Agricultural Research and Development: The Need for Public-Private Sector Partnerships

Issues in Agriculture 9

CLIVE JAMES

CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

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About the CGIAR

The Consultative Group on International Agricultural Research (CGIAR) is an informal association of 52 public and private sector members that supports a network of 16 international agricultural research centers. The Group was established in 1971.

The World Bank, the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), and the United Nations Environment Programme (UNEP) are cosponsors of the CGIAR. The Chairman of the Group is a senior official of the World Bank, which provides the CGIAR system with a Secretariat in Washington, DC. The CGIAR is assisted by a Technical Advisory Committee, with a Secretariat at FAO in Rome.

The mission of the CGIAR is to contribute, through its research, to promoting sustainable agriculture for food security in the developing countries. International centers supported by the CGIAR are part of a global agricultural research system. The CGIAR conducts strategic and applied research, with its products being international public goods, and focuses its research agenda on problem solving through interdisciplinary programs implemented by one or more of its international centers in collaboration with a full range of partners. Such programs concentrate on increasing productivity, protecting the environment, saving biodiversity, improving policies, and contributing to strengthening agricultural research in developing countries.

Food productivity in developing countries has increased through the combined efforts of CGIAR centers and their partners in developing countries. The same efforts have helped to bring about a range of other benefits, such as reduced prices of food, better nutrition, more rational policies, and stronger institutions. CGIAR centers have trained more than 50,000 agricultural scientists from developing countries over the past 25 years. Many of them form the nucleus of and provide leadership to national agricultural research systems in their own countries.

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Introduction

The world's population is approximately 5.5 billion and is expected to double to 11 billion by the year 2050. Ninety-seven percent of this population increase will occur in developing countries in Africa, Asia, and Latin America (Swaminathan 1995). Even with today's population, 700 million people do not have adequate food supplies, and more than 1.1 billion people—30 percent of the population of the developing world—live in abject poverty, barely surviving on one dollar per day or less for food, shelter, and other essential needs. The challenge for the future is global food security, which will require at least a doubling, and preferably a tripling, of food production by the year 2050 to meet the needs of the rapidly growing global population of 11 billion, approximately 90 percent of whom will reside in developing countries. Compounding the problem, this additional food will have to be produced on the existing area, or less, of agricultural land. The enormity of the challenge of food security is best illustrated by the fact that in the next fifty years the global population will consume twice as much food as has ever been consumed since agriculture began 10,000 years ago.

Agricultural research and technological improvements are and will continue to be prerequisites for increasing agricultural productivity and generating income for farmers and the rural work force. This in turn will help to alleviate poverty, which is primarily a rural phenomenon, but which also afflicts the urban poor; 75 percent of the poor in Africa and Asia live in rural areas. Given that economic growth is the best antidote to poverty, and that few countries have

achieved economic growth without agricultural growth, it follows that agriculture, a principal sector in most developing countries, can contribute significantly to growth and development and should be accorded a high priority. During the last decade, however, investments in agriculture, at both the national and international levels, have declined. There is an urgent need to reverse this trend, which, if left unchecked, can threaten global food security.

Industrial countries have benefitted from agricultural research and development (R&D) investments in both the public and private sectors, but developing countries have by and large relied on public sector support from national programs and from international organizations such as the international centers of the Consultative Group on International Agricultural Research. In the future it is imperative that developing countries invest significantly more public sector funding in agricultural R&D and also encourage the indigenous and international private sectors to participate in activities where they have comparative advantages. To meet the challenge of global food security requires new partnerships in agricultural R&D between the public and private sectors that optimize the comparative advantages of each in pursuit of mutual objectives. Forging these new public-private sector partnerships would promote the most effective use of limited global resources for the development of sustainable agricultural systems. In the last decade governments in industrial countries have encouraged increased participation by the private sector in agricultural R&D, a trend that is being mirrored in many developing countries. During the 1990s there has been a growing awareness, in both the public and private sectors, of the significant benefits that can be derived from such collaboration.

This publication is not an exhaustive analysis of public and private sector investments in agricultural R&D; rather, it presents general information that demonstrates the need for public-private sector partnerships, with particular emphasis on developing countries. In order to provide a global contextual framework in which to view the activities of the public and private sectors, the declining official development assistance to agriculture as well as public and private sector investments in agricultural R&D are briefly reviewed; for the latter,

selected activities of the private sector active in international agricultural R&D are characterized. The need for collaboration between the private and public sectors is discussed and two different initiatives are described that involve collaboration between the public and the private sectors, aimed at building new partnerships for the future.

Declining Support for Developing Country Agriculture

A recent International Food Policy Research Institute (IFPRI) study (Brown and Haddad 1994) reported that the proportion of official development assistance (ODA) devoted to agriculture decreased from 20 percent in 1980 to 14 percent in 1990. The study also showed that real external assistance to agriculture for developing countries declined from $12 billion[1] in 1980 to $10 billion in 1990. Although there are many reasons for this decline, the following are believed to be the major factors. First, there are those within the development assistance community who (i) reject the view that investment in agriculture is a prerequisite for economic growth in developing countries, and (ii) contest the reported high private and social rates of return of 20 percent or more attributed to agricultural research projects. Second, during the 1980s and 1990s, bilateral and multilateral agencies that provided development assistance assigned a higher priority to environmental protection, which reduced the amount of funds available for support to agriculture. This change in priority occurred at the same time donor agencies were being forced to deal with their own domestic economic constraints. Consequently, donors were unable to satisfy all of the new and competing demands, such as significant financial aid to Eastern Europe and the countries of the former Soviet Union.

In the past, ODA and official investment assistance have been important for obtaining additional financial support from national

[1] All data in this publication are given in US dollars ($).

programs for agricultural research. There is now evidence that this external support is declining at the same time developing countries are providing less support to agricultural R&D. External assistance to national agricultural research systems (NARS) is estimated to be 35 percent for Sub-Saharan Africa, 26 percent for Asia and the Pacific, and 7 percent for Latin America and the Caribbean. The breadth of support for agriculture from the donor community tends to be narrow and, therefore, is vulnerable. For example, the World Bank provides 25 percent of the total agricultural R&D support to developing countries, and two-thirds of the World Bank's $817 million to developing countries during the period 1981 to 1987 was limited to six projects (Anderson *et al.* 1994).

In summary, declining support of public sector funds from ODA to aid agricultural research in developing countries does not bode well for the future, which highlights the importance of increased participation by the private sector in partnership with the public sector. It is noteworthy that public sector ODA funding for all sectors is currently estimated at approximately $60 billion annually, whereas private sector investments from the North for all sectors in the developing countries of the South are estimated at more than $170 billion per year (Serageldin and Sfeir-Younis 1996), equivalent to almost three times that of public sector ODA.

Public Sector Investments in Agricultural R&D

In the 1960s industrial countries accounted for approximately two-thirds of the total public sector investments in global agricultural research. It was not until 1990 that developing countries invested marginally more than industrial countries in agricultural R&D. In 1990 global investments in agricultural R&D by the public sector were estimated at $17.3 billion, with $8.8 billion invested by developing countries and $8.5 billion by industrial countries (Alston and Pardey 1996). One of the most useful and meaningful methods for comparing national agricultural research expenditures is to express them as a percentage of the corresponding national agricultural gross domestic product (GDP); Anderson

and others (1994) reported these as "agricultural research intensity ratios." Data for the period 1961 to 1993 is shown in Table 1.

Table 1. Investments in Agricultural R&D (espressed as a percentage of national agricultural GDP)

Region or Country	Number of Countries	1961-65	1971-75	1981-85	Most Recent Year
Developing Regions:					
Sub-Saharan Africa (excluding South Africa)	17	0.42	0.67	0.76	0.58[a]
South Africa	1	1.39	1.53	2.02	2.59[a]
Asia and the Pacific (excluding China)	15	0.14	0.22	0.32	-
China	1	0.57	0.44	0.42	0.42[b]
Latin America and the Caribbean	26	0.30	0.46	0.58	-
West Asia and North Africa	13	0.28	0.50	0.52	-
Developed Countries:	18	0.96	1.41	2.03	-
United States	1	1.32	1.36	1.93	2.22[c]
Australia	1	1.54	3.56	4.52	4.42[d]

[a]1991 estimate, [b]1993, [c]1992, [d]1998.

Source: Pardey and Alston (1995).

