sector to develop new agricultural technologies by enabling firms to capture a greater share of the commercial value of their inventions. However, IPRs remain controversial since they can involve tradeoffs between competing objectives. For example, the increased market power afforded to firms holding IPRs could result in higher seed prices. Furthermore, scientific progress could be hindered if IPRs slow the exchange of information on new technologies. However, unlike the use of trade secrets, an advantage of the IPR protection process is that discoveries are made publicly available, thereby enabling the disclosure of new technology. Furthermore, policies such as cooperative research efforts between the public and private sectors and the development of technology markets through patent licensing can facilitate the transfer of technologies or information.

Globalization of Markets

Globalization of agricultural input markets resulting from increased global demand for agricultural products and falling barriers to trade have provided opportunities for private industry to expand sales and increase research efforts in other countries. Pray and Fuglie (2000) indicate that there is an increasing global market for agricultural inputs, as evidenced by the 2.23-percent real annual growth in U.S. exports of these inputs since 1983. Foreign market and investment opportunities have also been broadened by trade agreements, such as the General Agreements on Tariffs and Trade and the North American Free Trade Agreement. Evidence shows that research investment activities by multinational firms in other countries have increased, partially as a result of these agreements. The number of foreign-owned patents for agricultural technologies also has been expanding in many countries (Pray and Fuglie, 2000).

Public and Private Collaboration in Agricultural Research

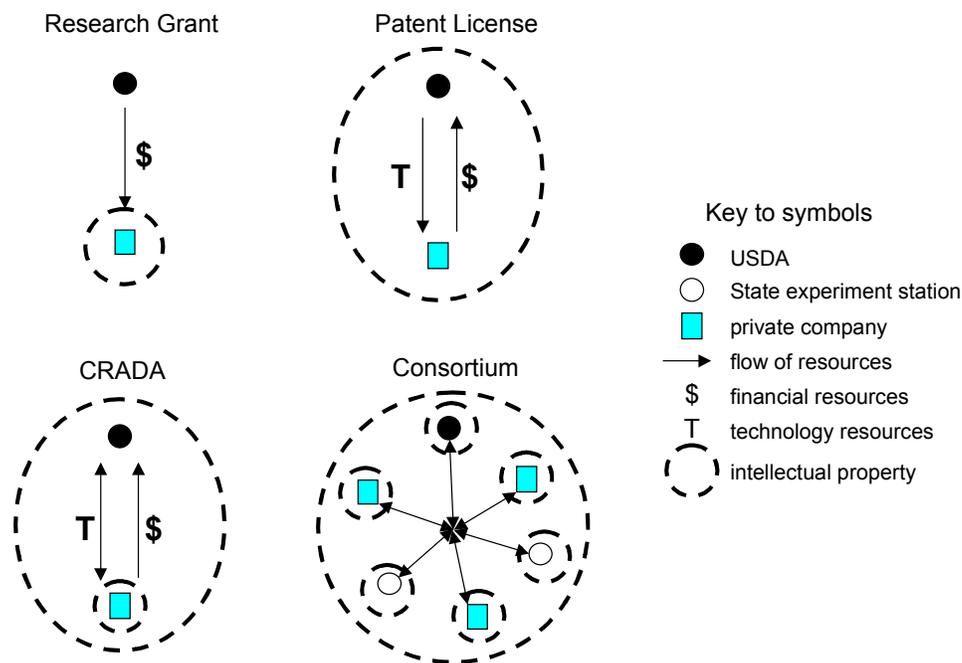
Another change affecting technology development in the agricultural input industry has been the growth of collaborations between the public and private sectors. Before 1980, U.S. patent policy limited collaboration,

