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AGRICULTURAL RESEARCH AND TECHNOLOGY IN THE 1990S IN ASIA AND THE NEAR EAST: TRENDS AND POSSIBLE STRATEGIES FOR A.I.D.

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EXECUTIVE SUMMARY

Impact of Agricultural R&D in ANE

Agricultural research has paid off in the past. Recent studies of the major field crops indicate that research by Asian governments, by the International Centers of the CGIAR and by the international and national research systems working together have consistently produced high rates of return to government investments. A few recent studies suggest that private R&D also produces high social rates of return.

Public research on the basic grains has had a generally favorable impact on income distribution. Much of the benefits from modern varieties have been passed along to consumers in the form of lower prices. Since purchases of basic grains make up a large share of the income of the poor, they benefit much more than the rich who spend little on grain.

Potential Future Impact

Agricultural research will continue to be a productive investment in the 1990's. There is some evidence that currently available technology and applied research may produce somewhat less growth in the near future. The spread of modern varieties of wheat is approaching 90 percent in Asia and the spread of modern rice varieties may also be slowing down. Nevertheless there are many technical opportunities for increase production through crop management research, research to spread modern varieties of coarse grains and oilseeds, and research on some plantation crops.

Biotechnology holds promise of increasing yield stability through better control of disease and insect pests. This could have an impact on rice production in the next five to ten years and other crops later. It is unlikely to have much impact on the yield potential of major field crops in Asia and the Near East until after 2000. To increase yields national research programs will have to build on the breakthroughs in biotechnology in rice, maize, and other crops in which basic research is currently underway.

Trends in R&D in ANE

Research systems in most ANE countries grew rapidly between 1960 and 1980. Since 1980, government R&D expenditure has gone up in some ANE countries but down in others. R&D expenditures in all ANE countries are low relative to the size of agricultural GDP.

Research expenditure by the international agricultural research centers in the CGIAR has leveled off. Within the CG system emphasis is shifting to sub-Saharan Africa. The number of international centers outside the CG is growing, and the CG is considering accepting some of them as members of the CG. Many of the new centers emphasize resource management rather than plant breeding.

Private sector research in Asia is growing rapidly but from a very low base. Private research expenditures is now as large as public research only in a few crops such as maize in some ANE countries.

Weaknesses of current systems

NARS spend too little on agricultural research particularly on the major food grains and subsistence crops. Most NARS in the ANE countries do have fairly strong applied plant breeding programs but their research to adapt the results of applied research to farmers' needs are weak and strategic and basic research is almost nonexistent.

Private research expenditures in ANE is much less than public expenditures. It is very applied and concentrates on hybrid seed development, pesticide research, machinery development and plantation research. As such, it neglects many of the same areas in which the public sector is weak.

The international centers are strongest in applied research. They are moving into biotechnology research. CG and non-CG centers are starting to work on some important resource management issues, but research on resources and the environment is still one of the most neglected areas of international and national research.

AID R&D Priorities for the 1990's

Countries: AID's R&D priorities should be investments in Burma, Philippines, and others that have low R&D expenditure to agricultural GDP ratios.

Within Countries: Priority should go to the relatively favorable agricultural regions in countries where food production is still an important problem.

Commodities: Basic food grains have priority especially in South Asia. Food grain self-sufficiency is still fragile in Asia. Production may not keep up with demand in Asia and will fall further behind than it is today in the Near East. Technical opportunities for productivity growth are available and countries are currently underinvesting in food grain research.

Non-commodity Research on resource and environmental issues must be strengthened.

Types of research: Adaptive research which tailors technology to farmers' needs and strategic research like applying biotechnology to breeding stress resistant crops should receive the most attention.

Types of institutions: To increase food grain production, public research and CGIAR centers need support. For diversification, AID should support private research and the government agricultural research institutions. For more basic biotechnology and resource research, LDC agricultural universities and general universities; international centers; and DC

universities and private research companies must play receive resources.

Strategies for Implementing Priorities

To increase the productivity of government research institutions in ANE governments, AID should encourage more participation in R&D priority setting by farmers and agribusiness. AID can provide money to existing farmer groups to fund research by the group or by other institutions. AID can support programs that help organize farmer groups. Finally, AID can encourage government research institutions to work more closely with farmer groups.

AID should also be investing in more basic strategic and basic agricultural research in ANE. This requires more than just scholarships, building and equipment. AID must find ways to support joint research, improve communications between scientists within LDCs, and with their colleagues elsewhere.

AID should do more to promote private sector research. It can help remove policy constraints on private research. It can encourage public research projects that will induce more private research such as the development and release of superior inbred lines. Finally, AID may be able to subsidize private research on certain important topics.

1. Introduction

Agricultural research has been a productive investment in Asia and the Near East. Ex post analysis has shown that investments in National Agricultural Research Systems (NARS) and the International Agricultural Research Centers of the CGIAR[1] have been among the most productive public investments in developing countries. Private sector R&D and technology transfer have also had an important impact on some commodities and have been a very productive investment for those companies that have invested in it. Analysis of AID's past investments in the NARS has shown that this is one of the most productive investments AID has ever made.

Despite the evidence on the benefits of agricultural research, the wisdom of further government investment in research is being questioned in a number of countries in the Asia and Near East (ANE) region. Expenditure on agricultural research as a percent of agricultural income is low in all ANE countries and it is declining in several countries. Despite AID's success in this area and the potential returns in the future, AID's investments are declining.

Section two of this paper reviews the evidence on past returns to research in ANE countries and the potential for high payoffs from R&D in the future. Section three examines current trends in research expenditure and institutional development. Section four looks at AID's current agricultural research program. Sections five and six present preliminary suggestions for future AID activities.

[1]. National Agricultural Research Systems (NABS) includes only the government agricultural research institutions. The International Agricultural Research Centers of the Consultative Group for International Agricultural Research (CGIAR) refers to the thirteen centers which are funded by the CGIAR. Private sector R&D refers to the research of private companies. Research by groups of private individuals or firms is referred to as commodity group or cooperative research.

2. Agricultural Research - A Productive Investment

2.1 Impact on Production and Productivity

Technological change has been a major source of agricultural growth in the recent past. With the closure of the land frontier in most countries of ANE technical change will be even more important in the future. Local agricultural research has been an important source of new technology because agricultural technology can rarely be transferred directly from one region to another. It almost always has to be adapted to local climatic, soil and market conditions by local research.

2.1.1 Impact of Public R&D.

The payoff to public sector agricultural research, estimated using a number of different economic techniques, has been very high in a wide variety of countries. Internal rates of return of 30 to 50 percent are the most common range while the returns to many specific projects are much higher. Table 1 contains a listing of rates of return from various studies.

The payoffs to government agricultural research in ANE have been calculated in a number of studies. In Table 2 Pray and Ruttan (1985) summarized studies conducted for Asia Bureau by the University of Minnesota and Yale University. Most of the studies covered the period of the 1960's and 1970's. The marginal rates of return were all very high except for maize in Pakistan. The average internal rates of return were also very high indicating that these research investments were indeed productive investments. Studies conducted in the Philippines and Thailand using the duality approach found that research had a statistically significant, positive influence on total output in the Philippines and on corn production in Thailand. The Philippine and Thai studies are not included in Table 2 because the rates of return to R&D were not calculated.

More recently the CGIAR Impact Study (Anderson,et.al.1987) examined the

impact of research by less developed countries (LDC) governments and the international centers of the CGIAR on crop production and agricultural productivity. The final report emphasized the collaborative nature of the CG and NARS and calculated the impact of this joint effort on food production in developing countries. Table 3 shows the percentage of total wheat and rice area under center-related varieties[2] in Asia and North Africa. These varieties resulted in an additional 50 million tons of food world-wide (World Bank 1985) of which 25 to 30 million tons were produced in the ANE region. Table 3 also contains data on improved open pollinated varieties (OPVs) and hybrids of maize. Many of the OPVs are related to International Maize and Wheat Improvement Center (CIMMYT) or earlier Rockefeller Foundation material as are the hybrids in the Philippines, Thailand and Indonesia. About half the hybrids in India were developed by public R & D working with the Rockefeller Foundation in the 1950's and 1960's and half are hybrids developed more recently by the private sector.