The data in Table 1 indicate that industrial country investments show continued growth, with at least 2 percent of agricultural GDP invested in R&D by the early 1980s; the average investment by eighteen industrial countries in the early 1980s was 2.03 percent, with the United States reporting 2.22 percent in 1992 and Australia 4.42 percent in 1988. Corresponding developing country expenditures averaged approximately 0.5 percent in the early 1980s, equivalent to one-fourth of the amount invested by industrial countries. Whereas public sector investments in agricultural R&D in developing coun-

tries doubled on average between the 1960s and the early 1980s, the initial rapid growth during the early 1960s slowed during the 1970s, and by the 1980s investments had either leveled off (China at 0.42 percent) or declined, with seventeen Sub-Saharan Africa countries showing a significant decrease, from 0.76 percent in 1981 to 1985 to 0.58 percent in 1991. It is noteworthy that the Republic of South Africa's investment in agricultural research continued to increase, from 1.39 percent in the 1960s to 2.02 percent in the early 1980s to 2.59 percent in 1991, and compared favorably with investment in industrial countries such as the United States, which reported 2.22 percent for 1992.

In summary, recent global investments in public agricultural research show that developing countries invest approximately 0.5 percent of agricultural GDP in agricultural R&D, one-fourth of the amount invested by industrial countries, which average 2 percent. The significant growth in public spending on agricultural research in the 1960s in developing countries has leveled off or declined in some countries, and there is growing concern that current investments will not be adequate for delivering the technology contribution necessary to increase food productivity sufficiently to ensure food security in the future. Given that global resources devoted to agricultural R&D are inadequate, one of the options that must be explored is better use of current allocated global resources, including the integration of public and private sector research resources, so that limited global resources can be used to achieve mutual objectives more effectively and efficiently at the national and international levels.

Private Sector Investments in Agricultural R&D and Estimates of Global Markets for Selected Products

There are no comprehensive and uniformly generated global estimates of private sector investments in agricultural R&D for industrial and developing countries. However, some data from selected industri-

al countries, where most of the private sector investments are made, provide an indication of the scale and scope of investment *vis-à-vis* the public sector. In the early 1960s private sector agricultural R&D expenditures in the United States were about $250 million annually, approximately 5 percent less than corresponding public sector expenditures. Recent estimates (United States Department of Agriculture 1995) for the United States indicate that in-house private sector agricultural research expenditures for 1992 were $3.3 billion, 27 percent more than the corresponding amount spent by the U.S. public sector. The data in Table 2 show the trends in private sector spending for various activities during the period 1960 to 1992. It is noteworthy that private sector agricultural R&D spending in the United States increased almost twentyfold during this period, with real expenditures (expressed in 1980 dollars) increasing by a factor of three, from $511 million in 1960 to $1,648 million in 1992 (Alston and Pardey 1996). During the 1960s and 1970s, spending on agricultural research by the private sector showed real growth rates of more than 4.5 percent per year and exceeded corresponding public sector spending. Despite the fact that U.S. private sector expenditures in agricultural R&D grew at lower real growth rates in the 1980s, compared with those of the 1960s and 1970s, the total investment by the U.S. private sector in 1992 was $700 million greater than the public sector. The highest rate of growth in the 1970s was in chemicals, which was also the only activity to decline in the 1980s, when postharvest and food processing investments increased rapidly from $456 million in 1982 to $1,088 million in 1992.

Although available data do not allow precise comparisons and breakdown of public and private sector spending in agricultural R&D, the trend in the United States—higher spending in the 1970s and 1980s by the private sector compared with that of the public sector—is probably representative of the spending in most other industrial countries. Comparable data for agricultural and food R&D in the United States, United Kingdom, and France for the mid-1980s indicate that annual private sector expenditures were $2,400 million, $530 million, and $270 million, respectively, equivalent to 49, 47, and 39 percent of total spending by both the

Table 2. Trends in Private Sector Spending on Agricultural R&D Input-Oriented, Postharvest and Food Processing, 1960 to 1992 (millions of current dollars)

Year	Input-Oriented				Postharvest and Food Processing	Total	
	Chemicals	Agricultural Machinery	Veterinary/ Pharmaceuticals	Plant Breeding		Current	Real
1960	9.7	75.9	6.0	5.6	80.0	177.2	511.9
1970	126.0	89.1	45.0	26.3	206.1	492.5	839.0
1980	1,390.0	287.0	111.0	96.7	456.1	1,340.8	1,340.8
1992	1,123.0	394.0	306.0	399.7	1,088.0	3,310.7	1,648.0

Source: Adaped from United States Department of Agriculture (1995).

public and private sectors (Anderson 1996), and these percentages are likely to have increased significantly in the interim period.

Expenditures on agricultural R&D by the indigenous and international private sectors in developing countries are much lower than in industrial countries and are concentrated in a few of the larger and more advanced developing countries, such as Argentina, Brazil, India, and Mexico (Pray and Echeverria 1991). More recent data (Falconi 1992, 1993) show that in the 1970s and 1980s private sector investments in agricultural R&D in some developing countries increased faster than public sector investments, similar to the trend in the United States. For example, private sector investments (expressed as a percent of total R&D expenditures) in Colombia increased from 22 percent in 1970 to 37 percent in 1991, and in Ecuador from 19 percent in 1986 to 27 percent in 1991. This trend is not surprising because it occurred at a time when many developing countries introduced policies to encourage increased participation by the private sector in agricultural R&D.

Given the nature of the marketplace and the competition among private sector corporations, comprehensive data on agricultural R&D

is not readily available in the public domain. However, much can be gleaned about the scale and scope of private sector activities in an international context. In this paper, information from industry sources has been used to characterize the international markets for selected products, and to estimate R&D expenditures, expressed as a percentage of revenues. These activities are discussed in the following section.

Activities of the Private Sector in International Agricultural R&D

Corporations active in international agricultural research include a large number of companies from the North and fewer, but an increasing number of, indigenous companies from the South. Companies from the North range in size from small corporations, often with specialized applications and operations in one or few industrial countries, to large transnationals with global operations in many industrial and developing countries. Companies from the South are generally smaller and focus on their home country or region. Recent acquisitions—the successive acquisitions by the Empressa La Moderna [Pulsar] Group from Mexico of Asgrow Seed, Peto Seed, Royal Sluis, and DNAP—however, indicate that some of the larger companies from the South are expanding their base of activities and becoming transnational.

The private sector has broad-ranging activities in agricultural research focused on the development, production, and distribution of products and services that lend themselves to commercialization. The private sector's major activities are in the industrial countries where currently there are more opportunities for commercialization than in developing countries, but this is changing. Most private sector activities in the developing world take place in the most advanced developing countries and favor working with large and wealthy commercial farmers and plantations rather than with small, subsistence, and resource-poor farmers. The corporations from the North and South that are active in agricultural R&D and are potential partners for public sector institutes are engaged in very diverse activities, some of which are listed below:

- Acquisition, exchange, distribution, and improvement of genetic stocks of crops, forest species, live-

stock, and fish using conventional and biotechnology applications.

- Production and distribution of improved seed and livestock to meet international needs.

- Production of fertilizers and development of management practices to optimize crop production.

- Development of diagnostics to detect diseases in crops, animals, and fish.

- Production of pesticides and pesticide application within the context of chemical control or integrated pest management.

- Development of strategies to ensure responsible deployment of resistance genes in crops that will optimize durability of the genes.

- Development and production of vaccines and other disease control agents for animal diseases.

- Processing, storage, and use of food and feed products, including control of postharvest losses.

- Global strategic planning and policy analysis aimed at developing commercial agriculture-based products to meet global needs.

Private sector activities in agricultural research, such as those listed above, are conducted by industry groups that can be conveniently classified according to the following product types:

- fertilizers;
- seeds;
- plant protection;

- plant and microbial biotechnology products;
- animal genetic stocks, including biotechnology-based technologies;
- animal health products;
- food and food processing;
- forestry;
- fisheries; and
- machinery and equipment.

The above classification can be used to match the activities of the private sector with those of the public sector. To provide an indication of the scale of the private sector's international activities, recent data on global markets for selected major industry groups have been collated, with major companies identified and listed according to their estimated global markets or their estimated R&D expenditures. Data have been collated for fertilizers, seeds, plant protection, animal health, and biotechnology. Many of the large transnational companies are listed in several of the groups, indicating that they are involved in several areas; for example, some companies have operations in seeds, agricultural chemicals (pesticides), as well as in plant and animal biotechnology.

