Changing Role of Public and Private Sectors in Agricultural Research

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Summary. The considerations involved in defining appropriate roles for the public and private sectors in agricultural research are examined with respect to mechanization, plant variety, and insecticide research and development. It is concluded that the public sector should continue to give mechanization a low priority. Varietal improvement should remain a relatively high priority until the effects of plant variety protection legislation become more apparent. Simultaneous achievement of safety, environmental, and productivity objectives in insect pest control will require that the public sector play a larger role in research and development.

In the United States there has been growing pressure to reexamine the linkages between the public and private sectors with respect to agricultural research and development. Populist critics of the federal and state agricultural research system have suggested that private sector objectives have been given too much weight in the selection of public sector research portfolios. Official critics have argued that public research in such fields as harvest technology and mechanization belongs in the private sector and is wasteful of public resources. Industry has been critical of state and federal research in product development and has suggested that the resources devoted to product development could be used more effectively for more basic research.

This article focuses on three areas of research where the boundaries between the public and private sectors are under dispute: mechanization, plant variety, and insect control. First, however, the principles that are appropriate in allocating research to the public and private sectors are specified and data on the allocation of research resources to the private sector are reviewed.

Rationale for Public Investment

The primary reason for public investment in agricultural research has been that, in many areas, incentives for private research are inadequate. That is, the social return exceeds private profit because a large share of the gains from private research are captured by other firms, by producers, and by consumers.

A second reason for public investment is its complementarity with education. There is a synergistic interaction between research and education in the agricultural sciences. This relationship is so strong that, in many fields, research carries a strong penalty when conducted apart from graduate education; and graduate education can hardly be effective when students and teachers are not engaged in research.

A third argument for public research is that it contributes to the maintenance or enhancement of a competitive structure in the agricultural production, farm supply, and marketing sectors. For example, the flow of new technology from public research and development has contributed to competition in the seed and fertilizer industries.

A different division of research activity between the public and private sectors may be implied by each of the above criteria. For example, when incentives for private research are particularly strong, the level of public investment implied by the educational criterion could exceed the level implied by the social return criterion.

Expenditures by the Private Sector

Research and development expenditures by the private sector in support of the U.S. food system are poorly documented. The best data available to us are the 1965 estimates developed by the Agricultural Research Institute (*1*). The most comprehensive estimates on the flow of public and private research funds in the United States are for 1976 (Fig. 1). The data on public research were reasonably firm. However, the estimates for the private sector appeared to omit several important areas of research.

Recent estimates suggest that research expenditures by private firms in the agricultural input, food processing, and distribution industries were about $1.6 billion in 1979 (Table 1). The data in Table 1 include expenditures that do not contribute directly to agricultural production or even consumer satisfaction. Yet there are important research expenditures that are not reflected in the data in Table 1. From 1969 to 1977, less than 10 percent of the patents for food industry processes and products originated in the U.S. food industry (*2*). A relatively high percentage of the patented inventions in the farm machinery industry emerge outside of formal research and development laboratories and shops. A complete accounting of private research and development in support of the agricultural input, food processing, and distribution industries for 1979 would probably show expenditures in excess of $2 billion. In comparison, public research, performed by the U.S. Department of Agriculture (USDA) and the state agricultural experiment stations, amounted to approximately $1.2 billion in 1979.

Despite the tentative nature of the available data, a few generalizations can be made.

Since 1965, private research has grown more rapidly than public research. In 1965 the private sector probably accounted for about 55 percent of all agricultural research. By 1979 the private share was probably about 65 percent. In both 1965 and 1979, research was divided about equally between agricultural input and food marketing and distribution.

The animal drug industry, with over 12 percent of the sales dollar allocated to research, and the pesticide industry, with about 10 percent of the sales dollar allocated to research, are the most research-intensive of the industries that produce the goods used in agricultural production. The farm machinery industry, which allocates about 3 percent of the sales dollar to research, is slightly above the average for all U.S. industry.

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The fertilizer industry spends considerably less than 1 percent of the sales dollar on research, and the food and kindred products industry apparently allocates less than 0.5 percent.