since the Federal Government assumed ownership of any inventions that resulted from federally funded research. The Government Patent Policy Act of 1980 (Bayh-Dole Act) granted institutions "certainty of title" for inventions resulting from federally funded research. This Act also allowed Federal laboratories to issue exclusive licenses for patents of their inventions. Previously, the only licenses granted were nonexclusive or open, which are often less attractive to firms. Other legislation sought to promote greater collaboration and exchange between Federal laboratories and the private sector. The 1980 Stevenson-Wydler Technology Innovation Act mandated that each Federal research agency develop specific mechanisms for disseminating Government innovations. The 1986 Technology Transfer Act gave Government agencies additional means to foster technology transfer by authorizing Cooperative Research and Development Agreements (CRADAs). Previously, Federal researchers were not permitted to collaborate directly with the private sector (Congressional Research Service, 1991).

Technology Transfer Mechanisms

Valuable technologies developed in the public sector are not automatically marketed by the private sector. For this reason, USDA and the SAES work to bring useful technologies to the agricultural sector. Both groups transfer a variety of innovations, both shielded and unshielded (i.e., protected by IPRs or not). The Bayh-Dole and Technology Transfer Acts greatly increased the ability of federally funded institutions to transfer successful technologies to the marketplace. The public sector can now use several methods to disseminate agricultural research results (figure 5.2.11). CRADAs are public-private agreements usually between the Federal Government and private industry. Using CRADAs, the Government works cooperatively with one or more outside institutions to develop new technologies. This mechanism allows USDA to transfer technologies at various stages of development, research results, and scientific resources (though not money) to industry through joint research ventures. The cooperating institution can provide any of these resources, and can also transfer money to the Federal agency as part of a research agreement. Cooperating institutions have the first right to negotiate for an exclusive license on any patented invention resulting from the agreement (ARS, 1992). USDA has established more than 1,000 CRADAs (Ruff, 2001, see also table 5.2.3). USDA provides basic scientific knowledge often unavailable to private industry, and receives insight into industry needs and resources, as well as shared fees and royalties. SAES also establish cooperative research agreements, although their structures can vary considerably.

Figure 5.2.11--Forms of Public-Private Research Collaboration & Technology Transfer



Patent licensing is another mechanism used by USDA, as well as by SAES. Public entities can patent inventions meeting PTO criteria. The institutions, such as USDA, can then grant an exclusive, limited exclusive, or nonexclusive license to a private company to use or market the invention. Exclusive or limited exclusive licensing of patents often provides incentives for a company to develop a technology. Before federally funded institutions were allowed to grant exclusive licenses, companies were often unwilling to make the investments necessary to bring these inventions to the marketplace (ARS, 1993). USDA maintains publicly accessible lists of patents available for licensing.

Two institutions are primarily responsible for bringing USDA inventions and knowledge to the private sector. The Agricultural Research Service (ARS) Office of Technology Transfer patents, licenses, and markets ARS technologies and negotiates CRADAs. To facilitate close cooperation between inventors and firms, ARS has patent advisors and technology transfer coordinators at laboratories throughout the country. A second related group, the Technology Transfer Information Center, provides informational support to ARS through the National Agricultural Library.

The center manages the information ARS needs to set priorities for research programs and to patent and license new inventions. Center staff assist ARS scientists by finding other relevant research results inside and outside the agricultural sector. The center also provides information to the public on ARS research and inventions. One product of the center, TEKTRAN, is an electronic database containing thousands of summaries of ARS research findings. The summaries include an interpretive summary in nonscientific language, a technical abstract, and information on the contact scientist.

Table 5.2.3—USDA technology transfer activities, 1987-2000

Year	Patents awarded	Patent license royalties	Active CRADAs ¹	Value of CRADAs ²	Small business research grants
	Number	Million dollars	Number	Million dollars	Million dollars
1987	34	0.09	9	1.6	3.5
1988	28	0.10	48	8.7	3.6
1989	47	0.42	86	15.6	3.7
1990	42	0.57	145	18.9	4.1
1991	57	0.83	181	25.6	4.5
1992	56	1.00	172	30.0	4.4
1993	57	1.50	172	34.0	6.9
1994	40	1.40	208	61.3	7.2
1995	38	1.60	229	80.1	9.4
1996	53	2.10	244	98.9	9.1
1997	35	2.30	273	155.5	9.8
1998	57	2.40	271	120.2	na
1999	74	2.40	298	136.7	na
2000	64	2.60	257	125.1	na

¹ Number of Cooperative Research and Development Agreements (CRADAs) with the private sector.