Estimates of R&D Expenditures for Selected Corporations

The data in Table 3 list annual revenues and R&D expenditures for selected agricultural companies that represent very diverse industry groups with interests in activities ranging from plant breeding to chemicals to biotechnology to large food and trading companies. Given this diversity of activities it is to be expected that the percentage of R&D expenditures will vary widely and reflect the nature of the R&D program necessary for products that are quite different. For this reason, the data cannot be compared directly with spending by the public sector in agricultural R&D; the intent is to provide a better understanding of the scale and scope of current expenditures by the private sector. R&D expenditures range from 13.9 percent of total revenue, for a very specialized corporation concentrating on plant genetic improvement, to 1.8 percent, for a company that is by and large a trading company

that also has major global interests in food and food processing. In general, industry considers 6 to 7 percent of revenue as the minimum investment necessary to ensure an acceptable level of competitiveness in the marketplace. Estimates of R&D expenditures by indigenous companies in developing countries suggest that on average R&D expenditures as a percentage of revenue is significantly lower, ranging from 1 to 5 percent, as compared with 5 to 10 percent or more in industrial countries.

Table 3. Annual Revenues and R&D Expenditures in 1994 of Selected Corporations with a Broad Range of Agricultural Activities

Company	Annual Revenue[1] ($ millions)	R&D Expenditure ($ millions)	Expenditures as Percent of Revenue
American Cyanamid Co.	4,276	595	13.9
DeKalb Genetics Corp.	320	44	13.7
Sandoz AG	15,870	1,635	10.4
Zeneca (AG)[2]	2,420	242	10.0
Ciba-Geigy	19,341	1,931	9.8
Pioneer	1,478	114	7.7
Monsanto[3]	8,272	609	7.4
Hoechst Celanese Corp.	7,794	313	7.3
Sumitomo Chemical[4]	9,798	554	5.7
DuPont	39,333	1,404	3.6
Unilever	45,419	831	1.8

[1] Annual revenues and R&D expenditures are for 1994 and are available only for publicly traded companies that disclose these data in annual reports.
[2] Sales of Zeneca PLC are $7,123 million, with R&D of $823 million (11.5 percent of sales).
[3] Sales of Monsanto Agricultural Group are $2,200 million.
[4] Sales for Sumitomo Agriculture are $840 million.

Source: Compiled by the author from various industry sources.

Fertilizer Industry

The annual global fertilizer market was estimated at $32 billion in 1992 to 1993, as shown in Table 4, with nitrogen at $20 million representing the major component in terms of value and tonnage, followed by phosphate at $8.2 million and potash at $3.9 million. Data in Table 5 show that developing countries use 60 percent of the nitrogen consumed on a global basis, 54 percent of phosphate, but only 33 percent of the potash. On average about 55 percent of global fertilizer is consumed in developing countries, and the private sector is responsible for at least half of the total global production. Due to significantly higher prices in 1995, the global fertilizer market was estimated at approximately $50 billion. The major fertilizer producers active in the international market are listed in Table A-1 of the Appendix.

Table 4. Global Fertilizer Market, 1992 to 1993

Nutrient	Millions of Tons	Annual Value[1] ($ billions)
Nitrogen (N)	73.6	20.0
Phosphate (P_2O_5)	31.5	8.2
Potash (K_2O)	20.8	3.9
Total	125.9	32.1

[1] Ex-factory value.

Source: Communication with the International Fertilizer Development Center (IFDC) and the International Fertilizer Industry Association (IFIA) using base data from World Bank Technical Report 252 (1994).

Table 5. Estimated Fertilizer Consumption in Industrial and Developing Countries, 1992 to 1993 (million nutrient tons)

Nutrient	Developed Countries	Developing Countries	World
Nitrogen (N)	29.3	44.3	73.6
Phosphate (P_2O_5)	14.6	16.9	31.5
Potash (K_2O)	13.8	7.0	20.8
Total	57.7	68.2	125.9

Source: FAO.

Doubling food production will require significantly more use of fertilizers despite the significant effort underway to develop crop varieties that are more responsive to fertilizers. Such increased use of fertilizer will exacerbate a situation that is already of environmental concern; that is, even with the current usage rate of fertilizer, intensified agriculture is resulting in nitrate levels in groundwater well above accepted tolerance levels. Various technologies are being investigated to determine their applicability for increasing the efficiency of nitrogen utilization and for using nitrogen-fixing organisms to develop cereals that can fix some of their own nitrogen supply, thereby decreasing dependence on inorganic nitrogen. Use of mycorhiza is also being explored as a means to increase the extraction efficiency of phosphate and other elements that are not available in sufficient quantities for crops growing in marginal areas, such as in acid soils.

Plant Protection Industry

Global food, feed, and fiber losses due to the combined effect of weeds, insect pests, and pathogens are estimated to reduce yield by approximately 35 percent. The annual value of the global plant protection market in 1994 was approximately $28 billion (Wood Mackenzie 1996). Herbicides represent almost 50 percent of the world pesticide market, insecticides 30 percent, and fungicides 20 percent, as shown in Table 6. Whereas herbicides are far more important than insecticides and fungicides in North America, Europe, and other industrial countries, insecticides predominate in developing countries. Approximately 75 percent ($20.6 billion) of the annual $27.8 billion global pesticide market is in industrial countries of the North; 25 percent ($7.1 billion) is in developing countries of the South. Nine countries consume 72 percent of pesticides, and the two major markets in the industrial North are the United States (27 percent) and Japan (17 percent), followed by several European Union countries and Canada, which consume 2 to 8 percent. Brazil, at 5.3 percent, is the only significant consumer from the South.

In terms of crops, horticultural crops (fruits and vegetables) are by far the most important, consuming approximately 25 percent of pesticides, as shown in Table 7. The other major crops, which consume

from 9 to 12 percent of the global supply are, in order of priority, cereals (small grains), rice, maize, cotton, soybean, sugar beet, and oilseed rape. The segmented market for different pesticide products indicates that more insecticide is used on fruit and vegetables than on any other category of crop, followed in order of importance by cotton, rice, and maize. The major use of herbicides is for maize (18 percent), cereals (17 percent), soybean (15 percent), fruit and vegetables (13 percent), and rice (10 percent). For fungicides, the major consuming crops are fruit and vegetables (46 percent), cereals (23 percent), and rice (17 percent).

Table 6. Global Pesticide Market in 1994, by Pesticide Product, by Region, and by Principal Country

Pesticide Product	$ Millions	Percent
Herbicides	12,995	46.7
Insecticides	8,110	29.1
Fungicides	5,420	19.5
Others	1,300	4.7
Total	27,825	100.0

Region	$ Millions
Western Europe	6,720
North America (United States/Canada)	8,300
Japan	4,700
Eastern Europe	955
Industrial Countries	20,675
Far East	2,715
Latin America	2,930
Others	1,505
Developing Countries	7,150
Total	27,825

Principal Country	Percent
United States	27.0
Japan	16.9
France	7.8
Brazil	5.3
Germany	3.5
Italy	3.3
South Korea	2.9
Canada	2.8
United Kingdom	2.5
Others	28.0
Total	100.0

Source: Wood Mackenzie (1996).

Table 7. Global Pesticide Market in 1994, by Crop and by Pesticide Product/Crop

Total Pesticide Market By Crop	$ Millions
Fruit and Vegetables	7,000
Cereals	3,960
Rice	3,625
Maize	3,110
Cotton	2,845
Soybean	2,260
Sugar Beet	790
Oilseed Rape	470
Others	3,765
Total	27,825

Herbicide Market By Principal Crop	$ Millions
Maize	2,365
Cereals	2,150
Soybean	1,920
Fruit and Vegetables	1,720
Rice	1,335
Sugar Beet	545
Cotton	530
Oilseed Rape	325
Others	2,105
Total	12,995

Fungicide Market By Principal Crop	$ Millions
Fruit and Vegetables	2,495
Cereals	1,240
Rice	940
Others	745
Total	5,420

Insecticide Market By Principal Crop	$ Millions
Fruit and Vegetables	2,465
Cotton	1,870
Rice	1,190
Maize	620
Others	1,965
Total	8,110

Source: Wood Mackenzie (1996).

With the advent of biotechnology, some conventional insecticides will be substituted for by novel genes—for example, *Bacillus thuringiensis* (*Bt*)—that confer resistance to insects through development of transgenic crops in which the active gene has been incorporated. Currently, industrial countries consume considerably more herbicides than developing countries, but this is likely to change. Labor shortages and higher labor prices will lead to reduced use of hand-weeding for crops such as rice, and more herbicides will be applied, perhaps in conjunction with use of herbicide-resistant varieties. In developing countries more than $1.25 billion worth of pesticides (insecticides 44 percent, herbicides 29 percent, and fungicides 27 percent) are used annually on rice. Use of

herbicides on rice in developing countries is likely to increase as the present trend to favor direct seeding in irrigated areas over traditional transplanting becomes more pronounced, and if more attention is focused on rainfed rice, where weeds are more of a problem. Water constraints associated with irrigated rice production will lead to less optimal control of weeds, which, in conjunction with the other factors noted above, could lead to significant increases in herbicide use on rice, more than 90 percent of which is grown and consumed in Asia.