Research and development in the agricultural input and food processing industries is focused on product development. The food industry, for example, stresses product development, but buys its processing technology from suppliers. Similarly, the agricultural chemicals industry focuses its efforts on new products, but not on the processes used to produce the products. The distinction between new product and new process is, however, quite arbitrary. A new product in the farm machinery industry becomes a new process when adopted by agricultural producers.

There are quite striking differences in the relative emphasis given by the public and private sectors to the various fields of agricultural science and technology, and, in the public sector, by USDA and the state experiment stations. Close to two-thirds of private sector research and development is concentrated in the physical sciences and engineering. Public research is much more heavily concentrated in the biological science and technology. At the state agricultural experiment stations, approximately three-fourths of the research is in biological science and technology. The share of the research dollar allocated to social science research related to agriculture is less than 5 percent in the private sector and less than 10 percent in the public sector.

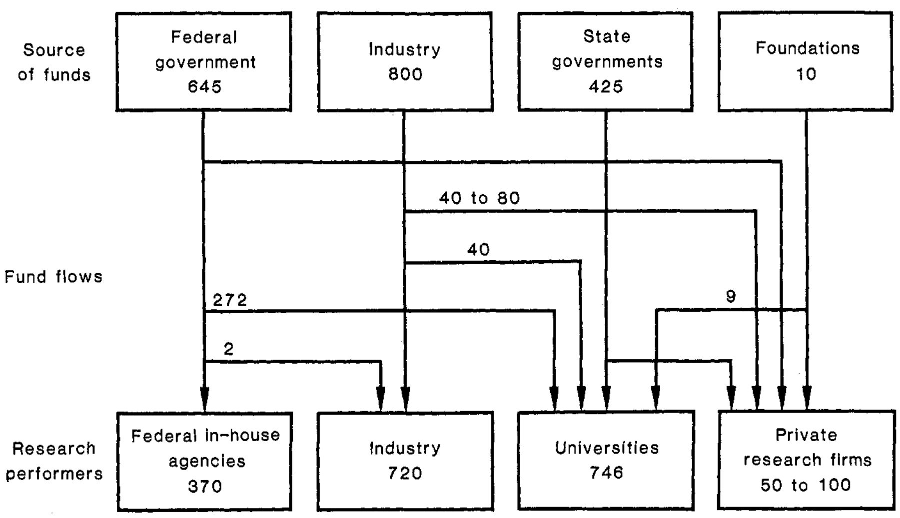

Fig. 1. Estimated 1976 expenditures on food research in the United States. Values are millions of dollars (*19*).

Table 1. Estimated recent expenditures on research and development by the farm input and food-processing industries (*20*).

Industry	Expenditure (millions of dollars) 1978	Expenditure (millions of dollars) 1979
Farm input	751 to 846	814 to 909
Plants		
Breeding	55 to 150	60 to 155
Pesticides	290	339
Nutrients	3	3
Total	348 to 443	402 to 497
Animals		
Breeding	49	59
Health (mostly drugs)	99	99
Feed	30	33
Total	178	187
Equipment and machinery	225	225
Processing and distribution	641 to 651	734 to 744
Produce transport equipment	40	45
Food processing machinery	85	100
Food processing	350	400
Tobacco manufacturing	40 to 50	40 to 50
Natural fiber processing	10	20
Packaging materials	116	129

Public Funding of Mechanization Research

The appropriate boundary between private and public research on mechanization has been debated for some time. Two issues have been prominent. One is whether public research duplicates or displaces private research. A second concerns who gains and who loses as a result of the new technology. The critics of public research in mechanization have emphasized its displacing effect on labor. However, empirical evidence suggests that mechanization has been induced by long-term increases in the price of labor. Mechanization in agriculture has primarily been a response to a shrinking agricultural labor force (*3*).

Concern over the public funding of mechanization research has been heightened by the role taken by the University of California in the development of mechanical and biological technology for producing and harvesting tomatoes and several specialty crops (*4*). The rationale for this undertaking has relied on two arguments. First, many of the specialty crops are unique to California. Because of limited acreage and small market potential, there supposedly is little incentive for private research and development. Second, California farmers desire to improve their ability to compete with producers in other areas of the United States and abroad.