Only one study (Boyce and Evenson 1975) has attempted to measure the relative impact of applied vs. more basic R&D in LDCs. It found that "science-related" research generated economic returns that were four times larger than the "technology-oriented" research.

The question of many policy makers is: Are these high returns simply a product of the Green Revolution of wheat and rice or is there really a high return to current research by the NARS? A recent study by Robert Evenson (1988) show that the impact of the CG and the NARS was not confined to wheat and rice. He used a data set of 10 crops[3] in 24 developing countries for the period from 1962 to 1982 to estimate the impact of the international centers and national research systems. Six of the ten Asian

[2]. Center-related means varieties that were developed at the centers and varieties developed in the NABS that germplasm or lines from the centers in their ancestry.

[3] Maize, millet, sorghum, rice, wheat, beans, cassava, groundnut, potatoes and sweet potatoes.

countries[4] in his sample are countries currently receiving assistance in agricultural R&D. He found that CG research has a significant positive impact on the production of all the crops except sweet potatoes. National research investment was highly productive in all commodity groups in Asia. He found rates of return to research by Asian NARS of 50 percent for rice and wheat research and over 80 percent for maize, millet and sorghum research. He also calculated separate returns to CG research in Asia and found returns of over 80 percent for wheat and rice and 68 percent for staples like potatoes and cassava.

Hybrid sorghum and pearl millet in India are good examples of the impact of national and international research on crops other than rice and wheat. Sorghum and pearl millet are the third and fourth most important food grains in terms of area and third and fifth in terms of production in India (Jansen 1988). They are coarse grains and as such are primarily eaten by the poor in poorer regions of the country. They are cheaper than wheat or rice. Less than six percent of pearl millet and four percent of the sorghum acreage is irrigated. Pearl millet is almost entirely grown on small farms, and most of the sorghum is grown on small farms.

The hybrid sorghum and hybrid pearl millet cultivars developed by the Indian government, by International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and by the private sector are grown on more than one third of the total area of these crops. Figure 1 shows the percentage of area under hybrids and improved varieties. Virtually all of the improved sorghum and pearl millet cultivars were public hybrids until 1983 when improved varieties of pearl millet WC-C75 from ICRISAT started to become popular. In the last two years a number of private hybrids based on ICRISAT inbred lines in the case of millet, and government and ICRISAT lines in the case of sorghum, have become popular. The most recent estimates are that private pearl millet hybrids are grown on about 880,000 hectares and private sorghum hybrids on 260,000 hectares (Pray et.al.1988).

[4] Sri Lanka, Indian Taiwan, Pakistan, Indonesia, Thailand, Philippines, Korea, Malaysia, Turkey.

WC-C75 now covers about 1.5 million hectares and an ICRISAT hybrid known as M-179 may cover as much as a million hectares (ICRISAT 1988).

A study still underway at Yale looks at productivity growth in India after the Green Revolution. The analysis uses district level data for ten Indian states. The only region that is seriously under-represented is the Eastern rice region. The preliminary results are that productivity grew more rapidly in the period 1974 to 1983 than it did during the Green Revolution period 1964 to 1974. The use of commercial inputs also grew more rapidly in this period, but output growth was considerably greater.

2.1.2 Impact of Private R&D and Technology Transfer on Productivity and Diversification.

Private research is also starting to contribute to the productivity of major food grains. Research by seed companies in India using germplasm gathered and improved by the Indian government and ICRISAT produced pearl millet hybrids which yield 25 to 30 percent more than earlier hybrids and are resistant to downy mildew (AICMIP 1988). These yields clearly translate into yield gains under farmers' conditions because private hybrids have been adopted on almost 900,000 hectares. There is also evidence of the impact of private R&D on maize. Using data for major maize growing LDCs Echeverria finds a positive statistical relationship between Multinational seed company's R&D and maize yield per acre (Echeverria 1989). The Philippines, Thailand, India, Pakistan and Egypt were included in his sample.

The private sector has been a major source of new technology for successful cases of diversification. Diversification has been led by market demand and in some cases by government subsidies rather than by technology, but technology has played an important role. The breakthroughs in poultry production throughout the ANE regions have been dramatic. Growth in poultry production in Asian LDCs excluding China was 6.2 percent annually between 1961 and 1985. During that same period poultry production grew by 8.4 percent annually in the Near East/North Africa. This compares with 2.5

percent growth in beef production in both regions (FAO). The technology behind this revolution was US and European breeds of poultry, pharmaceuticals, feeds and confinement management. The feeds, management practices and buildings have been modified to fit the available raw materials and climate. The other inputs have not been adapted with the exceptions of the breeds used in India which were developed in R&D by joint ventures. Commercial swine production is also largely based on imported technology which has been adapted to local conditions by private companies.

The "white revolution" in dairy production in India was based on a combination of indigenous feeding technology, crossing local and exotic cattle and pharmaceuticals developed in other countries. The adaptive research which put this package together was financed and conducted at Anand Dairy and later by the National Dairy Development Board which are private cooperatives.

Crop diversification in Asia has also been based on privately supplied technology. The key technology in the expansion of cassava in Thailand was the pelletization process which cut transportation costs and made cassava acceptable to the European market. This technology was introduced by Cargill. The rapid expansion of banana production in the Philippines is based on production technology which was developed in Central America by United Fruit and adapted to conditions in the Philippines. Other examples of private companies importing and adapting foreign technology are commercial tomato production in the Philippines, pineapple production in the Philippines and Thailand, and rubber and oil palm technology the Philippines, Thailand and Indonesia.

In addition to technology importation and adaptive research, some applied private research programs have contributed to the diversification process. Venkateswara Hatcheries (VH) in India has impressive R&D facilities in Pune which have modified the layers and broilers which came from the US to fit Indian conditions better. VH chicks now dominate India's huge market.

2.2 Impact on Income Distribution

Public research on the basic grains has had a generally favorable impact on income distribution. Consumers have gained most of the benefits from modern varieties through lower prices of food. Since purchases of basic grains make up a large share of the income of the poor, they benefit much more than the rich who spend little on grain. The only places where local research may not have reduced prices are the North African countries that import much of their food grain. Increases in local production would have little impact on prices which are determined in the world market.

Agricultural laborers are affected through changes in their wages and in the prices of staple foods. The consensus of economists that have looked at the question is that the effect of high yielding varieties has been to increase the demand for labor (Lipton & Longhurst 1986). This has not shown up as higher wages in most areas because the supply of labor due to population growth has gone up more rapidly than demand for labor. Attempts to measure directly the impact of public R&D on the demand curve for labor have been successful statistically, but they do not show a consistent pattern across countries (see Pray and Ruttan 1985). In north India HYVs shifted demand for labor upward, while local research had a negative effect. In Thailand the effect was positive but insignificant while in the Philippines the impact was negative.

The people who are probably most negatively affected are the farmers in regions which are not suited to new technology. Increased productivity of food grains in favored areas reduces the demand for the food grains grown in unfavored conditions and pushes the price of food grains down. They do not have any new technology to reduce their costs of production and so their net income and profits are reduced. These problems are mitigated somewhat by new technology, as the examples of hybrid pearl millet and sorghum illustrate. Agricultural laborers will go to areas which can adopt new technology and they will not be affected as adversely as owners of land. This has happened in the Punjab which has absorbed much labor from U.P. and Bihar.