Concern for the environment, large-scale commercialization of transgenic crops with resistance to insects, herbicides, and plant pathogens, and widespread implementation of integrated pest management (IPM) are all factors that will likely have a significant effect on the structure of the pesticide market in the future. The private sector, however, will continue to dominate the pesticide market and will probably become more dominant as technologies become more sophisticated and as penetration of markets in the developing countries of Asia and Latin America, and to a lesser extent Africa, advances.

The principal companies involved in the international plant protection industry are transnationals with headquarters based in Europe (7), the United States (7), and Japan (9). Companies involved in plant protection are by and large also those involved in the chemical, pharmaceutical, seed, and agribiotechnology industries. The principal companies involved and their respective share of the global market are listed in Table A-2 of the appendix. The turnover of the companies ranges from $0.21 billion to $4.1 billion per year, and the leading ten companies account for approximately 75 percent of the $28 billion global market.

The plant protection industry went through a consolidation phase that featured mergers and takeovers, the most recent of which occurred in March 1996 with the merger of Ciba and Sandoz to form Novartis. Novartis, which will benefit from the combined pesticide markets of both Ciba and Sandoz, is now the largest pesticide company in the world, with the equivalent of $4.12 billion in combined Ciba/Sandoz 1994 sales [see Table A-2]. In 1995, Hoechst and Scherring merged to form AgroEvo, which is now, along with DuPont, ranked the second

largest corporation involved in plant protection, with 1994 revenues of $2.1 billion. Whereas the incentive for the merger between Ciba and Sandoz was driven mainly by the needs of the pharmaceutical industry, it nevertheless has important implications for the pesticide industry, which is anticipating more mergers in the coming decade.

A survey of pesticide use in the United States (Anonymous 1995) for the period 1991 to 1993 showed that use, as measured by volume of active ingredients, continued in 1993 a ten-year pattern of nearly flat growth, which was due to lower application rates of more potent compounds and more efficient use of pesticides. Twenty new active ingredients were registered in the United States in 1993, the highest number since 1975, with regulation costs estimated at $303 million, or 3.6 percent of pesticide revenues.

Seed Industry

The value of the global seed trade is estimated at $45 billion annually, equally divided among the three different segments (Rabobank 1994): commercial seed, which is dominated by the private sector; farm-saved seed; and seed from government institutions. The latter is particularly prevalent in developing countries and in centrally planned economies. For example, in Africa, governments completely control the seed industry in 60 percent of the countries, and both the government and private sectors are active in 28 percent of the countries. Consumption of agricultural seed, which includes farm-saved seed, is approximately 120 million tons per year, and global consumption has been stable since about 1980. Asia and the Commonwealth of Independent States are the largest consumers of seeds, approximately 38.4 and 37.3 million tons, respectively, in 1990, and together represent approximately two-thirds of the world market, as shown in Table 8. Consumption has been stagnant during the last decade, except in Asia, where consumption has increased by 18 percent since 1980; one-third of the seed used in Asia is rice.

Cereals dominate the world seed market, accounting for approximately two-thirds of the 120 million ton market, as shown in Table 9. Wheat is the major cereal crop for the seed market (35 million

Table 8. Total World Consumption of Agricultural Seed, by Continent (millions of tons, including farm-saved seed)

Region	1980	1985	1990
Commonwealth of Independent States	41.7	37.7	37.3
South America	4.3	4.4	4.2
Europe	23.2	23.6	21.3
North and Central America	10.9	10.4	11.0
Asia	32.6	35.0	38.4
Africa	3.9	4.3	4.6
Oceania	1.2	1.4	1.1
Total (World)	118.8	117.7	118.7

Source: FAO (Rabobank 1994).

Table 9. Total World Consumption of Agricultural Seed, by Crop (millions of tons)

Crop	1980	1985	1990
Wheat	34.0	33.2	35.0
Barley	11.8	11.6	11.1
Rice	11.5	12.2	13.0
Maize	6.4	6.5	6.8
Other Grains	9.5	9.3	8.9
Root and Tuber Crops	36.8	35.4	33.3
Pulses	3.4	3.9	4.0
Oilseeds	5.4	5.6	6.6
Total	118.8	117.7	118.7

Source: FAO.

tons), followed by rice (13 million tons), barley (11.1 million tons), and maize (6.8 million tons); root and tuber crops are exceptionally high, at 33.3 million tons, because of the high water content of "seed tubers." Of the $15 billion annual market in commercial seed, horti-

cultural seed accounts for only $1.75 billion, and this includes both vegetable and flower seed. In 1990 approximately $13 billion of the $15 billion commercial seed market was in the OECD countries. The European Union ($5.8 billion), the United States ($4.5 billion), and Japan ($2.7 billion) were the largest markets; Turkey, Argentina, and Brazil also were important.

The private sector dominates the $15 billion annual global commercial seed market. There are approximately 1,500 seed companies worldwide, 600 based in the United States and 400 in Europe. The fifteen principal seed companies that are active internationally are listed in Table A-3 (Anonymous 1996) of the Appendix and, with the exception of Empresas La Moderna, S.A.-ELM (Pulsar), which is based in Mexico, are transnationals based in North America (3), Europe (10), and Japan (1). The annual turnover of the companies ranges from approximately $0.12 billion to $1.5 billion per year. Their combined turnover is approximately $5.5 billion, about one-third of the global commercial seed market. The market shares of these companies are expected to increase in the future. Of these fifteen seed companies, approximately half are specialized seed companies, the other half are owned by larger corporations with diversified interests.

Until the 1960s the seed industry comprised traditional seed companies that specialized in the improvement, production, and distribution of seed. During the late 1960s several transnational corporations with activities in farm chemicals and pharmaceuticals acquired seed companies to capture the range of products and services for the agricultural industry within one corporate structure, thus providing them with the necessary R&D critical mass and benefiting from economies of scale. After a decade or so, however, some of the transnationals sold their acquired seed operations, for several reasons: incompatibility with an evolving business strategy, lower margins than expected in seed operations where they lacked business linkages and experience, and a realization that the opportunities for using the seed industry to capture and market proprietary transgenic crops was a longer-term venture than they had anticipated. In the 1980s and 1990s acquisitions and mergers have resulted in fewer but larger seed companies, a trend that is expect-

ed to continue into the next decade, ultimately resulting in a few very large companies dominating the international market. This trend is fueled by the long-term investments in research that are necessary to ensure competitiveness and an international marketing structure to effectively compete in the global market.

Mergers and acquisitions are not the only way critical mass for R&D is being created in the industry. Collaborative arrangements, which range from cooperative R&D agreements to cross-licensing, are becoming prevalent, with Pioneer Hi-Bred International recently reporting that it has 800 agreements with various private and public organizations. In 1995, ELM (Pulsar) of Mexico acquired Asgrow Seed owned by Upjohn, added Peto Seed and Royal Sluis to its portfolio later in the year, and in early 1996 acquired DNAP, a small agricultural biotechnology company. In February 1996 there was a merger between the seed operations of Zeneca (formerly ICI, United Kingdom) and Suiker Unie, which owns the Vander Have Group from the Netherlands. The two corporations view the merger as an opportunity to mobilize the necessary critical mass for research, to benefit from the complementarity in their respective operations, and to increase the probability that the newly formed company will be one of a few large companies to dominate the market in the coming decades.

In March 1996, Sandoz and Ciba merged to form Novartis, which now is the second largest seed company in the world, with a turnover of $907 million in 1994. The former operations of Sandoz were estimated at $727 million and included four companies, Hilleshog NK (France), Northrup King (United States), S&G Seeds (the Netherlands), and Rogers (United States), with subsidiaries in twenty-five countries, and those of Ciba were in ten or more countries, with operations estimated at $180 million. Seed industry representatives expect such mergers to continue as companies attempt to build the minimum critical mass necessary for efficient R&D operations to be implemented and for products to be more competitive in the international marketplace. In developing countries, where it is estimated that 80 percent of seed is currently supplied by government organizations or by farmer-saved seed, private sector activity in the seed industry is expected to become increas-

ingly strong. Private sector growth is likely to be important in Asia, as well as in Latin America and selected countries in Africa. As the former centrally planned economies of Eastern Europe and the Commonwealth of Independent States become politically and economically stable, these regions should also experience significant growth of the private sector seed industry.