The tomato harvester was developed over a period of about three decades (Table 2). Its development was speeded by the demise of the bracero program, which permitted Mexicans to enter the United States to harvest crops and do other field work. In conjunction with new biological methods to increase yield, the tomato harvester enabled California producers to capture a large share of the processed tomato market from older producing areas in the Midwest and East. Initially, this led to an increase in demand for labor in tomato production. As the process continued, however, it led to the displacement of labor. The implications for state economic development were ambiguous. The gains to producers exceeded the losses to workers by a substantial margin. But the losers were poor and the gainers relatively well off, and compensation was not made (*5*).

In late 1979 Secretary of Agriculture Bob Bergland responded to the controversy over public funding of mechanization by announcing that the USDA would no longer support research leading to the replacement of labor with machines (*6*). Bergland qualified his remarks by indicating that he had no objection to innovations designed to ease the drudgery of work rather than replace workers. This is a distinction that is not feasible technically or analytically.

The importance of publicly supported research in agricultural mechanization has been blown out of proportion by both critics and defenders. The USDA Science and Education Administration has been able to identify only about $1 million in the USDA research budget that could lead to significant labor displacement. The harvest mechanization issue has been more important as a battleground for the forging and testing of political power. Neither critics nor defenders of publicly funded mechanization research have been overly scrupulous in adhering to analytical distinctions or in ensuring the accuracy of the empirical content of their arguments.

Those who support mechanization research by the public sector have frequently attempted to interpret Bergland's remarks as an attack on mechanization rather than the more limited questioning of the rationale for public funding of mechanization research. Those who protested seemed less concerned with the displacement of labor than with (i) the failure of the University of California Experiment Station to consider farm workers as well as farm operators and processors as part of its clientele and (ii) the failure in California, and in the United States generally, to provide parity to farm laborers in social insurance and collective bargaining legislation.

The private sector has been an effective source of new mechanical technology for agriculture. Some observers believe that the Blackwelder Company would have developed an efficient tomato harvester by the early 1970's even without participation by the University of California. Development of the mechanical cucumber harvester in Michigan might also have been achieved without public funds. In both cases, the demand for commercial development associated with the ending of the bracero program appeared to be more important than the public research effort.

There is little reason to believe that substantial federal funding of agricultural machinery research produces widespread social benefits. Research and development by state experiment stations leads primarily to local, not national, benefits. University research in this area probably must be justified primarily for its value in training.

Plant Variety Development and Protection Legislation

The U.S. seed industry evolved along two distinct lines. The private sector tended to be the predominant source of new varieties for the home gardener and for horticulturists. The public sector tended to be the dominant supplier of new varieties of field crops. This pattern began to change with the advent of hybrid corn. Control of inbred lines capable of serving as parents for superior hybrids enabled the private sector to establish proprietary control over new hybrid corn varieties. In the mid-1970's, over 80 percent of the corn and sorghum varieties used in commercial production and approximately 70 percent of the sugar beet and cotton varieties were controlled by private interests. Over 80 percent of the rye, wheat, oats, soybeans, rice, barley, peanuts, dry edible beans, and forage grasses were public varieties (*7*).

The complexity of the involvement of the public sector can be illustrated by using Minnesota as an example. When the performance of a new variety of soybeans developed by Minnesota Agricultural Experiment Station warrants seed multiplication, breeder seed is released to the Minnesota Crop Improvement Association for multiplication. The association, a nonprofit corporation whose owners are mostly farmers and small seed companies, has also been designated by the state legislature as the official seed certification agency in Minnesota. To ensure the quality of the seed grown by seed growers, the association carries out field inspections and conducts laboratory tests for purity and viability before issuing certificates and labels.

The system has been remarkably effective in the generation and distribution of new seed varieties. It has also helped to maintain a competitive structure in the seed industry. However, it is highly dependent on public support. The larger seed companies have argued that, if new plant varieties could be patented, or given equivalent protection, it would serve as an incentive for them to greatly expand their research and development efforts in this area. They cite the large investments they have made in the development of hybrid corn and sorghum varieties as a result of the natural protection provided by their control of the inbred parent lines.