The impact of private research and technology transfer on income distribution has been mixed. To the extent that private technology lowers the price of basic foods, it improves the position of the poor. Private plant breeding which produces higher yielding hybrids of pearl millet, sorghum and maize would lower prices unless the research only improves the crops as livestock feed.

The impact of private R&D on the relative position of landowners and agricultural labor depends on the technology. Herbicides, improved tractors, and threshers are generally labor-displacing while hybrid seeds and fertilizer are usually labor-using.

There is an additional impact of private research on employment in production of the input. The largest seed company in India has annual seed production contracts with over 6,000 farmers about half of whom are producing the company's private hybrids. They also employ hundreds of women each year to hand pollinate cotton to produce their private hybrid seed. Plantation research that increases exports by improving the quality of plantation output would probably increase the demand for labor. If plantation research increases exports by lowering the cost of production through labor saving technology, labor would be displaced. As yet no studies have attempted to quantify the aggregate impact of private research and technology transfer on income distribution, and there are very few case studies of the impact of specific technologies developed by the private sector.

2.3 Need for New Agricultural Technology

Research on major food grains is still essential to LDC development despite the fact that many countries have reached self-sufficiency. Most Asian countries will probably stay above the self-sufficiency level in food grains through the 1990's. Paulino (1986) projects a negative food trade balance for all developing countries in 2000, a net surplus of major food crops in all regions of Asia by 2000 and large and growing food

deficits in North Africa and the Middle East. FAO predicts that rice will remain at the self sufficiency level in 2000 while the deficit in wheat production will grow to about 64 million tons or 17 percent of LDC consumption (FAO, 1987).

There is a need for research on major crops to ensure that their production and productivity keeps growing so that more of the poor can reach the minimum consumption levels which are not affordable at present. Research is needed to find ways to make these crops less vulnerable to drought and other fluctuations in the weather and policies. Self-sufficiency and the low price of food grain are likely to be vulnerable to changes in policies of developing and developed countries, to the weather and to diseases and pests.

There is a need for maintenance research to preserve the gains of the Green Revolution in the face of continually evolving pests and pathogens. This is most dramatically illustrated by pearl millet in India (Jansen, 1988). Since public sector research on hybrid pearl millet started in the late 1950's, it has produced three series of hybrids. ICRISAT and the private sector have produced a fourth series. The first series was based on a male sterile line from Tifton, Georgia, called Tift 23 and released over the period 1965 to 1972. They gained immediate popularity because of their yield potential of 2500 kg/ha (compared to the 500 kg/ha average yield in farmers' fields). They covered over 20 percent of the pearl millet area in 1972-73. These cultivars became susceptible to downy mildew in the early 1970's and acreage and production of pearl millet declined dramatically when downy mildew attacked. A second series of public hybrids were released in 1975. They were popular, but their resistance to downy mildew broke down within a few years. They were replaced by public hybrids BJ-104 and BK-560. Their resistance broke down in 1983-84, and they were withdrawn from the list of approved hybrids by the government. They were replaced by the fourth generation of hybrids: the private and public hybrids based on ICRISAT lines and ICRISAT variety WC-C75 as described above.

In the absence of the maintenance research which produced the new downy

mildew resistance hybrids and varieties, pearl millet production might well be back at the 3.86 million ton level of 1961-65 rather than the current (1983-87) level of 5.4 million tons (India 1988).

In countries where increases in food grain production have pushed down food prices, market forces lead farmers to diversify. This will lead to demand for new technology some of which can be provided by public sector research. For example, if more pulses or oilseeds are desired for nutrition or input substitution, new pulse and oilseed varieties need to be much higher yielding to compete with food grains. With the exception of crops which potentially have hybrid seeds such as sunflower and pigeon peas, private seed companies are not interested in field crops. Therefore the public sector will have to breed them.

Much of the technology needed for diversification can be acquired through the private sector. Foreign technology and local adaptive research is required for Asian plantations to compete internationally on some new crops like cocoa. Diversification into sunflower in Asia is being led by private sunflower hybrids from abroad. Hybrid and varietal vegetable seeds are imported throughout ANE from the US, Europe and Japan.

Concerns about the impact of deforestation, erosion, and salinity in irrigated areas have already become sufficiently serious problems to attract some NARS and international research resources. These problems will become more serious in the 1990's and demand for research on these topics will undoubtedly grow. Agricultural and non-agricultural pollution is not a big issue now but more tragedies like Bhopal, poisoning from pesticides on vegetables and US and European barges dumping hazardous wastes in LDCs will increase demand for research on these issues in the 1990's.

2.4 Technological Opportunities

The NARS and IARC research that produced the original HYVs also created opportunities for high pay-off local research to adapt HYVs to replace traditional varieties. Dalrymple(1986) estimates that about 79 percent of

the wheat and 45 percent of the rice in Asia are planted to HYVs. Table 3 shows that there is considerable variation between countries and that the North African countries have a lower level of adoption of wheat. There is much more scope for improved maize (lower panel Table 3). In most countries the area planted to high yielding sorghum, millets, pulses or oilseeds is very small.

Robert Herdt (1988) has recently evaluated the potential for further spread of HYVs of wheat, rice and maize. He felt there was little opportunity for further spread of wheat and rice, but that there were some opportunities in maize - particularly in Africa. Robert Evenson at the HIID/USAID meeting in September, 1988, stated that Herdt was too pessimistic about rice and that there were still opportunities to adapt rice HYVs to new areas. Sorghum, pearl millet and sunflower probably offer good opportunities for the spread of HYVs, since HYVs are starting to spread in some countries as noted above.

In regions which are already covered by modern varieties there are still possibilities for improving yields through R&D. Modern varieties now cover about 90 percent of wheat acreage in Asia. In Pakistan and Mexico since the Green Revolution, plant breeders have been able to maintain yield gains in new varieties of one percent a year in irrigated areas (Byerlee, 1987). CIMMYT staff feel that opportunities are even greater from research to improve management:

> There are, however, considerable opportunities to increase yields and productivity in irrigated areas through changes in other cultural practices such as reduced and zero tillage, better stand establishment , more efficiency in fertilizer use, identification of soil micronutrient deficiencies, control of weeds and pests, crop rotation to manage soils and reduce conflicts with wheat planting, and more efficient management of irrigation water. Likewise, in dryland areas, improvements in productivity usually rest on better tillage to conserve moisture, weed control, and efficient use of fertilizer...To realize these gains, a strong crop management research program, linked with effective extension and input supply systems and combined with skilled farmers and a conducive price policy environment is often required. (Byerlee 1987).

The trends in private sources of technology in the U.S. and Europe which could the basis of applied and adaptive research in ANE vary from industry to industry. The growth of aggregate private R&D on agriculture by the input industry in the US is slowing down (Pray, Neumeyer and Upadhyaya,1988). This is particularly dramatic in farm machinery where expenditure has declined every year since 1980. Agricultural chemicals R&D growth has just kept up with inflation, but the number of new chemicals produced from a dollar of research has declined. Biotechnology is one area where there is an increase - probably at the expense of traditional agricultural chemicals research. There is no recent industry level data available for the seed industry but two of the leading research firms - Pioneer and DeKalb - both increased their research by 9 percent between 1986 and 1987 ("R&D Scoreboard",1988).

These trends imply that there will be less R&D opportunities available in agricultural machinery and agricultural chemicals but more in seeds and biotechnology products (veterinary pharmaceuticals, biological pesticides, improved plant and animal varieties).

There are conflicting trends in technological opportunities in the plantation industry. Advances in tissue culture can greatly increase the efficiency of breeding tree crops - especially oil palm. However, the productivity of the Malaysian Rubber Research Institute, which was an important source of technology for all of Southeast Asia, continues to deteriorate. In addition the Malaysians are attempting, so far unsuccessfully, to prevent the export of planting material of plantation crops. The future of banana technology is also uncertain. United Fruit turned their banana research facility in Honduras over to a research foundation of unproven capacity. Public sector research on banana has been strengthened by the develop of an international network for bananas called INIBAP.