² Value of CRADAs includes the total value of USDA and private-sector resources committed to active CRADAs over their lifetime.

na = not available.

Source: USDA, ERS, compiled from ARS Office of Technology Transfer data.

One example of a successful USDA technology transfer is a biofungicide developed from a common soilborne fungus by ARS scientists and commercialized by Thermo Trilog, Inc. The fungus *Gliocladium virens* has been incorporated into soil mixtures, where it suppresses a variety of soilborne plant pathogens. The fungus is an “environmentally friendly” pesticide, having virtually no mammalian toxicity and reducing the need for other, more toxic, fungicides (Lumsden et al., 1996). The soil mixture is sold under the name of SoilGard.™ It is currently used for ornamental and food crop seedlings. Because the fungal formulation is both stable and highly effective, registration is being expanded to include use for controlling soilborne diseases in agricultural fields (Lumsden et al., 1996).

SAES and other university institutions also may have offices of technology transfer. These are generally used for shielded innovations. Such offices will determine the commercial prospects of research output. Generally, those innovations that are sufficiently developed will go through the patent and licensing process (Parker and Zilberman, 1993). If further research is needed, the university may pursue a CRADA. Unshielded innovations generally are transferred through conferences, publications, education, or training, for example, through the extension system (Parker and Zilberman, 1993).

Research Consortium Model of Technology Transfer

Research consortia are somewhat more complex than the more traditional models of collaboration (figure 5.2.11). A consortium brings together several institutions to undertake joint research, with or without a public-sector partner. Consortia are often created to address a particular research challenge, rather than to develop a specific technology, where CRADAs may be used. However, these distinctions are not necessarily hard and fast. Consortium members contribute resources for the research and have first rights to technologies developed

by the consortium. Companies can protect spinoff technologies through trade secrets or patents. Research consortia have proven useful for increasing support for strategic research and research that is considered to be long term and high risk. Additional applied and adaptive research is often required, however, to develop and diffuse technology to farmers. Thus, consortia generally rely on the in-house research capacity of their members (either private companies or national agricultural research programs) to develop specific applications from the more generic results of consortium-sponsored research.

One successful research consortium was the Genetic Enhancement of Maize (GEM) project, which was born out of the Latin American Maize Project (LAMP). The objective of LAMP was to promote crop genetic diversity by evaluating corn germplasm accessions from various countries in the Western Hemisphere (GEM, 1999). Once LAMP determined which germplasm was most suitable to the growing conditions in respective participating countries, these countries promised to use the corn germplasm to develop new varieties. GEM was established to carry out the objectives of LAMP in the United States (Knudson, 2000).

Members of GEM come from USDA's Agricultural Research Service, land-grant universities, and private industry. Germplasm enhancement and longer term plant breeding projects are usually undertaken by the public sector, and cultivar development is primarily conducted by the private sector (Frey, 1996; and Knudson, 2000). GEM's collective research efforts rely on the comparative advantages of its members. Private cooperators agree to donate germplasm from their elite lines for crosses with the LAMP accessions, and provide nursery rows and field test plots to evaluate GEM crosses. In return, GEM members have access to any crosses developed by cooperators. Initially, there was concern by private firms that information-sharing could compromise their competitiveness. These concerns were allayed, however, since the identity of elite germplasm provided by private industry for GEM crosses was kept confidential. Resources for GEM come from Congressional appropriations (\$500,000/year), and from scientist-years and other in-house resources provided by cooperators (more than \$450,000/year). GEM has been quite successful, generating about 400 breeding crosses with desirable germplasm attributes, such as disease resistance, yield potential, or value-added traits.