The Plant Patent Act of 1930 was the first plant variety protection legislation passed in the United States (*8*). It extended patenting rights to breeders of certain asexually reproduced plants. At that time, efforts to extend patenting privileges to breeders of sexually produced plants were rejected by farmers and scientists who feared that such legislation would inhibit the free exchange of genetic materials and lead to excessive concentration of proprietary control in the seed industry. Certified seed growers objected on the grounds that such privileges would lead to concentration of seed production in the hands of larger firms capable of maintaining their own breeding programs.

In 1970 Congress passed a Plant Variety Protection Act developed by the American Seed Trade Association. The 1970 act included seeds, transplants, and about 350 plant species. Several species (tomatoes, carrots, cucumbers, okra, celery, and peppers) were omitted because of objections by canners and freezers. There was also substantial opposition to the act from scientists and breeders in the state agricultural experiment stations and USDA. They argued that adequate consideration had not been given to such factors as (i) variability in crop performance and genetic drift under different environmental conditions and (ii) exchange of information and germ plasm among public and private breeders.

In 1979 and 1980, hearings were held in the House of Representatives and the Senate on a bill to amend and extend the Plant Variety Protection Act (*9*). The 1980 amendments included the vegetables not included in the 1970 act (the canning and freezing industry no longer opposed this), extended the period of protection from 17 to 18 years in conformity with the provisions of the International Convention for the Protection of New Varieties of Plants, and tightened up several provisions to facilitate administration.

Experience with the 1970 act resulted in a number of changes in perception regarding the effect of variety protection. Most participants in the amendment debate concluded that the act has encouraged an expansion of plant breeding efforts in the private sector. Fears that the act would lead to excessive litigation have not been realized. Much of the opposition to variety protection by public breeders has disappeared.

There remain a number of legitimate concerns about the implications of plant variety protection. The 1979 and 1980 hearings served to focus these issues but did little to resolve them. Testimony presented by the USDA tended to be uninformative. Opponents often relied more on rhetoric than on analysis. Testimony by the seed industry regarding favorable effects of the 1970 act rested more on simple assertions than on presentation of evidence.

Marketing restrictions. A major issue raised during the hearings was whether the restrictive provisions in European seed certification and marketing programs are essential to variety protection. In Europe, specific "value for cultivation and use" criteria are used to shorten the list of varieties that may be offered for sale. Varieties are evaluated by official government tests. Failure to meet established standards of performance precludes the sale and use of a variety. Individual countries have developed national lists, and the Common Market has developed common catalogs of approved and recommended varieties. The lists are based on performance tests conducted by the national seed agencies. The objectives are (i) to protect farmers and commercial gardeners from inferior varieties and (ii) to reduce the use of different names for the same varieties in different countries, enabling more effective monitoring of trade in breeder, foundation, and certified seed.

The U.S. legislation is flexible in that it does not preclude the marketing of seed that does not go through the registration process. Seed marketing legislation in Europe clearly is more restrictive. Excessive rigidity in the application of distinctiveness, uniformity, and stability criteria could impose an excessive burden on crop variety development.

Variety conservation and development. A second major issue in the debate about plant variety protection is whether it threatens the conservation of genetic resources or the exchange of information and breeding materials among public and private plant breeders. It is now generally accepted by those concerned with conservation of genetic materials that it is the increased availability of higher yielding crops rather than varietal protection itself that is the major threat to varietal diversity. The appropriate response to this concern is more adequate support for crop exploration, seed storage and preservation, and associated taxonomic and cytogenetic research. It is no longer reasonable to expect that the traditional landraces will be maintained in their original form by subsistence farmers.

The issue concerning the free flow of scientific information among public and private breeders has not been resolved (*10*). At present, much of the germ plasm released by the USDA and the state experiment stations does not have variety status. It is elite germ plasm (or parental lines), useful for breeding stock but not for immediate cultivation. It has no legal status under the Plant Variety Protection Act. However, there is no restriction on the use of a variety registered under the Plant Variety Protection Act by public or private breeders.