Animal Health

The world market for animal health products was estimated to be approximately $13 billion in 1994 (Wood Mackenzie 1996), as shown in Table 10. Animal health products are divided into four categories: nutritional feed additives; medicinal feed additives; biologicals; and pharmaceuticals. [These categories are defined in detail in the footnote of Table 10.] Pharmaceuticals represent just under half of the global market of animal health products, and nutritional feed additives approximately one-third. More than half of the total global pharmaceutical market of $5.6 billion is in the OECD countries, with sales of $1.9 billion in Europe, $1.6 billion in North America, $870 million in East Asia, and $750 million in Latin America.

The data in Table 11 indicate that cattle are the major consumers of animal health products, consuming approximately 31 percent of the global market supply, of which approximately half is pharmaceuticals, followed by pigs (24 percent), poultry (18 percent), and sheep (6 percent). In developed countries, care of domestic pets is a significant and growing market, making up approximately 20 percent of the global market in animal health products.

The animal health industry has many similarities to the plant protection industry in that the principal companies active internationally are either part of, or have association with, large transnationals that have operations in chemicals, pharmaceuticals, and biotechnology. Global sales of animal health products are dominated by the private sector. Ten companies account for the majority of such operations [see Table A-4], totaling almost $11 billion, just over 80 percent of the world market. With the exception of Tortuga (Brazil), all the principal companies are transnationals based in the United States (9),

Table 10. Global Animal Health Sales in 1994, by Product Group and Region ($ millions)

Region	Nutritional Feed Additives	Medicinal Feed Additives	Bio-logicals	Pharma-ceuticals	Total
North America	945	690	500	1,660	3,795
Western Europe	800	425	570	1,860	3,655
East Asia (China, Southeast Asia, Australia)	820	450	350	870	2,490
Eastern Europe	395	180	135	320	1,030
Latin America	210	170	300	750	1,430
Rest of World (Africa, Middle East, India)	130	80	110	180	500
World Total	3,300	1,995	1,965	5,640	12,900

Note. Product categories include the following: nutritional feed additives include vitamins, minerals, amino acids, nonprotein nitrogen and other nutritionals; medicinal feed additives include antibiotics, antibacterials, anticoccidials, growth promotants, and other medicinals; biologicals include livestock biologicals, poultry biologicals, and companion animals; pharmaceuticals include antimicrobials, parasiticides, and performance enhancers.

Source: Wood Mackenzie (1996).

Table 11. Global Animal Health Sales in 1994, by Product Group and Animal Species ($ millions)

Animal Species	Nutritional Feed Additives	Medicinal Feed Additives	Bio-logicals	Pharma-ceuticals	Total
Cattle	890	374	620	2,230	4,114
Pigs	990	693	310	1,055	3,048
Sheep	110	85	150	475	820
Poultry	880	785	455	215	2,335
Pets/Others	430	58	430	1,665	2,583
Total	3,300	1,995	1,965	5,640	12,900

Source: Wood Mackenzie (1996).

Europe (13), or Japan (2), but they have significant and growing business in the developing countries estimated to be approximately 25 percent of the global market of $13 billion annually.

Biotechnology

Private sector investments in biotechnology are multidisciplinary in the sectors of medicine, pharmaceuticals, agriculture, and industrial applications such as fermentation. Because most private sector R&D investments are subject to a degree of confidentiality and many of the companies investing in biotechnology have multisector investments in biotechnology research, it is difficult to desegregate the proportion of R&D investments devoted to agriculture. Thus, because there are no precise data available on biotechnology R&D expenditures, and because estimates are not always comparable, because of lack of uniform methodology for consolidating and comparing data, the intent here is to describe the scope and scale of the investments and to highlight order-of-magnitude differences.

Global R&D investments in 1990 by both the public and private sectors in biotechnology for all sectors were estimated to be $11 billion, of which $6 billion was in the United States, $3 billion in Europe, and $2 billion in Japan; the private sector in Japan invested $1.4 billion (70 percent) of the total $2 billion (Persley 1990). The most recent detailed estimates of the relative contributions of the public and private sectors in the different biotechnology markets are from 1985 (Persley 1990); these data are detailed in Tables 12, 13, and 14, and indicate that 50 percent of total global investments were in the United States, 25 percent in Europe, 15 percent in Japan, and the balance of 10 percent in other countries. The estimates also show that global R&D expenditures in biotechnology by the private sector was $2.7 billion, slightly more than twice the $1.3 billion by the public sector. Corresponding comparisons for agricultural biotechnology indicate that slightly more than 60 percent of the investments were by the private sector and the balance by the public sector. Of the total $900 million spent in agricultural biotechnology R&D by the public and private sectors, $550 million, equivalent to almost two-thirds of total expenditures, was spent

by the private sector. Of the $900 million invested by both the public and private sector on agricultural biotechnology, two-thirds was spent on seed, and the balance on microbiology applications.

Table 12. Global Estimates of R&D Expenditures in 1985 on Biotechnology, by Country or Region ($ millions)

Country or Region	Private Sector	Public Sector	Total
United States	1,500	600	2,100
European Union	700	300	1,000
Japan	400	200	600
Others	100	200	300
Total	2,700	1,300	4,000

Source: Persley (1990).

Table 13. Global Estimates of R&D Expenditures in 1985 on Biotechnology, Private and Public Sectors ($ millions)

Sector	Agricultural Biotechnology	Other	Total
Private	550	2,150	2,700
Public	350	950	1,300
Total	900	3,100	4,000

Source: Persley (1990).

Table 14. R&D Global Expenditures in 1985 on Agricultural Biotechnology, by Application ($ millions)

Application	Private Sector	Public Sector	Total
Seeds	350	250	600
Microbiology	200	100	300
Total	550	350	900

Source: Persley (1990).

It is probable that private sector R&D investments in agricultural biotechnology will increase dramatically in the late 1990s given that significant progress with regulation has resulted in the delivery of biotechnology-based products in the international marketplace. For example, approximately twenty transgenic crops were approved in 1995 for commercialization in industrial countries, fourteen in the United States alone. Without exception, all these approved transgenic crops in the industrial countries have been developed by the private sector. However, China has grown transgenic crops for several years and in 1994 was reported to have transgenic tobacco equivalent to 5 percent of the total tobacco area in the country. In addition, in 1996 it is estimated that more than four million acres of transgenic crops have been grown in other industrial and developing countries, including cotton (>2 million acres), soybean (1.5 million acres), maize (0.5 million acres), canola (>0.2 million acres), and the balance in tomato, potato, and squash (James and Krattiger 1996). In summary, the reported total global acreage of transgenic crops grown by industrial and developing countries in 1996 was known to be at least 6.5 million acres, with probably close to 10 million acres actually planted.

There are numerous potential opportunities for applying biotechnology in developing countries, but for commercial reasons many of these will not be pursued by the private sector. These opportunities often exist for what are termed *orphan commodities* (Persley 1989); for example, low-value, vegetatively propagated crops such as cassava and sweet potatoes, which are important primarily as staples for poor people in the developing world. Similarly, crops grown over a relatively small area would not be attractive to the private sector, even though these crops may make a vital contribution to the diet of poor people in a specific country or region. Given that basic biotechnology knowledge is broadly applicable to diverse problems, however, industry often has a comparative advantage in developing the most cost-effective solutions to many of the problems in the developing world. This situation represents a challenge to both developing countries and to international development agencies (James and Persley 1990).

Assuming equal research competence in the private industrial and public sectors, and acknowledging that industry's principal objective is product delivery, it is reasonable to suggest that the private sector will emerge as the principal, although not the only, generator of biotechnology products for agriculture. The comparative advantage of industry lies in several areas:

- Large R&D resources for funding long-term and sometimes high-return, but speculative, agricultural projects.
- Diversity, from small, dedicated biotechnology companies to large transnational corporations that have extensive and increasingly collaborative research links with the public sector, particularly universities.
- Critical mass of scientific research resources, which is of paramount importance in biotechnology. These resources often are consolidated within a core research group in the private sector (e.g., in a life sciences department), which is a cost-effective way to provide common research support for two significant product development markets—medicine and agriculture.
- Knowledge of and expertise in marketing and distribution systems.
- Access to global markets and the associated advantages of economies of scale, which allow development costs to be amortized over long periods in large markets.