Cooperative Efforts in Plant Genomics

Future crop improvements will benefit from identifying and deciphering the function and interaction of genes that control certain crop traits. Several cooperative efforts in plant genomics, nationally and internationally, are underway to map, sequence, and analyze the genomes of several model plant species that are important for developing new crop varieties. These collaborations are generally coordinated and funded by the public sector because industry has little capacity or economic incentive to initiate such extensive, long-term research efforts. Despite this public funding, industry has been a key contributor and benefactor. Recently there have been greater contributions from industry, particularly as the costs of gene sequencing have fallen sharply. These collaborations in plant genomics have proven successful and the discoveries have been made publicly available.

In the United States, public-sector research agencies are actively involved in plant genomics research. In 1997, the Office of Science and Technology Policy established the Interagency Working Group on Plant Genome Research (National Science and Technology Council, 2000) to coordinate the National Plant Genome Initiative (NPGI). The agencies involved in this endeavor include the National Science Foundation (NSF), the U.S. Department of Agriculture (USDA), the Department of Energy (DOE), the National Institutes of Health (NIH), and the Office of Management and Budget (OMB). The goal of the working group is to enhance knowledge of the structure, organization, and function of plant genomes with application to agriculture, energy, health, the environment, and industrial uses of plant material. The group plans to make new data accessible to the public

via web sites, and to deposit germplasm into public resource centers for the international research community. In support of the initiative, NSF plans to provide peer-reviewed grants totaling \$85 million for plant genome research over 5 years. Through the Initiative for Future Agriculture and Food Systems, the USDA also supports the NPGI by providing \$32 million in competitive grant funding for agricultural genomics research. While funding is primarily provided to public-sector research institutions, there are also many industry and international cooperators.

The United States also contributes to several international efforts (NSTC, 2000). A multinational genome sequencing project that includes contributions from research communities in the United States, Europe, and Japan was formally established in 1996 to determine the genome of *Arabidopsis thaliana*. *Arabidopsis* is a flowering plant from the mustard family with a relatively simple genome. It serves as an important model for many plant genomes (Gale and Devos, 1998). *Arabidopsis* became the first completely sequenced plant in 2000 and sequencing data was made publicly available throughout the process. Furthermore, the functions of many genes were discovered and the process increased knowledge of plant biology in general. Now that the genome is fully sequenced, the goal is to determine the function of every gene (Pennisi, 2000).

Another noteworthy international endeavor in plant genomics is the International Rice Genome Sequencing Project (IRGSP). Because of this project, rice will be the first food crop entirely sequenced. Rice is an economically important food crop, particularly in Asia and Africa, and has one of the smallest genomes of food crops, making it more readily sequenced. IRGSP is led by Japan, but includes efforts by the United States, Canada, China, the European Union, France, India, Korea, Singapore, Taiwan, and Thailand. In the United States, NSF, DOE, and USDA jointly plan to contribute \$12.3 million to the project over a 3-year period. Although largely a government effort, private industry also provided significant scientific assistance, particularly supplying data free-of-charge to help the IRGSP achieve goals more quickly and at lower cost (Fischer et al., 2000; NSTC, 2000). In 2001, a noncontributing private firm announced that it had completed the rice genome sequence. However, it will not be publicly available and the results will be less thorough than what will be accomplished by IRGSP (Davenport, 2001). It is expected that the IRGSP cooperators will fully sequence the rice genome by the year 2004. Discoveries made in rice will be applicable to other plants that are major food crops. Although many of these food crops, including corn, wheat and barley, have more complex genomes, they share many of the same genes as rice (Gale and Devos, 1998). Throughout the sequencing process, the consortium has made data freely available, and it is hoped that the research results will benefit both commercial and subsistence farmers (Fischer et al., 2000).