A viable public crop breeding program should be maintained until it is possible to monitor the effects of varietal protection on the performance of private varietal improvement efforts. Experience with hybrid maize, where proprietary inbred lines have provided even more secure protection than the provisions of plant variety legislation, casts doubt on the efficiency of private breeding programs. Inbred lines developed by public breeders continue to account for more than half of the hybrid maize seed production in the United States (*11*). The private seed companies continue to make only limited investments in such supporting sciences as genetics, plant pathology, and plant physiology.

It still has not been determined whether the Plant Variety Act is an effective instrument for inducing optimum private investment in varietal development. Research by the public sector in plant breeding and the supporting sciences continues to be highly beneficial to society (*12*). As further institutional innovations result in more secure property rights and as private varietal development efforts continue to evolve, there will be a need to reevaluate the appropriate division of labor.

Innovation and Regulation in Insect Control

The intensive use of chemical insecticides in agriculture is a relatively recent phenomenon. The first generation of insecticides was dominated by arsenic compounds (calcium arsenate, lead arsenate, white arsenic) and copper sulfate. Small amounts of organic insecticides, such as pyrethrum, rotenone, and nicotine sulfate, were also used. Commercial-scale use was confined to fruits, vegetables, potatoes, and cotton. Evidence of the excessive use of insecticides on some fruits and vegetables helped lead to major food and drug legislation in 1906 and 1938 (Table 3).

A second generation of insecticides began in 1939 with the discovery of the effectiveness of DDT. This discovery was followed by the development of a series of synthetic organic pesticides, including other chlorinated hydrocarbons, the organic phosphates, and the carbamates. The effectiveness and relatively low cost of these materials led to their wide use in crop and forest production and in controlling insect vectors of disease. By the mid-1950's, the use of first-generation insecticides had been sharply reduced.

During the 1950's and 1960's, evidence accumulated to indicate that the benefits associated with the new organic insecticides were obtained at a substantial cost. These costs included development of resistance in target populations; destruction of beneficial insects; damage to bird, fish, and other wildlife populations; and effects on human health (*13*).

Search for a pesticide policy. Before World War II, debates over insecticides focused on (i) direct effects of residues on human health and (ii) safety in manufacture and application. Later debates centered on the problem of resistance and on a broad spectrum of environmental effects. By the late 1950's there was general agreement among both agriculturally and ecologically oriented entomologists on the desirability of reducing the reliance on toxic chemicals for insect control.

The bureaucratic response to pressures from environmentalists, agricultural interests, and the general public was to commission several studies (Table 3). The most significant of the studies was the National Academy of Sciences–National Research Council's assessment of pest control strategies (*14*). The study concluded that problems inherent to chemical control, such as resistance, were so serious that a major effort was needed to develop alternative strategies.

These studies served to reinforce the agreement that, to the extent feasible, development and use of nonpersistent and more selective insect-control agents was to be encouraged. Greater effort was to be devoted to the development of biological control agents, cultural control procedures, and crop varieties with enhanced resistance. It was recognized that each element in the strategy had significant limitations. It was believed, however, that many of the limitations could be overcome by an "integrated" approach that would employ a combination of control agents (including limited use of insecticides) and management techniques.

The legislative response to concerns about the effects of insecticides on human health and the environment was a new set of institutional innovations designed to monitor and regulate insecticide development and use (Table 3). The scientists, reformers, and legislators who worked together to bring about the legislation and to establish administrative agencies at the federal and state levels anticipated that their efforts would be followed by the introduction of a set of third-generation pest control methods that would satisfy the needs of agricultural producers and the demands of the environmentalists.

The expectations have been only partially realized. There has been a sharp decline in the use of chlorinated hydrocarbons and a modest decline in the amount of insecticides applied per crop acre. Development of a new control strategy has, however, been impeded by serious economic constraints stemming from natural and institutional sources. The new control agents tend to be specific to a single insect species or crop. This imposes a natural limit on the size of the market. Institutions seeking to develop third-generation agents have also been burdened by the Environmental Protection Agency (EPA) through its adminis-

Table 2. Evolution of the tomato harvester (*21*).