The advent of biotechnology has resulted in a significant change in the relative investments of the public and private sectors in agriculture, with the private sector now investing significantly more than the public sector in biotechnology R&D. As the

adoption of biotechnology-based products in agriculture becomes more widespread, this gap between public and private sector investments is expected to increase. This trend will be accentuated by current government policies, in both industrial and developing countries, that encourage participation by the private sector in areas where it has comparative advantages over the public sector. Estimates of future markets for agricultural biotechnology products vary widely; industry sources suggest that a realistic estimate is $3 billion to $5 billion for total sales at the farm level by the year 2000. Of this, seeds are predicted to comprise approximately $2 billion to $3 billion, with the balance in veterinary products and microbiology-based products. The increased market for agricultural biotechnology products is expected to be at the expense of existing markets, with some restructuring of those markets, rather than by major expansion of current markets (Persley 1990).

Summary of Private Sector Activities in Agricultural R&D

In summary, the private sector plays a major global role in agricultural R&D. The importance of its role is evident from the data presented in this section and in the appendix, even though these data do not include all the activities of the private sector; for example, the subsectors of postharvest/food processing and agricultural machinery, which are not featured, represent significant investments that are dominated by the private sector. In the future, private sector investments in agriculture and food are expected to increase faster than investments by the public sector, in both industrial and developing countries. Anderson and others (1994) noted that, as farmers use more purchased inputs and as the value-added in agriculture increasingly moves off the farm to the marketing and processing subsectors, it is likely that the incentives for private sector investments in agricultural research will grow. With current private sector global revenues in fertilizers, seeds, pesticides, and animal health alone estimated conservatively at approximately $70 billion per year, the private sector is an essential partner for the global public sector engaged in agricultural research.

The Need for Collaboration Between the Public and Private Sectors

There is no greater incentive for collaboration between the public and private sectors in agricultural research than the enormous challenge posed by global food security, which will require that limited global resources be used in the most effective way to develop sustainable systems that also conserve natural resources. The urgency of this challenge cannot be overstated. Knowledgeable observers judge that the current joint investments of the public and private sectors in agricultural research are inadequate to double (or preferably triple) agricultural production in the next fifty years. Furthermore, this is occurring at the same time external aid to agricultural research, which is viewed by many to be the catalyst that will stimulate economic growth in developing countries and as the best antidote for poverty, is declining.

There is, and will continue to be, a critical and essential role for governments in developing countries to address policy issues in agriculture and to implement technical programs that optimize social welfare for the public good. Governments should not view for-profit private sector activities as detrimental to the public good because these private sector activities often are the most effective way—in seed production and distribution—to achieve national goals set by the governments. The collective goal must be to build partnerships that use the comparative advantages of the public and private sectors to achieve mutual goals. Governments can use policy instruments to encourage and stimulate private sector investments in joint venture programs, and donors can facilitate implementation of such collaborative programs (Anderson *et al.* 1994).

In the last decade there has been a strong trend for governments of donor countries to encourage, and in some cases require, increased participation by the private sector in agricultural research. Many of the more advanced developing countries have emulated this trend and established policies that encourage increased partici-

pation by the private sector in areas where it has comparative advantage. Whereas in the past policymakers in developing countries did not recognize the private sector as an important resource for carrying out national programs, there has been a marked and progressive change in which the private sector is now generally acknowledged to be a key player in development. This view is endorsed by the international development and finance community, which recognizes the private sectors in the North and the South as increasingly important national and international resources (James and Persley 1990).

The significant investment of the private sector in biotechnology, perhaps more than any other single factor, has clearly demonstrated the need for and significant advantages associated with collaboration between the public and private sectors in agricultural research and development. Indeed, the requirement for a minimum critical mass in R&D, particularly in biotechnology, has been the major stimulus for most of the mergers and acquisitions in the private sector. The development of biotechnology applications is capital intensive, requiring substantial long-term investments, which often can be mobilized only by the private sector. Thus, most investments in biotechnology are made by the private sector. A major challenge for both the private sector and the public sector is to find ways to collaborate in sharing and transferring appropriate new and superior technologies, which often are proprietary, from the private sector to the public sector.

Collaboration between the public and private sectors is essential in planning future research strategies that are global in coverage, and requires cooperation by all the major entities in agricultural research in industrial and developing countries. This cooperation should ensure that limited global resources in agricultural research are used in the most effective way to strategically address the issue of food security in the developing world by optimizing the comparative advantages of the public and private sectors. Assuming that the data from selected industrial and developing countries are representative, current private sector investments in agricultural and

food R&D are conservatively estimated to be about $11 billion in the industrial countries and $2 billion in the developing countries; this compares with $8.5 billion and $8.8 billion, respectively, by the public sector. The issue here is not the precision of the estimates; rather, it is that both the public and private sectors are spending, independently, about $30 billion on agricultural R&D. This $30 billion investment is inadequate to meet current global agricultural R&D needs. In addition, it does not benefit from the considerable efficiencies that could accrue if the same amount were invested in a more coordinated manner by the public and private sectors. It is, therefore, vital that the two major players, the public and private sectors, involved in agricultural R&D on the global scene collaborate to address the important and impending challenge of global food security. Governments of developing countries, the donor community, and the private sector must take the necessary and urgent steps to initiate the building of partnerships. It is encouraging to note that there are several initiatives already underway to build new partnerships between the public and private sectors. Two of these initiatives are the founding of the International Service for the Acquisition of Agri-Biotech Applications (ISAAA) in 1991 and the establishment of the Private Sector Committee of the CGIAR in 1995. These two initiatives, quite different in character, are described below.

Founding of the International Service for the Acquisition of Agri-Biotech Applications

The Mission

The mission of the International Service for the Acquisition of Agri-Biotech Applications is to help alleviate poverty by increasing crop productivity and income generation, particularly for resource-poor farmers, and to create a safer environment and promote more sustainable agricultural development. ISAAA's objective is the transfer and delivery of appropriate biotechnology products, particularly proprietary technology from the private sector in the North, to developing countries in the South by building part-

nerships between institutions in the South and the private sector in the North.

The Need

In the past, developing countries, and the organizations that assisted them with agricultural research, have had free access to non-proprietary traditional technology from the public sector in industrial countries. With the advent of new biotechnology applications, however, this situation is changing. The new applications are increasingly proprietary, and are owned primarily by private sector corporations in industrial countries, which account for the majority of the investment in biotechnology R&D on a global basis. The greatest need for agribiotechnology, however, is in the developing countries. The benefits of biotechnology generally are not accessible to developing countries due to institutional, political, and infrastructural constraints and to a lack of financial resources. The applications of agribiotechnology offer promising means to a more sustainable agriculture and a safer environment; for example, by providing alternatives to the use of toxic conventional pesticides. Conventional technology alone can no longer increase food, feed, and fiber productivity at a growth rate fast enough to keep up with population growth and still respond to environmental and sustainability pressures. There is consensus in the scientific community that biotechnology is an essential element for increasing food, feed, and fiber productivity in the future.

The Institutional Response

A new institutional mechanism, ISAAA, sponsored by public and private sector institutions, was created to transfer agribiotechnology applications from industrial countries in the North, particularly proprietary technology from the private sector, to developing countries (James 1991; Krattiger and James 1993). ISAAA's role and comparative advantage as an honest broker is to bring together institutions from national programs in the South and from the private sector in the North into partnerships to transfer biotechnology applications. Thus, ISAAA is not an executor, but a facilitator. ISAAA's organizational structure permits both the public and private sectors to work together as true partners in an international biotechnology

program for the benefit of the developing world. Acknowledging that technology adoption by resource-poor farmers is, and probably always will be, challenging and difficult emphasizes the importance of ISAAA's mission in its quest for equity in technology transfer. In the absence of organizations such as ISAAA, developing countries may be denied the opportunity to access the full potential that current and future superior biotechnology applications offer.

To assist developing countries in the acquisition and application of proprietary biotechnology applications, ISAAA was founded as a not-for-profit international organization. It is cosponsored by philanthropic foundations, bilateral organizations, and corporations from the private sector that provide financial support and share biotechnology applications. ISAAA is a small, responsive, nonbureaucratic, international network. There are three centers established in the North—the *Ameri*Center, at Cornell University in the United States; the *Euro*Center at the John Innes Centre in the United Kingdom; and the precursor liaison office for the *Asia*Center in Japan—to monitor and evaluate the availability of biotechnology for transfer to the developing world. There will be three centers in the South—the *Afri*Center, *SEAsia*Center, and *Lati*Center—to help national programs identify priority needs for biotechnology applications. The *Afri*Center was established in 1994, the other two are planned for the near-term. Programmatic, organizational, and policy guidance is provided by an international board of prominent individuals representing developing and industrial countries, public and private sectors, and professional interest groups, particularly those in environmental protection.