Changing Industry Structure and R&D

The agricultural input industry has undergone many changes during the past several years. Increased private sector efforts in agricultural R&D have been accompanied by recent consolidation of biotechnology, seed, and chemical companies. At first these industries redefined themselves as new “life sciences” companies, not only focusing on seed, food and agricultural chemical production, but also on medicine and health. However, uncertainty about consumer acceptance of genetically modified crops, coupled with expectations that research synergies may not provide a competitive advantage, recently spurred firms to divest their agricultural operations (King, 2001). This recent consolidation of seed, biotechnology, and agricultural chemical industries, and subsequent spinoff of agricultural operations, however, may merely reflect a natural pattern of change, largely attributed to the life cycle of innovations. Research suggests that the appropriability of an innovation and expected market share will determine the level and nature of consolidation (Kalaitzandonakes and Hayenga,

1999).

Research endeavors in the biological sciences encouraged the startup of many agricultural biotechnology firms in the early 1980s. The development of biotechnology that could be used to create new crop varieties, engineered to exhibit traits valuable to producers and consumers, had promised large markets. Large, agricultural input and chemical firms purchased biotechnology and seed companies primarily to gain access to biotechnology research tools and products, crop germplasm, and greater seed market share. After the introduction of the first biotechnology-derived crops in 1995, larger and more diversified companies specializing in agricultural inputs increased their merger and acquisition activity. These companies vertically integrated with seed companies and horizontally integrated with biotechnology startups to gain access to human capital and intellectual property rights for important enabling and product technologies (Kalaitzandonakes and Hayenga, 1999). According to a report by King (2001), there were 381 mergers, acquisitions, and other strategic alliances in the agricultural input industry from 1980 to 1998. Most of these, 238, were associated with either full or partial acquisitions, while 46 were related to mergers or joint ventures. To further illustrate increased concentration, 10 firms accounted for almost half of the activity observed.

Initial consolidation by diversified agricultural input companies stemmed from research efforts focused on the development of crops with input traits. Consolidation by these firms took advantage of new linkages between seed and chemical inputs. New crop varieties, such as herbicide-resistant crops, can complement established herbicide product lines and boost sales by expanding the types of crops that can resist these herbicides. While the development of insect-resistant crops is expected to reduce the use of certain insecticides, the sale of these varieties enables seed and chemical companies to extend their crop protection businesses. Another research platform driving strategic alliances between private sector entities is the area of genomics. These efforts may increase future market possibilities available to these firms. As quality-enhanced products near market commercialization, there may be further vertical industry consolidation (Kalaitzandonakes, 1999; Shimoda, 1999). Vertical integration with food processing firms and distributors may allow these firms to capture product market shares or create identity-preserved supply chains.

Increased market power can affect the innovation process. On the positive side, increased market power resulting from industry concentration and increased appropriability of technology can enhance incentives for private-sector innovation, leading to greater agricultural productivity. Additionally, there may be some economies of scale associated with the increased research capacity of larger companies (King, 2001). The average costs of research may decline as firms gain access to important research tools, facilities, and human capital through consolidation. Consolidated firms with large market share also may motivate private research efforts because these firms are often in a better position to capture the economic gains from research investments.

While there are research benefits from increased consolidation and some forms of market power stemming from IPR, too much market power may inhibit technological advancement. Market power potentially may inhibit technological progress by creating barriers to entry for new firms and limiting access to critical technology and knowledge. Specifically, concentrated firms with strong patent portfolios may have greater access to capital and markets than smaller, startup technology firms (Barton, 1998), thereby blocking new firm entry. Furthermore, as a smaller set of firms increase their patent portfolios through consolidation, there may be research “hold-ups” if other firms and the public sector cannot gain access to important enabling technologies and knowledge from the companies holding critical IPRs. However, as technical barriers arise, firms or the public sector may seek to

invent around patents by developing competing technology. Finally, market power can also affect the distribution of benefits between the input supply industry and producers and consumers. For example, if consumers do not see clear benefits from new technologies, demand for these products could be limited, thereby affecting technological advancement.