Period	Event
World War II	Labor shortage creates demand for tomato harvester
1941 to 1942	Conveyer machine developed in Pennsylvania
1942	A. M. Jongennel, a California tomato grower, suggests to G. C. Hanna, a University of California professor, that the university develop a machine-harvestable tomato plant
1943	Hanna begins search for desirable plant type. A blacksmith in Holt, California, begins building a tomato picker for a canning firm in Stockton
Late 1940's	Hanna releases pear-shaped tomato suitable for machine harvesting
1949	Coby Lorensen begins work on a tomato harvester at the University of California, Davis
1951 to 1952	Tomato growers in California experiment with conveyer systems
1956	California Tomato Growers Association grants funds to University of California for work on tomato harvester
1958	Michigan State University constructs a tomato harvester. University of Florida develops a conveyer belt machine. Food Machinery Corp. and H. D. Hume Co. fund work on a tomato harvester at Purdue University
1959	University of California successfully completes development of its tomato harvester. Blackwelder Manufacturing Co. is licensed to undertake the harvester's commercial manufacture (Blackwelder had been working closely with the university)
1961	Tomato harvester first used commercially. Hanna releases improved variety (F-145) of tomato for machine harvesting. A strain selected from this variety is integral to the mechanization of tomato harvesting in California
1964	Public Law 78 (bracero program) rescinded
1965	Tomato growers in California obtain special dispensation to import Mexican workers for the harvest. First major strike of National Farm Workers Association (later United Farm Workers)
1967	Federal minimum wage extended to agricultural workers
1970	Adoption of mechanical tomato harvester completed in California
1974	California Tomato Growers Association recognized by processors as grower bargaining association for negotiating prices
1975	California law (Agricultural Labor Relations Act) allows agricultural employees to form unions and bargain collectively. Electronic sorter (which reduces the necessary labor on the harvester from about 15 to 5) used commercially
1976	California law enacted to ensure unemployment benefits for agricultural workers. United Farm Workers attempt to organize labor in the harvesting of tomatoes. Mass adoption of electronic sorter eliminates approximately 5000 workers from tomato harvesting

Table 3. Evolution of pesticide regulation (*22*).

Year	Event
1906	Food and Drugs Act establishes federal jurisdiction over food treated with pesticides and traded interstate
1910	Insecticide Act
1938	Federal Food, Drug, and Cosmetic Act (FFDCA) attempts to regulate use of chemicals on fresh fruits and vegetables but is too complex for tolerance levels to be established
1947	Federal Insecticide, Fungicide, and Rodenticide Act
1950 to 1952	Hearings are held by the House Select Committee to Investigate the Use of Chemicals in Food and Cosmetics. The committee recommends that FFDCA be amended to require that chemicals employed in or on food be subjected to safety testing
1954	Miller Amendment to FFDCA gives Food and Drug Administration the means to set tolerance levels for pesticide residues on food
1958	Delaney Amendment to FFDCA bans food additives found to induce cancer in animals or humans
1962	Rachel Carson's *Silent Spring* is published
1963	President's Science Advisory Committee issues *The Use of Pesticides*, which generally concurs with Carson
1969	Secretary's Commission on Pesticides and Their Relationship to Environmental Health recommends limiting the use of DDT, DDD, and other persistent pesticides because of adverse environmental effects
1970	The National Environmental Policy Act requires a statement of environmental impact for every major federal activity "significantly affecting the quality of the human environment." Passage of Occupational Safety and Health Act
1972	Federal Environmental Pesticide Control Act amends the 1947 Federal Insecticide, Fungicide, and Rodenticide Act (additional amendments made in 1975) and orders that pesticides be classified for general or restricted use. Restricted chemicals must be applied by trained personnel or under their supervision. Most uses of DDT are eliminated by EPA
1975 to 1976	National Academy of Sciences recommends a major effort to develop alternatives to chemical pest-control technologies
1978	Federal Pesticide Act of 1978 amends the Federal Environmental Pesticide Control Act of 1972 to permit conditional registration of pesticides, relaxes requirements for registration of minor-use pesticides, transfers enforcement responsibilities to states, and tightens label requirements

trative interpretation of the new legislation (*15*). In addition to its more stringent regulatory requirements for registration of insecticides, EPA announced in 1972 an intensive review of the toxicological properties and residue characteristics of the insecticides then in use. A procedure, "rebuttable presumption against registration" (RPAR), was established to review pesticide registration on the basis of data that imply a health hazard. When an established insecticide is placed on the RPAR list, it becomes subject to a risk-benefit analysis similar to that required for a new material. Because of the economic importance of some of the materials, USDA and the state agricultural experiment stations have had to divert resources that could have been devoted to third-generation strategies to conducting the studies necessary to maintain the registration of existing materials. They also have been devoting more resources to the research necessary to register new minor-use insecticides and control methods.