ISAAA is funded by fixed-term commitments through a donor support group that includes a balanced representation of public and private sector institutions. No core funding is being mobilized, allowing full flexibility for changes in future directions without encumbering donors with long-term and less flexible core commitments. The fixed-term funding strategy exposes the program to regular peer review when accessing competitive international funding. Early tangible expressions of support from the public and private sectors were the significant grants awarded to ISAAA by eighteen donors.

The Program

ISAAA has initiated a pilot program that uses a five-step strategy to provide the following services:

- assist developing countries in identifying biotechnology needs and priorities and in assessing potential socioeconomic impacts in a demand-driven program;

- monitor and evaluate the availability of appropriate biotechnology applications, particularly proprietary technologies, from the private sector in industrialized countries;

- provide "honest broker" services by matching needs with appropriate proprietary technologies;

- mobilize funding from donor agencies for client countries to implement projects; and

- counsel developing countries on the safe and responsible testing of biotechnology products, and provide targeted assistance for implementation of biosafety and food safety regulatory procedures, socioeconomic analysis, management of resistance genes, and intellectual property rights.

The Strategy

The strategy is to focus on the safe and effective introduction of near-term biotechnology applications that already have been tested in industrial countries, particularly to:

- emphasize applications to increase the productivity of food crops, particularly *orphan commodities* grown by resource-poor farmers; contribute to sustainable agriculture and a safer environment through the development of alternative technologies

to conventional toxic pesticides; and assign high priority to horticulture and forestry;

- concentrate on three classes of plant biotechnology applications: tissue culture, diagnostics, and transgenic crops; and
- assign priority to the assessment of benefits and constraints of biotechnology in developing countries, including biosafety and food safety considerations, and the responsible deployment of resistance genes to optimize durability.

An example of such an application of biotechnology would be in forestry. Some of the tropical species that contribute to biodiversity in natural and commercial forests in developing countries do not lend themselves to easy seed propagation. Biodiversity will be threatened and genetic erosion will occur if biotechnology cannot be applied to offset these disadvantages.

ISAAA implements a demand-driven program that responds to the priority needs of twelve target national programs in Africa (Egypt, Kenya, and Zimbabwe), Asia (Indonesia, Malaysia, the Philippines, Thailand, and Vietnam), and Latin America (Argentina, Brazil, Costa Rica, and Mexico). These target countries were selected because they are developing nations that have some capability in agribiotechnology and the political will to play a leadership role in biotechnology transfer. Establishment of ISAAA centers in the South will encourage the diffusion of technology, at marginal cost, to neighboring countries with similar needs.

Program Achievement

Twelve ISAAA projects have been developed, brokered, and implemented or are under development. The most advanced model project involves Monsanto's donation of coat protein genes to Mexico for the control of potato viruses (PVX/PVY), which is funded by the Rockefeller Foundation and features technology transfer and training

of Mexican scientists. The first generation of transgenic potatoes, developed by Mexican scientists, has been field-tested in Mexico and is promising. Monsanto also has agreed to a South-South transfer of the PVX/PVY technology that will allow Mexico to share this technology with Kenya. A companion project assisted Mexico in developing the infrastructure and regulatory biosafety and food safety procedures for testing and introducing recombinant products. Discussions between Mexico and Monsanto are currently being held about technology transfer that involves use of a gene that confers resistance to potato leaf virus (PLRV), aimed specifically at varieties, such as Rosita, that are grown exclusively by resource-poor farmers. Monsanto also has agreed to a further donation of PLRV resistance to enhance the benefits for resource-poor farmers growing potatoes in other developing countries.

Other ISAAA projects include:

- Diagnostic for black rot of crucifers, one of the most important diseases of cabbage in Asia (Washington State University/Asian Research and Development Center-AVRDC).

- Development and transfer of several diagnostics for maize diseases in Brazil (Pioneer Hi-Bred International/EMBRAPA).

- Network for the development and testing of papaya that is resistant to Papaya Ring Spot Virus (PRSV) (Cornell University/Brazil/Thailand).

- Insect-resistant cotton (Monsanto/Brazil/Argentina).

- Transfer of a selectable marker gene in cassava (Sandoz/CIAT).

- Tissue culture-based pilot production facility for more productive, virus-free banana seedlings (South Africa/Costa Rica/Kenya/Uganda).

- Improved and healthier fruit trees with the application of diagnostics (South Africa/Zimbabwe).

- Breeding for maize streak virus resistance in maize (John Innes Centre, United Kingdom/Kenya/Pan Africa).

- Micropropagation and distribution of multipurpose trees (Mondi Corporation, South Africa/Kenya).

Projects under development include:

- Transgenic sweet potatoes resistant to one of the most devastating virus diseases of sweet potatoes (Monsanto/Kenya/Rwanda/Tanzania/Uganda).

- Cryopreservation technology for the conservation of plant genetic resources.

Project Support Activities

ISAAA initiated a series of activities to support project implementation. These include an initiative on biosafety and food safety regulatory development, socioeconomic analysis, intellectual property rights, issues related to biodiversity, and deployment and management of crops resistant to insects *(Bt)*. A series of five biosafety workshops were completed in Argentina, Costa Rica, and Indonesia, and two were completed in Kenya.

Investment in Human Capital, ISAAA's Fellowship Program

Recognizing that human capital and training are the most important factors for sustainable and successful projects, ISAAA has a strong fellowship program. Training, an element in all ISAAA projects, is essential to build capacity and sustainability *vis-à-vis* biotechnology in national programs and to preclude dependence of developing countries on industrial countries for the new technologies. To date, ISAAA has arranged mid-career training for twenty scientists from eight countries in transformation, regeneration, diagnostics, and molecular biology. Unlike traditional training programs, which usually have

involved the public sector in industrial countries, a noteworthy feature of the ISAAA Fellowship Program is that most of the project-specific, hands-on training has been undertaken with private sector corporations rather than with the public sector.

Four regional biosafety workshops organized in Latin America (2), Asia, and Africa have provided training for approximately 250 regulatory officials and scientists from developing countries in the promulgation and implementation of biosafety guidelines. In the workshops, representatives from industrial country public sector regulatory agencies and from private sector corporations, which are the major users of biosafety regulations, have shared their experience with colleagues from the developing countries. The thrust of the biosafety activities is to build capacity in regulatory oversight in national programs. For projects that involve genetically engineered plants, ISAAA ensures that products are tested and introduced in a safe and effective way, and preferably in harmony with existing biosafety regulations of industrial countries. A similar series of training activities is being developed for food safety, and future plans include activities in intellectual property rights and socioeconomic studies, which are incorporated in all projects that deal with recombinant technology.

Summary

In summary, the ISAAA experience has already demonstrated that partnerships can be built between the public and private sectors to their mutual advantage, and that win-win options can be negotiated. These options include a partnership between the public sector in a developing country and a private sector corporation in an industrial country that involves outright donation of a biotechnology application by the private sector corporation; a joint venture that involves a contribution of technology from the two partners (for example, adapted germplasm from the developing country and a gene that confers added value from the private sector corporation), with an arrangement for development costs and return on investments to be shared by both parties; and a partnership between two private sector corporations, one from the North and one from the South, to commercialize a product by optimizing the comparative advantages of the partners.

Establishment of the Private Sector Committee of the CGIAR

Proposal to Establish the Committee

At the CGIAR Ministerial-Level Meeting in Lucerne, Switzerland, February 9–10, 1995, ministers, heads of organizations, and delegates representing the membership of the Consultative Group on International Agricultural Research recommended that the CGIAR broaden its partnership within the global agricultural research system. More specifically, as part of their *Declaration and Action Program*, the Ministerial-Level Meeting encouraged the CGIAR to convene a committee of the private sector as a means to improve the dialogue among the CGIAR, the private sector, and members of the civil society interested in the same issues as the CGIAR. Interaction between the committee and the CGIAR was envisioned to be collaborative and of a consultative nature. The CGIAR was urged to work in closer partnership and collaboration with the private sectors in the North and in the South to design and conduct joint research programs and to ensure that the CGIAR's research agenda reflects the views and goals of global and regional partners in agricultural research. Under the leadership of the Chairman of the CGIAR, Mr. Ismail Serageldin, a proposal was developed, discussed, and agreed to by the CGIAR, to establish the committee, which first met in December 1995.

Terms of Reference of the Committee

The committee interacts with the CGIAR to provide a private sector perspective on the current status of global agricultural research and future needs. It serves as a link between the CGIAR and the agricultural private sector organizations at large, in the North and the South, and facilitates the liaison between the agricultural private sector and the CGIAR. Through rotation of membership, over time the committee will incorporate representative views of a broad cross section of the private sector in relation to policies, strategies, research priorities, and program activities in agricultural research and development in the North and in the South.