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References

- Agricultural Marketing Service (various). Plant Variety Protection Office. <http://www.ams.usda.gov/science/pvp.htm>.
- Agricultural Research Institute (1985). *A Survey of Agricultural Research by Private Industry III*. Bethesda, MD.
- Agricultural Research Service (1992). *Technology Transfer Agreements with the Agricultural Research Service*. U.S. Department of Agriculture.
- Agricultural Research Service (1993). *Patents in ARS: A Plain Language Guide*. U.S. Department of Agriculture.
- Animal and Plant Health Inspection Service (1999). Environmental Release Permits. Data from 1987-Sept. 3, 1999. <http://www.nbiap.vt.edu/cfdocs>.
- Barton, J. H. (1998). "The impact of contemporary patent law on plant biotechnology research" in S.A. Eberhart, H.L. Shands, W. Collins & R.L. Lower (eds.) *Intellectual property rights III, global genetic resources: Access and property rights* (pp. 85-97). Crops Science Society of America, American Society of Agronomy, Madison, WI.
- Buttel, Frederick H. (1986). "Biotechnology and Agricultural Research Policy: Emergent Issues" in K. Dahlberg (ed.) *New Directions for Agriculture and Agricultural Research*. Rowmand and Allanhand, Totowa, NJ.
- Congressional Research Service (1991). *Transfer of Technology from Publicly Funded Research Institutions to the Private Sector*. U.S. Congress. Washington, DC, July.
- Davenport, R. John (2001). Syngenta Finishes, Consortium Goes On," *Science*. Vol. 291, February.
- Day-Rubenstein, K. P. Heisey, C. Klotz-Ingram, and G. B. Frisvold. "Competitive Grants and the Funding of Agricultural Research in the U.S," presented at the AAEA, July 30-August 2000, Tampa, FL. http://agecon.lib.umn.edu/cgi-bin/pdf_view.pl?paperid=2182.
- Fischer, Kenneth S., John Barton, Gurdev S. Khush, Hei Leung, and Ronald Cantrell. (2000). "Collaborations in Rice." *Science*. Vol. 290, October.
- Frey, Kenneth (1996). *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. Iowa State University, Ames, IA.
- Fuglie, Keith, Nicole Ballenger, Kelly Day, Cassandra Klotz, Michael Ollinger, John Reilly, Utpal Vasavada, and Jet Yee (1996). *Agricultural Research and Development: Public and Private Investments Under Alternative Markets and Institutions*. AER-735. U.S. Dept. Agr., Econ. Res. Serv., July, at <http://www.ers.usda.gov/publications/aer735/>.
- Fuglie, Keith, Cassandra Klotz, and Mohinder Gill (1995). *New Crop Varieties*. AREI Update No. 14. U.S. Dept. Agr., Econ. Res. Serv.
- Gale, M. D., and K. M. Devos (1998). "Plant Comparative Genetics after 10 Years." *Science*. Vol. 282, October.
- GEM (1999). Genetic Enhancement of Maize project. <http://www.iastate.edu/~usda-gem/gem.html>.
- Huffman, Wallace, and Robert Evenson (1993). *Science for Agriculture: A Longterm Perspective*. Iowa State University Press, Ames, IA.
- Kalaitzandonakes, Nicholas (1999). "Biotechnology and Agrifood Industry Competitiveness" in Amponsah, W., et al. (eds) *The Competitiveness of U.S. Agriculture*. Hayworth Press.
- Kalaitzandonakes, Nicholas and Marvin Hayenga (1999). *Structural Change in the Biotechnology and Seed Industrial Complex: Theory and Evidence*. Presented at the Transitions in Agbiotech: Economics of Strategy and Policy Conference. June 24-25, Washington, DC.
- King, John (2001). *Concentration and Technology in Agricultural Input Industries*. Agricultural Information Bulletin, No. 763, Econ. Res. Serv., USDA. March. <http://www.ers.usda.gov/publications/aib763/>.