The developments in biotechnology have opened up opportunities for developing new technology through more basic research combined with traditional plant breeding. Advances through biotechnology require

knowledge about the genetic charactistics of the crop. Rice is the only tropical crop in which there is a major program to generate this knowledge. Research programs in the US and Europe study the genetics of crops like maize that are important in temperate climates. Thus, it is possible that research in the ANE region could build on basic knowledge of rice and maize. In other important crops much basic research still needs to be done.

Even in rice, which is probably the most advanced in terms of genetic engineering, there will be little impact of biotechnology on agricultural production in LDCs in the next five to ten years (Herdt 1988). The impact will be primarily on stability of rice yield. It will be achieved by reducing the susceptibility of rice varieties to disease and insects. Advances that actually raise the yield potential of rice will not come until the next century (Herdt 1988). Since less is known about other crops, it will take even longer to improve them through biotechnology.

Despite these somewhat pessimistic predictions about the impact of biotechnology on major field crops, it appears that research on improving stability and eventually increasing yield potential will have high economic rates of return. In addition, biotechnology research may have a more rapid impact on tree and bush crops like oil palm, rubber, and tea. It may also reduce some of the environmental problems like deforestation through rapid propagation of improved trees and environmental problems like pesticides by introducing pest resistant characteristics from bacteria into the plant.

The Impact Study (Anderson et.al.1987) is one of the few studies that attempt to calculate the future rates of returns to research in LDCs. They examine a limited number of projects that are currently underway in the CGIAR centers. They were improvement of upland rice for favored areas of Latin America, biological control of cassava pests, aluminum tolerance in wheat, downy mildew resistance in maize, and true potato seed. The Impact Study concluded:

> Even after conservatively estimating gains in productivity and attributing only a small share of those to the centers, expected annual rates of return range from 20 to 40 percent. The high prospective rates

of return reflect the fact that the centers' work is applicable to broad areas, so even small advances in productivity have an impressive payoff (Anderson 1987).

3.Trends in Size and Structure of R&D

3.1 Past Trends and Current Position

Research in Asia and the Near East is conducted largely by the government research systems. Table 4 provides an overview of the relative importance of government research, International Agricultural Research Centers of the CG and research by private companies in seven Asian countries in 1985. The public sector clearly dominates expenditures on agricultural research. In some countries, however, the private sector invests more in R&D on certain crops and inputs than the public sector. Table 5 contains some rough estimates of the allocation of private breeding, pesticides, plantation and livestock R&D in the Philippines. Private R&D in rice is greater than public R&D (excluding IRRI) because several multinational corporations have regional pesticide research stations in the Philippines. Private corn R&D is larger primarily because of Pioneer's large breeding program and private fruits and vegetables R&D is due to large investments by private plantations and exporters.

The trends in agricultural research by the public sector vary considerably within this region. In general the 1960's and 1970's were periods of rapid growth in ANE research. All ANE countries increased real research expenditure in the 1960's. In the 1970's some countries like Bangladesh and Indonesia made huge increases in expenditure while most of the others grew quite rapidly (see Table 6). Agricultural R&D expenditure declined in only two countries - Egypt and Sri Lanka. The right side of Table 6 shows the trends in five countries for which 1980's data is available. Real expenditure in the Philippines declined. Local expenditure in Indonesia declined, but this decline was offset by increased donor expenditure. Research expenditure in India, Thailand and Bangladesh increased.

Research by CGIAR centers in ANE or on topics of importance to ANE has grown quite rapidly since 1960 when IRRI was established. IRRI grew rapidly in the 1960's. CIMMYT was established in 1966, but it was already working with India and Pakistan while it was formally part of the Mexican research system before 1966. ICRISAT was founded in India in 1972. The International Food Policy Research Institute (IFPRI) and International Potato Centre (CIP) also began to play a role in Asia in the 1970's. The International Center for Agricultural Research in the Dry Areas (ICARDA) was set up in Syria in 1976.

The first non-CG international center in Asia was the Asian Vegetable Research and Development Center in Taiwan which started in 1972. It was followed by the International Center for Living Aquatic Resources Management (ICLARM) in 1973. In the 1980's two other centers which were oriented to resource management were established - the International Irrigation Management Institute (IIMI) in Sri Lanka and the International Board for Soils Research and Management (IBSRAM).

A recent survey (Pray 1987) indicated that private sector research is growing rapidly in a number of countries in Asia. Both India and Pakistan have seed industry research programs that are growing in number and size. Agricultural chemicals research is growing in India as is agricultural machinery research. In Southeast Asia, private sector research is growing probably most rapidly in Thailand. The Philippines did have a growing private sector research capacity until the last years of the Marcos regime. As the Philippine agricultural economy recovers, private research may also revive.

3.2 Institutional Development

As the NARS have grown in size, their institutional structures have also changed. In the 1950's most research institutions were part of the local ministry of agriculture or were single crop institutions - usually on export crops - financed by groups of commercial farmers. Linkages to agricultural science in the rest of the world were to scientists in former

colonial powers through organizations like the British Commonwealth.

Two major institutional changes in the NARS were the establishment of research in agricultural universities and the centralization of research. Research at agricultural universities started in the Philippines and India in the 1950's. These governments established agricultural universities modelled after U.S. land grant universities in contrast to the colonial agricultural colleges were concentrated almost all of their effort on undergraduate teaching. Agricultural universities of this type were established in almost all of the ANE countries in the 1960's and 1970's.

Governments of most Asian countries centralized their research systems during the 1960's and 1970's. This usually took the institutional form of a national agricultural research council which took control of regional research and research by commodity group. Centralization of R&D was part of a general trend toward centralization of government power in Asia.

Another major institutional innovation of the 1960's and 1970's was the establishment of the International Agricultural Research Centers (IARCs). They provided LDC scientists with external linkages with DC and other LDC scientists and with sources of germ plasm. In addition, the multi-disciplinary, problem-oriented approach of the centers became an institutional model for NARS. Through the example set by the IARCs and R&D institution-building projects of the IARCs, public research throughout Asia changed from programs organized along disciplinary lines to more flexible, multidisciplinary programs.

In recent years an important development in some countries has been research by private companies. They have broken the public sector's monopoly on research in certain crops and substantially changed the total allocation of research resources in some countries. Research by multinational corporations has provided new linkages to scientists in other countries. Pioneer Hi-Bred seed company, for example, tests corn hybrids in more than 90 countries. This network is almost as widespread as CIMMYT's.

Attempts to decentralize research are probably the major institutional change in the public sector since the 1980. India is building experiment stations in all 121 agro-ecological zones. Indonesia is building regional agricultural universities and experiment stations. Bangladesh has built a number of regional experiment stations. Most Asian research stations are doing more on-farm research, usually called farming systems research. India has the "lab-to-land" program. Despite these efforts most of the control over budgets and the allocation of research resources remains centralized.

3.3 Strengths and Weaknesses of Present R&D System

The major shortcoming of the government research systems of ANE is their low level of investment relative to the size of their agricultural sector. Judd, Boyce and Evenson (1988) calculated that public agricultural research expenditure as a percent of the value of agricultural product in 1980 was .59 percent in North Africa, .47 percent in West Asia, .43 percent in South Asia and .43 percent in Southeast Asia. In specific ANE countries like the Philippines public research is still around .2 percent of the value of output.