The productivity of private pesticide research and development firms has also been declining. This decline can be measured in terms of (i) diversion of scientific resources from synthesis, screening, field-testing, and development to environmental testing, residue analysis, registration, and administration; (ii) increases in the costs, measured in money or scientific manpower, of developing new insecticides; (iii) extension of the time between scientific discovery and registration, and (iv) reduction in the number of new insecticide products and uses registered each year (*16*).

Steps have been taken to correct some of the problems created by the Federal Environmental Pesticide Control Act. A major emphasis of the Federal Pesticide Act of 1978 was to simplify and shorten the registration process to reduce the regulatory burden resulting from administrative and judicial interpretations of the 1972 act. The amendments permitted conditional registration and the waiving of efficacy requirements for new agents, relaxed requirements for registration of minor-use pesticides, provided a mechanism for the transfer of registration data among firms, transferred enforcement responsibility to the states, and tightened label requirements (Table 3).

In December 1978 EPA announced its intention to issue new registration guidelines for biorational and biological pest control agents (*17*). Discussion has focused on a sequential testing scheme designed to ensure that only the minimum data necessary to make sound regulation decisions will be required. This procedure would eliminate the need for submission of data on biological pest-control agents determined to be safe by the first tier of tests. The 1978 act has not, however, been fully implemented. The new EPA guidelines, which were to be issued in fall 1980, are still in draft form, and certain provisions are still being contested in the courts. Although it is too early to determine how sensitively the new procedures will be administered, it does seem that EPA intends to provide a more favorable environment for developers of the third-generation insect control strategy.

The evolution of an insect control strategy capable of achieving agricultural production and environmental and health objectives will involve at least three major elements:

1) Implementation of regulatory procedures that encourage the private sector to develop traditional chemical pesticides, biorational chemical agents, and biological agents that are compatible with human health and the environment. Explicit attention should be given to the special research, development, marketing, and use characteristics of the biorational and biological agents.

2) Expanded public support of research on biological and cultural control agents and procedures. This will involve additional support for research on the biology of insect predator and host populations, identification of insect control agents and the design of control technologies, breeding of insect-resistant crop varieties, and design of cultural practices to depress insect populations.

3) Public support for the design and operation of insect population management programs. Substantial progress has been made in the integrated management of several insect pests, such as those affecting cotton in Texas and tree fruits in Michigan. But the full potential of integrated pest management has yet to be realized. The appropriate roles of the state agricultural extension services and of privately organized laboratory, scouting, and consultation services are not yet defined (*18*).

The effectiveness of both the public and private efforts will depend on adequate funding for publicly supported pest- and weather-monitoring, pest management training, and relevant information systems.

Perspective

Research to advance mechanical technology should remain a low priority in the allocation of public resources. Improvements in mechanical technology have seldom been constrained by limitations in basic knowledge. Market incentives have been adequate to induce substantial innovation by the private sector and a rapid rate of improvement in mechanical technology. The level of public funding of mechanization research is more appropriately guided by educational needs than by the demand for new technology.

Continuation of strong public involvement in plant variety improvement is clearly warranted. Advances in this technology remain linked to advances in basic knowledge. Market incentives do not yet appear adequate to generate an efficient level of private research and development in this area. As private research expands, the appropriate role and function of public institutions will need to be reevaluated.

In the area of insect pest control and management, the tensions that are inherent in attempts to achieve both economic and environmental objectives imply a need for substantial expansion of public research and development. Lack of knowledge remains a serious constraint to the development and adoption of third-generation control and management technologies. More must be learned about the effects of the new technologies on human health and the environment. At present the market provides only weak incentives for the private research needed to support the development of many of the insect control technologies that are compatible with productivity, safety, and the environment.

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