Klotz, Cassandra, Keith Fuglie, and Carl Pray (1995). *Private-Sector Agricultural Research Expenditures in the United States, 1960-92*. Staff paper No. AGES-9525. U.S. Dept. Agr., Econ. Res. Serv. Oct.

Knudson, Mary (2000). "The Research Consortium Model for Agricultural Research" in *Public-Private Collaboration in Agricultural Research: New Institutional Arrangements and Economic Implications*. Keith Fuglie and David Schimmelpfennig (eds.). Iowa State University Press, Ames, IA.

Lumsden, R. D., J. A. Lewis, and D. R. Fravel. (1996). "SoilGard™ for Soilborne Disease Control" in *Methyl Bromide Alternatives*, Agricultural Research Service. Vol. 2, No. 1, January.

National Research Council (1972). *Report of the Committee on Research Advisory to the U.S. Department of Agriculture*, Springfield, VA, National Technical Information Service (The Pound Report).

National Science and Technology Council, NSTC (2000). "National Plant Genome Initiative – Progress Report." Committee on Science, Interagency Working Group on Plant Genomics, November. <http://www.ostp.gov/html/plantgenome/start.html>.

National Science Foundation (2000). *Federal Funds for Research and Development: Fiscal Years 1998, 1999, and 2000*. NSF 00-317, Division of Science Resources Studies, Arlington, VA. <http://www.nsf.gov/sbe/srs/nsf00317/>.

Office of Technology Transfer (2001). Unpublished data. Agricultural Research Service.

Parker, Douglas, and David Zilberman (1993). "University Technology Transfers: Impacts on Local and U.S. Economies" *Contemporary Policy Issues*. Vol XI, April.

Patent and Trademark Office (2001). Data from online patent search. <http://www.uspto.gov/patft/index.html>.

Pennisi, Elizabeth (2000). "Arabidopsis Comes of Age" *Science*. Vol. 290, October.

Pray, Carl (1993). "Trends in Food and Agricultural R&D: Signs of Declining Competitiveness?" in *U.S. Agricultural Research: Strategic Challenges and Options*. Robert D. Weaver (ed.). Agricultural Research Institute, Bethesda, MD. pp. 51-67.

Pray and Fuglie (2000) "The Private Sector and International Agricultural Technology Transfer" in *Public-Private Collaboration in Agricultural Research: New Institutional Arrangements and Economic Implications*. Keith Fuglie and David Schimmelpfennig (eds.). Iowa State University Press, Ames, IA.

Ruff, Michael (2001). Personal communication.

Shimoda, Sano M. (1998). "Agricultural Biotechnology: Master of the Universe?" *AgBioForum*, Vol. 1, No. 2. Fall.

Shoemaker, Robbin, ed. (2001). *Economic Issues in Agricultural Biotechnology*. Agricultural Information Bulletin, No. 762, Econ. Res. Serv., U.S. Dept. Agr. February, at <http://www.ers.usda.gov/publications/aib762/>.

U.S. Department of Agriculture (various years 1979-2001). Current Research Information System. Data prior to 1998 are drawn from the *Inventory of Agricultural Research*, published by the Cooperative State Research, Education, and Extension Service. Data after 1998 are from the Research Information System web site <http://cris.csrees.usda.gov/>. Because the series are not identical, growth rates based on web site data were used to determine figures for 1998 and 1999.

UPOV (1999). International Union for the Protection of New Varieties of Plants <http://www.upov.int/eng>.

WIPO (1999). World Intellectual Property Organization. <http://www.wipo.int/eng/main.htm>.

WTO (1999). World Trade Organization. <http://www.wto.org/wto/intellect/intellect.htm>.