A second problem is that the major food grains do not receive the optimal share of research. In four countries in Asia for which data is available on the commodity allocation of public research expenditure the major food grain - rice - has the lowest research intensity[5] (Pray and Ruttan, 1985). Poor peoples crops like cassava and sweet potatoes tend to be neglected and also have low research intensity. Cotton and cattle research have the highest intensities. Another study using publications to split up research expenditure of ten Asian countries found that cassava and beans had the lowest intensity and beef had the highest (Evenson, Pray, Scobie, 1987). It was somewhat different from the four country expenditure data in that rice intensity was about average rather than below average. The high intensity of beef research probably is primarily due to the small

[5]. Research intensity is defined as research expenditure divided by the value of the crop.

amount of beef produced in these markets rather than the size of the research.

Private companies or commodity groups research will not make up for the low level of public R&D in food grains and subsistence crops. Private companies sector will probably not be spending much on R&D unless the crop is a hybrid, has serious pest problems that are amenable to chemical treatment, or is used by the processing industry. Commodity group research in Asia is strong only in a few export crops.

The weaknesses of the NARS do not affect different types of research equally. Research can be divided into four categories as defined in the Second Review of the CGIAR:

(a) basic - designed to generate new understanding (e.g., how the partitioning of assimilates is influenced by plant height);

(b) strategic - designed for the solution of specific research problems e.g., a technique for detecting dwarfing genes in wheat seedlings);

(c) applied - designed to create new technology (e.g. breeding new varieties of dwarf wheat that can respond to high levels of nitrogen without lodging);

(d) adaptive - designed to adjust technology to the specific needs of a particular set of environmental conditions (e.g., incorporating dwarf wheats into farming systems in a designated, perhaps unirrigated, area).(quoted in Anderson 1987)

The NARS concentrate on applied research. In the opinion of Derek Byerlee, head of the economics program at CIMMYT, the NARS are fairly strong in applied research: "Most Asian countries now have reasonably well-established plant breeding programs for major food crops capable of sustaining a continuing flow of improved varieties" (Byerlee, 1987). Breeders at CIMMYT and ICRISAT generally agree with this assessment for ANE countries. In contrast, adaptive research is quite weak. Officials at the International Service for National Agricultural Research (ISNAR) and scientists at CIMMYT and ICRISAT agreed with a recent World Bank review which says that adaptive research is generally "the weakest, most neglected

and most confused aspect of national research systems" (The World Bank, 1985).[6]

The government research programs that have the most effective adaptive and applied research programs are those in which the users of technology have some power over the research agenda. Punjab Agricultural University, the Academy for Rural Development in Comilla, Bangladesh and the Philippine Tobacco Research and Training Center are (or were) public sector institutions with very effective research programs. In the Punjab, farmers control the state legislature which provides most of the money for research in the state. This makes the Punjab Agricultural University very responsive to farmers' needs. The Comilla Academy and the Philippine Tobacco Center have close ties with organized farmers groups which makes them responsive to farmers' needs.

At the other end of the research continuum, none of the ANE countries have strong strategic and basic agricultural research. India is furthest along in developing this capacity. There is a strong biotechnology research programs at Jawaharlal Nehru University in New Delhi (Jones,1988). The Philippines, Egypt and Thailand are also investing in more basic biotechnology research but do not as yet have much capacity.

The private sector does a lot of adaptive research and some applied research. It is probably more efficient at doing applied and adaptive research than the public sector. Private research programs have to be responsive to farmers' needs or no one will buy their products. If no one buys their products, they will go out of business. In Asia this pressure has resulted in small R&D programs that borrow what they can from the public sector, other companies or other countries and adapt the technologies to local conditions. When that does not work or becomes too expensive they establish their own applied research program. Bangladesh

[6]. Another important weakness of many NABS is a weak public extension system and weak linkages between extension and research. Extension is not included in this report because AID has left extension to the World Bank and others.

Tobacco Company, Maharashtra Seed Company in India, and several of the Charoen Pokphand companies in Thailand are some of the most successful cases of this type of strategy.

The major limitation of private research from the social welfare standpoint is that it only works on specific commodities and inputs where it can make profits. Thus many important crops are ignored, as are many important resource management issues. The private sector does very little, if any, strategic research in developing countries. The exceptions are large Indian food processing firms, which spend some resources on biotechnology research related to industrial processes and to crop production, and some chemical companies that do some of their synthesis of new chemicals in India.

The strength of the CGIAR institutions' R&D is the applied research that has developed improved varieties and germ plasm. The Impact study attempted to categorize the senior scientific staff of the CGIAR according to the above categories. It found that there was no basic research. A small proportion of the scientists do strategic research (10 to 15 percent in the crop oriented centers). About 60 to 70 percent of the scientists work on applied research and the rest are in "training, research support and administration."

The other major strength of the CG is in networking. Since the institutes are viewed by most scientists and governments as apolitical, scientists from countries that are at war can sit together at a conference and communicate. Their networks of trials are extremely valuable in spreading germplasm and also as a stimulus to local breeding programs. The centers also are an important link between DC and LDC scientists.

3.4 Projections

Growth of public sector R&D depends on government budgets and public demand for research. Thus, research will be limited in many countries by their external debt problems and the general pressures to cut budgets.

Demand for research has been reduced in some countries by the absence of food crises and the achievement of self sufficiency in major food grains. The goals of import substitution and export growth are still important forces behind research in some countries. Demand for research on environmental or sustainability issues is still limited to areas where there are acute problems. Thus, support for research in these countries will probably decline unless there is a severe food shortage and a sharp jump in food prices, or unless enthusiasm for biotechnology is sufficient to pull the whole research system along.

One of the new types of demand for research is the demand for biotechnology research. In many countries the interest in biotechnology seems to be based as much on the desire to keep in touch with modern science and to eventually improve the country's competitive position as the expectation that biotechnology will produce practical results in agriculture and medicine. The governments of the ANE region are placing high priority on biotechnology. India has established a new Department of Biotechnology in the Ministry of Science and Technology. Indonesia has decided that the development of biotechnology is a national priority (Sastrapradja, 1986). Almost all countries in the region have set up some new biotechnology programs in their agricultural research systems.

The recent breakthroughs in biotechnology may well lead to increased agricultural research in the public sector. At the moment, however, biotechnology seems to have led primarily to a reallocation of public research resources in ANE. Most NARS have started some "biotechnology" research, although in many cases this has primarily meant shifting some resources into tissue culture work. In some cases, though, biotechnology has helped to generate new resources for government agricultural research. In India there will be an increase in research on biotechnology due to the establishment of the UNIDO international biotechnology laboratory there. In addition, government laboratories like the National Chemicals Laboratory, which did little R&D on agriculture, are now working on biotechnology.

The CGIAR budget has remained fairly steady in recent years. The budget of the 13 current CG centers will probably remain constant. The "fatigue" of some donors like USAID seems to be offset by greater support from other donors. The CG will probably expand to accept other international centers currently outside the CG fold. It is now studying the possibility of accepting:

Asian Vegetable Research and Development Center
International Board for Soils Research and Management
International Centre of Insect Physiology & Ecology
International Center for Living Aquatic Resources Management Inc.
International Council for Research in Agroforestry
International Fertilizer Development Center
International Irrigation Management Institute

The names of these centers indicate that if the CGIAR does accept them, it will be making a major shift away from plant breeding toward resource management. The original centers are also placing more emphasis on resource management. Another shift which is taking place is into upstream research such as applying some of the more sophisticated tools of biotechnology. IRRI and CIMMYT are both investing resources in biotechnology.

Private sector technology transfer and research will continue to grow in many countries in the ANE region as commercial input supply, agricultural processing and plantation industries grow. Demand for improved agricultural inputs is growing in most ANE countries as their agriculture modernizes. Demand for processed foods is increasing with urbanization and growth in per capita income. Exports of plantation crops are growing in many countries. Most of the increased demand is supplied by the private sector because budgetary pressure is forcing governments to reduce their role in supplying inputs and to privatize processing industries.