The CGIAR initiative to form the committee aims at encouraging the private sector to foster and develop new programmatic partnerships that exploit fully the respective strengths, network of relationships, and comparative advantages of the CGIAR and the private sector.

The committee brings to the CGIAR its perspectives on issues such as the following:

- current and future needs and priorities for agricultural research and development in developing countries;

- current and future strategies of the private sector, especially in the South, to respond to those needs;

- private sector views on CGIAR policies, strategies, and activities, including views on recent private sector research breakthroughs or cutting-edge technologies that the private sector would be willing to share with the CGIAR;

- identification of program thrusts that represent an opportunity for the private sector and the CGIAR to collaborate and to optimize the comparative advantages of the partners to achieve mutual goals and objectives; and

- evolution of a new partnership between the private sector and the CGIAR that will represent a holistic and all-encompassing global approach to food security.

The committee expects to carry out its work by:

- meeting two times per year, for approximately two days, at locations in the North and in the South (these meetings may or may not coincide with the

Mid-Term Meeting and International Centers Week of the CGIAR);

- interacting with the various elements of the CGIAR system and the clients that it serves in the developing countries;

- consulting with the CGIAR and its Chairman, as necessary;

- organizing meetings, workshops, and consultations to broaden interactions between the CGIAR and private sector institutions; and

- presenting to the CGIAR views and proposals emerging from the committee's deliberations.

The committee is represented at CGIAR meetings through attendance by the Co-Chairs.

Composition and Membership of the Committee

The committee has ten private sector members, including two Co-Chairs, one from the North and one from the South. Half of the members are from the private sector in the North, the other half from the private sector in the South. Members were selected from small, medium, and large companies and represent the major activities of the private sectors in the North and South, focusing on the particular areas where the CGIAR is active (for example, genetic improvement and management of crops, livestock, forest, and fisheries; soil fertility; conservation and use of genetic resources; formulation of government food policies; and conservation and management of natural resources). The committee has reasonable geographic coverage, and is a manageable size. Members are senior executives who are leaders in their respective fields, have experience in strategic planning and policy decisions, and have a broad range of professional backgrounds in the principal areas where the private sector and the CGIAR are active.

Initial Areas of Interest Identified by the Committee

The committee has identified the following four topics for exploration and dialogue with the CGIAR:

- biotechnology;
- intellectual property rights, genetic resources, and biodiversity policy;
- mechanisms of interaction between the CGIAR, NARS, and the private sector; and
- international centers and private sector practices in research and research management.

Summary

In summary, the establishment of the Private Sector Committee of the CGIAR represents an important development that should provide mutual benefits. The CGIAR, with a current annual budget of approximately $300 million (equivalent to 4 percent of public sector spending on agricultural research in developing countries), is the single largest public sector investor in international agricultural R&D. The significant impact of the international centers of the CGIAR on productivity and production of staples, such as wheat and rice, is well documented and internationally recognized, as shown by Dr. Norman Borlaug being awarded the Nobel Peace Prize in 1970 for his pioneering work on semidwarf wheats. More recent objectives of the CGIAR focus on food self-reliance rather than food self-sufficiency, acknowledging both that agricultural and economic growth can alleviate poverty and the need for an eco-regional perspective to develop sustainable systems that conserve natural resources and protect the environment. The private sector faces the same challenges. These challenges demand more resources than the public and private sectors can marshal independently, and, thus, it is both logical and desirable for the public and private sectors to collaborate in the pursuit of a goal that is vital for the survival of the global community—food security.

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Appendix

Table A-1. Principal Fertilizer Companies (listed alphabetically)

Company	Country
Nitrogen/Ammonia (N)	
Arcadian	United States
CF Industries	United States
DSM Agro BV	Netherlands
Farmland Industries Inc.	United States
ICI Fertilizer	United Kingdom
Kemira Oy	Finland
National Fertilizer Ltd.	India
Norak Hydro As.	Norway
Pemex	Mexico
Pupuk Kaltim	Indonesia
Rashtriya Chemicals & Fertilizers Ltd.	India
Phosphate (P_2O_5)	
CF Industries	United States
Freeport McMoran Resource Partners	United States
ICW/SIAPE/SAEPA	Tunisia
IMC Fertilizer Group Inc.	United States
Occidental Chemical Corp. Ag. Products	United States
OCP	Morocco
Texas Gulf Inc.	United States
Potash (K_2O)	
Arab Potash Company	Jordan
Entreprise Miniére et Chimique	France
Dead Sea Works	Israel
IMC Fertilizer Group Inc.	United States
Kali and Salz	Germany
Kallum Chemicals	Canada
Potash Corporation of Saskatchewan	Canada

*List excludes producers in China, the former Soviet Union, and Central Europe.

Source: Communication from International Fertilizer Industry Association (IFIA), Paris, France.

Table A-2. Major Plant Protection Companies (based on estimated 1994 global sales of crop protection products)

RANK	NAME	COUNTRY	APPROXIMATE SALES ($ MILLIONS)
1	Novartis	Switzerland	4,126
2	AgroEvo	Germany	2,140
2	DuPont	United States	2,140
4	Monsanto	United States	2,123
5	Zeneca	United Kingdom	2,120
6	Bayer	Germany	2,041
7	Rhone-Poulenc	France	1,866
8	DowElanco	United States	1,737
9	Cyanamid	United States	1,618
10	BASF	Germany	1,316
11	Sumitomo	Japan	603
12	FMC	United States	504
13	Kumiai	Japan	500
14	Sankyo	Japan	459
15	Ishihara	Japan	455
15	Nihon Nohyaku	Japan	455
17	Rohm & Haas	United States	439
18	Hokko	Japan	380
19	Takeda	Japan	363
20	Nissan	Japan	356
21	Sipcam Oxon	Italy	351
22	Makhteshim	Israel	320
23	Uniroyal	United States	268
24	Atochem	France	240
25	Nippon Soda	Japan	210
Total			27,130

Source: Wood Mackenzie (1996), with adjustment for mergers that have taken place subsequent to 1994.

Table A-3. Major International Seed Companies (ranked by worldwide sales in 1994)

RANK	NAME	COUNTRY	APPROXIMATE SALES ($ MILLIONS)
1	Pioneer	United States	1,500
2	Novartis	Switzerland	907
3	Limagrain	France	820
4	ELM (Pulsar)	Mexico	500
5	Vander Have/Zeneca	Netherlands/ United Kingdom	460
6	Takii	Japan	450
7	Dekalb Plant Genetics	United States	320
8	KWS	Germany	315
9	Cargill	United States	250
10	Pau Euralis	France	170
11	Sigma Semences de France	France	160
12	RAGT	France	150
13	Rhone-Poulenc	France	140
14	Cebeco	Netherlands	125
15	Barenbrug	Netherlands	120
Total			6,387

Source: *Cited in* Anonymous (1996).

Table A-4. Major Animal Health Companies (based on estimated 1994 global sales of animal health and nutrition products)

Rank	Name	Country	Sales ($ millions)
1	Hoffman-La Roche	Switzerland	1,293
2	Pfizer	United States	1,251
3	Rhone-Poulenc	France	1,158
4	Merck	United States	815
5	Bayer	Germany	663
6	BASF	Germany	629
7	Novartis	Switzerland	485
8	Hoechst	Germany	464
8	Eli Lilly	United States	464
10	Mallinckrodt	United States	448
11	American Home Products	United States	374
12	Upjohn	United States	346
13	Degussa	Germany	288
14	Solvay	Belgium	232
15	Novus	United States	220
16	Akzo	Netherlands	216
17	Boehringer Ingelheim	Germany	204
18	Virbac	France	199
19	Schering-Plough	United States	167
20	Sanofi	France	162
21	Takeda	Japan	153
22	Alpharma	United States	141
23	Nippon Zenyaku	Japan	136
24	Janssen	Belgium	132
25	Tortuga	Brazil	110
Total			10,750

Source: Wood Mackenzie (1996), with adjustment for mergers that have taken place since 1994.

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Prior to his association with ISAAA, Mr. James was Deputy Director General for Research at the International Maize and Wheat Improvement Center (Centro Internacional de Mejoramiento de Maiz y Trigo—CIMMYT), a CGIAR center headquartered in Mexico.

Mr. James has served as Senior Agricultural Adviser to the Canadian International Development Agency (CIDA), the Food and Agriculture Organization of the United Nations (FAO), and has consulted for many international development agencies, including the United Nations Development Programme (UNDP) and the World Bank, and for the Hitachi, McKnight, and Rockefeller Foundations.

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