Recent changes in companies' ability to capture the benefits from research will continue to induce more private research. The possibilities offered by hybrids of the coarse grains, sunflower and cotton are just

starting to be exploited in ANE. Companies are likely to increase their investments in breeding these crops. The CG centers and private companies are developing methods to produce economical hybrid seeds for crops like rice and pigeon pea. If these projects succeed they will induce more private research on rice and pigeon pea.

The promise of biotechnology has induced some Asian companies and multinationals to increase R&D expenditure in Asia. Oil palm breeders are making use of new methods of cloning, tissue culture, and micropropagation. Agricultural chemical, pharmaceutical and seed MNCs are investing heavily in biotechnology at their central laboratories. Their subsidiaries will have to do adaptive research to transferring biotechnology products to ANE.

Private R&D expenditure will not exceed public R&D in most ANE countries in the 1990's. It started from too small a base, and there are still limitations on the profitability of private R&D. It will, however, certainly grow and make a larger contribution to agricultural productivity than it has in the past.

4. USAID's Current Agricultural Research Projects

4.1 Levels and Trends of USAID's Investments in R&D

AID started funding agricultural universities during the 1950's with Cornell University's program to rehabilitate the agricultural college in Los Banos in the Philippines. AID's next university building programs were in India in the late 1950's. By the mid 1960's AID was supporting university building programs in six provinces of India and five other countries in Asia. AID has also supported university-building projects in Morocco, Tunisia and Egypt in North Africa. The number of countries with university projects has declined to five at present - Morocco, Nepal, Pakistan, Thailand and Indonesia.

In the mid 1960's AID started to support the development of government research institutions other than universities. By 1970 AID had agricultural

research projects with national governments in India, Pakistan, Bangladesh, and Thailand. In addition AID started providing core funding to IRRI and CIMMYT around 1970.

Asia Bureau's funding for NARS seems to have peaked around 1982. The first column in Table 7 shows Asia Bureau's annual expenditure on agricultural research was approximately $41 million in nine countries. In 1987 that amount declined to about $21 million in the same nine countries. The available data for North Africa is for a shorter time period. Obligations there have also fallen. In addition to project funding, AID missions are providing funds for operating expenses for government R&D in Indonesia, Bangladesh, Morocco and possibly other countries.

AID is still the largest contributor to the CGIAR although its contribution has declined slightly in the last few years. AID also provides $10 million of the $50 million of funding for the other centers which the CG is considering for entry.

4.2 Characteristics of AID Projects

AID is engaged in some "traditional" research institution building projects. These projects include money for facilities and equipment, long and short term training and technical assistance to improve management and implement institutional changes. Many of these projects have a farming systems component in them. AID's agricultural research project in Egypt is one example of this. The AID/Pakistan project, which is strengthening the agricultural university in the North West Frontier Province and at the same time reorganizing the provincial research and extension system, follows a long line of agricultural university projects. A slight variation on this type of project is the project to build regional research stations or regional agricultural universities. The Indonesia and Bangladesh missions have supported projects of this type.

A relatively recent type of R&D support is funding for operational expenses of public research systems in Bangladesh, Indonesia, Morocco and

perhaps other countries. The money usually comes from the sale of PL480 commodities and is quite a large amount in some countries. For example is Bangladesh it amounts to $1 million plus/year.

Another type of project has a research component but is not primarily an agricultural research project. Such projects aim to strengthen government research on the adaptive end of the research spectrum and focus on a particular agro-climatic region. The Hill Areas Land and Water Development project in India, the Highland Agricultural Development project in Jordan and the Upland Agriculture project in Indonesia are examples of this type of project.

A new type of project is the Science and Technology Project which includes food production or food processing technology. Thailand's S&T project provides resources to strengthen Thai research institutions through technical assistance, studies on S&T policy and funding for research in the biological sciences and agricultural biotechnology at agricultural and general universities. In addition, there is money to match funding of public R&D by the private sector.

AID has a number of programs that encourage private sector agricultural research. AID has stimulated private research indirectly through assistance to develop private input and processing industries. In the 1960's and early 1970's AID helped create demand for modern inputs by subsidizing imports from the US. More recently, AID has used its financial leverage to encourage privatization of government input industries in Pakistan and Bangladesh. In addition it has funded studies of S&T policy in several countries and financed policy seminars on privatization in others.

AID assistance to public sector research was an important factor in encouraging private research. Public research developed the disease-resistant inbred lines of maize, sorghum and pearl millet which are the basis of the private plant breeding programs in the Philippines, Thailand, India and Pakistan. IRRI is working on hybrid rice, CIMMYT on hybrid maize and ICRISAT on hybrid pigeon pea. AID training programs provided the

graduate education of many private sector scientists in ANE. Experience in government research and/or CGIAR research centers is part of the background of most private scientists. Asia Bureau financed the IRRI rice mechanization program that successfully supported agricultural research by small scale machinery companies in the Philippines, Thailand and Indonesia (Mikkelsen, 1984).

Currently a number of AID missions are experimenting with S&T policies to encourage more private research and technology transfer. In India joint ventures between US and Indian firms are eligible for loans to finance applied research necessary to transfer technology to India. Several countries are attempting to encourage joint ventures between high technology companies. Pressure from the US government for better protection of intellectual property could eventually lead to greater property rights and more local R&D.

5. Agricultural Research Priorities for USAID in the 1990's

There is strong evidence that ANE countries are not investing enough in agricultural research. There will be a need for technology in the basic food grains, technology for diversification and technology to deal with environmental/sustainability issues. There is also evidence that AID's investment in agricultural research has been a productive one. Therefore, the ANE Bureau should continue to invest at least the current level of funds in R&D.

The main issues addressed in this section are how USAID's research resources should be allocated. The priorities given below are very broad and have to be tailored to the level of development of the country, the state of the research system and AID's budget in the country.

5.1 Country and Regional Priorities

Countries like Burma and the Philippines that have low R&D expenditure to agricultural GDP ratios should have top priority in AID's research

expenditures. The size of the rates of return to research in section 2 suggest that research will be a very productive investment in most of these countries. Those countries with the smallest systems (in terms of research intensity) would have the most to gain from increased research investments.

Within countries which still are facing shortages of basic food grains AID money for R&D should probably go the regions with relatively favorable water and soil conditions. Innovations can be achieved more rapidly in those regions, and there will be positive impact on the poor in an unfavored region through lower food prices and jobs created in the favored region. AID appears to be putting more emphasis on marginal areas to alleviate the perceived income distribution problems caused by the Green Revolution. There is a serious question as to whether research is the best policy instrument available to AID in dealing with these inequalities. If it is decided the research is the proper policy instrument and support goes to R&D in the less favored regions, countries may be trading off substantial amounts of growth for relatively small gains in equity.

In ANE countries where providing basic food is not likely to be a problem in the 1990's, AID should support research on less favored agricultural regions like forests and hills. Research to improve the management of these areas can not only improve their productivity but can also improve the productivity of the main agricultural areas by reducing destruction through floods or the silting up of irrigation systems.

5.2 Commodity Priorities

Research on food grains must be AID's top priority commodities for R&D, especially in South Asia. Food grain self-sufficiency is fragile in Asia. Production may not keep up with demand in Asia, and it may fall further behind than it is today in the Near East. Technical opportunities for productivity growth are available as section 2.4 indicated. Finally, countries are currently underinvesting in food grain research (see section 3.3).

The low research intensities and technical opportunities of major food grain and subsistence crops suggests that more research in those crops would bring high rates of return. This conclusion is supported for major food grains by a recent, quite elaborate attempt at ex ante priority setting. The Australian Centre for International Agricultural Research and IFPRI collaborated on this study (Davis, Oram and Ryan 1987). They found that, in Asia, rice was the crop that would give the highest present value from research. Rice was followed by potatoes, which would give only about one third of the returns from rice research. Wheat and maize were ranked next. In West Asia/North Africa wheat, potatoes and maize ranked first, second and third.

AID should invest more money in R&D on resource development, resource management and environmental topics. Ruttan (1987) has suggested that a major gap in the current national and international research system the area of resource development and management. It appears that there is little research being done at present on environmental issues. These issues will grow more important in the 1990's, and there will be more demand for research on them then.

5.3 Strengthening Adaptive and Strategic Research

AID's top priorities should be adaptive research and strategic research like applying biotechnology to breeding stress resistant crops. Applied research like plant breeding is relatively strong in ANE. The argument for more AID investment in strengthening adaptive research is that it is the key link between effective applied research programs and farmers. A small amount of investment to adapt technology to particular regions would thus lead to substantial returns. In fact, the few studies that have calculated rates of return to adaptive research do show very high rates of return (Byerlee 1987).

Ruttan (1987) argues that LDCs need research capacity in strategic and basic research:

> ...the experience of the present IARCs indicates that intellectual commitment to the solution of even scientific problems is enhanced when the scientists working on a problem are located in the environment in which the problems exists. Basic research capacity in the tropics will also facilitate more effective dialogue with the basic research community in the developed countries.

In addition, there are problems encountered in LDCs that are not important elsewhere. An example of this might be locating genetic markers of important characteristics of plants like pearl millet or pigeon pea which are not important crops in DCs. The one study that tries to separate the impact of technology-oriented from science-oriented research in LDCs (see Boyce and Evenson, 1975) finds that science-oriented research gives higher returns than technology oriented research.

5.4 Which Research Institutions?

AID has the choice of supporting government agricultural research institutions, agricultural universities, general universities, international centers, and private companies that do research. AID's choice of institution must be based on the goal of the program. Table 8 is a preliminary attempt to sort out which goals go with which institutions. If the goal is more food production, the primary institutions to conduct applied research will be the NARS and the CGIAR.

Many NARS still need bricks and mortar and human capital in certain regions, commodities and disciplines. For research systems like Burma's where research institutions and agricultural universities which still need Masters and PhD training equipment and some buildings, AID should be running "traditional" institution building projects. Most ANE countries now have basic infrastructure but certain disciplines and types of research are still weak. These include the social sciences - economics, anthropology and sociology in particular - and agronomists who work on crop management. Research areas like maintenance research are generally also undermanned and underfunded.

In some institutions the buildings, equipment and scientists exist but operating expenses are not available. In these cases AID support for operating expenses could have a very high payoff. The danger is that a research system could become dependent on AID for funds.

The CGIAR needs continued core support from AID. Substantial reductions in funding or switching resources from core to contract funding will eliminate their advantages of the centers - their ability to run networks, to run long term crop improvement programs, to conduct important maintenance research and to be flexible in building new research based on their research and breakthroughs in science.

The private sector should be strengthened in most ANE countries through strengthening and redirecting public research, through changes in regulations and through incentives to R&D (see 6.3.) It will probably play a secondary role in increasing basic food grain production but will play an important role in breeding those crops where the hybrid seed can be profitably sold. It will also do some adaptive research on chemicals and machinery for food grains.

The NARS and the private sector should play more nearly equal roles in diversification than in foodgrain production. Public research will be important on many commodities which are not attractive to the private sector but overall the private sector should play a larger role in diversification. Input industries should at least increase their adaptive R&D on imported fruit and vegetable varieties, on livestock inputs, and oilseed hybrids. The plantation industries may expand their research if government policies are favorable toward plantations. If the diversification is aimed at exports or at urban markets, the processing industry will assume increased importance in making sure the quality demands of the market are met. The processing industry will increase its research to make sure they can purchase the quality they want at a low price.

As a country moves upstream into the environmental area or towards basic

or strategic research such as molecular biology of plants, AID needs to support general universities and research institutions as well as agricultural research universities and institutes. In addition, agricultural universities need to be encouraged to do this type of research with their graduate students. General universities could benefit from funding for competitive grants programs on important agricultural or environmental topics. Funding for joint research between general universities, agricultural universities, government R&D institutes and/or with private agribusiness could strengthen all of the institutions. It could encourage interaction among scientists who normally do not talk to each other. This interaction could provide new ideas for research and some needed competition between scientists on the basis of research. Many universities may need PhD training in molecular biology and related disciplines and in disciplines that relate to environmental issues. They also need to be included in networks of scientists who are working on these issues.

Environmental and sustainable agriculture issues require strengthening at all levels of research. The strategic research must be done at the general universities, the agricultural universities and the NARS. Some of the CGIAR institutions will also play a role. Applied research will probably be performed by the NARS and CGIAR although some research may be done by biotechnology companies and lumber companies. Match companies in several countries in Asia are trying to improve forest production and some flue-cured tobacco processors are doing some adaptive research on trees for firewood.

6. Strategies for Increasing the Efficiency of ANE Countries' Research Systems

The priority areas for AID's agricultural program have been listed before. In many countries they have not been followed or if they were followed there is still much inefficiency in the way they were implemented.

This final section proposes three strategies for AID' assistance to

research which would address enable research systems in LDCs to implement research in priority areas more efficiently: (1) Farmer and agribusiness participation of government research decisions; (2) Strengthening strategic and basic research; and (3) Strengthening private research and technology transfer. The strategies 1 and 3 increase user control over R&D and potentially the monetary rewards for producing useful technology. The strategies to strengthen strategic and basic research will assist in improving professional rewards for good research. Any of these strategies could be pushed too far and would have negative effects on the supply of technology. But given the current state of most ANE research systems movement in these directions would have a positive effect in most countries.

6.1 Demand Driven Public Research or "Power to the People"

Many agricultural research institutions have sufficient capital and budget but are not very productive. Research priorities are skewed away from the major food grains to export crops or new crops with little potential like wheat in the Philippines. Management is poor. Motivation of the scientists to do research is low. Adaptive research is very weak.

Training by ISNAR or others on management information systems, research planning and management practices could be very useful. However, the most effective way to improve output is to increase the pressure to and provide rewards for research administrators and scientists who develop more technology. If farmers have more power over budgets, they will push for practical results. The NARS will then be under pressure to produce and will find ways to improve management efficiency and to provide monetary and professional rewards to productive scientists. Without pressure or rewards for efficiency the best training or suggestions for reform will have little impact.

The most important element in strengthening adaptive research is greater participation in R&D decision making by farmers and private companies. Farmers and agribusinesses can provide scientists with information on

farmers' needs, provide incentives for effective research and provide financial and political support to public research. This can be encouraged by giving existing farmers' organizations control over research resources, encouraging the organization of farmers' groups interested in technology, and strengthening the private sector.

AID might establish a fund to be used by farmers' organizations to finance adaptive research conducted by the government, by the private input companies or by the groups themselves. In most Asian countries there are now many private rural voluntary organizations, commodity groups and farmer political organizations. In India there are voluntary organizations that specialize in providing technological information and assistance to other voluntary organizations. The Sarvodhaya movement is a large voluntary organization in Sri Lanka which is concerned with identifying appropriate technology for small farmers. In some countries farmers have formed movements to influence government policies on agricultural prices and input prices (Nadkarni, 1987). Asian governments will be wary of allowing AID to assist these organizations because of their involvement in politics but there may be some way for encourage these groups to become involved in R&D.

Voluntary organizations have already been used to do adaptive research in some Asian countries. AID could provide money to expand such programs. The Bangladesh Rice Research Institute developed an effective farming systems network based on private voluntary organizations. The Pakistan Agricultural Research Council and CIMMYT linked up with the Agha Khan foundation to conduct on-farm research in northern Pakistan.

In addition to private organizations, AID might provide funds for R&D to various quasi-government farmers' organizations which could be used to adapt and transfer technology. These include irrigation associations throughout Asia, farmers' cooperative societies in many countries, and the National Dairy Development Board in India. AID might support R&D by government organized groups associated with commercial crops in some countries - the Federation of Outstanding Tobacco Farmers of the Philippines, the small scale rubber and oil palm producers in Indonesia and

Malaysia and tea and coffee producers in India, Bangladesh, Sri Lanka and Indonesia.

AID could encourage more adaptive research by assisting in the development of farmer or agribusiness organizations which are interested in research. Organizations of farmers and merchants who produce and distribute improved seed such as the crop improvement associations that are associated with land grant universities in most U.S. states could play an important role in encouraging adaptive research and spreading new technology. In the past AID has encouraged the development of cooperatives and commodity groups such as the National Dairy Development Board in India. It is now involved in a number of water management projects which attempt to build or strengthen irrigation associations or water user groups. AID has a number of projects in the resource area such as social forestry projects which are engaged in institution building. AID supports also supports institution building activities of PVOs in many countries of the region.

AID should encourage the further development of small farmer organizations in ANE. AID should include linkages to public research in the organizations that are being established in present AID projects. In some cases, it should consider providing resources to government research institutions to organize "Outstanding rice farmers organizations" or technology users associations which conduct trials or actually do farming systems research.

Public sector R&D on certain commodities or problems could be improved through greater cooperation with the private sector. AID could encourage this interaction through funding programs to subsidize R&D that is jointly financed or jointly performed by the public and private sector. At present a few large agribusiness companies fund research or hire scientists at Indian, Thai, and Philippines universities as consultants. A government-financed matching grant program to encourage joint R&D might help provide the contacts and confidence in each others' programs that are needed for greater communication. This in turn could lead to applied public research that is more appropriate to the needs of the farmers served by

agribusiness. In addition, it might lead to greater private sector funding of public research. In Thailand, the AID Science and Technology project will pay for half of the costs of a biotechnology research project funded by the private sector at government research facilities. In India, a project is being considered that would bring the state and centrally funded research organizations in one state together with the private sector to fund joint research centers. The focus would be industrial R&D, including the food industry, but similar projects could work for agriculture.

6.2 Strategic and Basic Research in Biotechnology and the Environment

This component of the strategy is appropriate for the more advanced research systems of ANE such as India, Thailand, Egypt, the Philippines and perhaps specific institutions in Pakistan, Morocco and elsewhere. It should have at least three parts: training and some buildings and equipment; networking and scientific communication; and joint research between US and ANE institutions.

PhD level training in the sciences needs to be strengthened in some of the universities in Asia. Even where strong programs exist there is a need for money to finance a continuing stream of students who go abroad for a Ph.D or scientists who go for post-doctoral research and training. Buildings and equipment for institutes on the environment or biotechnology in agriculture can be productive investments in some countries where such facilities do not exist.

Communication is the key to encouraging scientists to be productive. Communications with other scientists is particularly important as countries move into strategic and basic research. Scientists are motivated by the opinion of others in their discipline. They get their sense of achievement by publishing in disciplinary journals, and they learn what others are doing by reading those journals. Scientist need access to the latest books and journals in his discipline. In addition, they need sources of information about articles in other journals like the CAB Abstracts and then some way to obtain important articles. Conferences and meetings

between scientists in ANE, the US or wherever good research is being done will allow them to learn from what others are doing and find out where they rank.

The problem is that conferences and good libraries are expensive and require foreign exchange. To many bureaucrats they seem like luxuries. When there is a budget cut or foreign exchange shortage, they are among the first things governments cut. Therefore, funding libraries and conferences is a role that AID could usefully play.

Joint research between scientists in DCs and LDCs on topics of common interest is another way of stimulating better research. Truly joint research is a very personal thing that arises out of contacts developed at graduate school, post-doctoral study, conferences and correspondence based on publications. As more ANE research institutions develop research programs at the cutting edge of their disciplines and communication with other scientists grows, the possibility of having joint research grows.

At present there appear to be limited opportunities for scientists from universities and research institutions to get resources for joint research. The main purpose of the Australian Centre for International Agricultural Research is to promote such research between LDC and Australian scientists. AID has a few small programs in this area, but it could finance more joint research. Possible models include the USDA/OICD research programs to encourage joint research between US and European scientists and the BARD program between the US and Israel.

One possible model for organizing networks on strategic research like biotechnology, resource management and the environment is a CGIAR for basic biological research (Ruttan, 1987). It could be organized around a center that is actively doing research like the CG centers, or Resources for the Future for environmental. The danger of a basic CG and the danger in the new UNIDO biotechnology centers is that it would isolate the more basic scientists from the applied scientists. The basic scientists might then work on questions which are not important to applied science or to farmers.

A related model is to upgrade the strategic research of the expanded CGIAR. This model would keep the applied and strategic scientists from being separated.

Another possible model is the Rockefeller Foundation agricultural program or Agricultural Development Council in which a network of developed country scientists conduct research and teach in ANE universities and research institutions for a period of three or more years. They are colleagues of local scientists. They identify promising students for study abroad and provide resources for small research projects, journals and books.

6.3 Support for Private Research

The third part of AID's strategy for strengthening research could be to strengthen private sector research. Greater research by the private sector in most ANE countries would increase the countries' total expenditure on R&D. In many ANE research systems shifting scientists from the public sector to the private sector would increase their efficiency because they would have more resources and would be in more direct contact with farmers than they had ever been before. The scientists make sure they know farmers' needs because if they produce technology that farmers do not purchase, they may lose their jobs.

Strong private research programs can increase the efficiency of public research. Competition from private research would force the public sector to be more efficient or pull out of certain commodities. The public sector could reduce their research on crops in which the private sector is active and concentrate on other important areas where private companies will not do research.

The major problem with trying to encourage private research is that there is no certain formula for strengthening private research. There is a well developed literature in economics on the factors that influence private R&D in developed market economies (Griliches 1984). The literature

suggests that three main factors influence firms' decisions on R&D:

1. Expected demand for the new products or for the product produced using cost reducing new processes and expected input prices;
2. The appropriability of the economic benefits from new products and processes by the firm; and
3. Technological opportunity -- the productivity of R&D or the cost of the R&D needed to produce innovations.

These three factors can be broken down into various economic and technical components. The main factors and their components are listed in columns one and two in Table 9. Government policies and investments can affect the components and, through them, the main factors. The last column presents some of the policies that can influence the determinants of research.

General AID support for privatization and for the removal of legal and administrative barriers can be very useful. As mentioned in section 3.4 AID policies that encourage privatization of input industries has had a positive impact on private research in several countries. Restrictions on private research by the seed industry in Pakistan and India were an important constraints to private R&D until they were removed a few years ago. Similar constraints may exist elsewhere.

CGIAR and government research can be a very effective policy instrument with which AID can influence private research. Column three shows that public research influences private research through increasing technological opportunity. For example, ICRISAT and Indian research provide disease resistant male sterile lines of pearl millet, which private companies use to develop their hybrids. Public research also influences appropriability by finding an inexpensive way to produce hybrid seed of rice or other self-pollinated crops. This allows companies to produce hybrid seed and sell them at a price sufficiently high to make it profitable to breed new hybrids.

Some other policies to encourage research have been tried in Asia but

there is little evidence on how effective they have been. Government subsidies for research in Asia have been very limited so far and appear to have little impact. The efficacy of patents in encouraging technology transfer is very much in doubt, but it does appear that patents can be designed to stimulate more private research. Other factors like firm size are positively associated with R&D and R&D intensity, but it seems unlikely that AID can do much more than indicate the problems of industrial policies that greatly restrict the size of firms.

Figure 1 Spread of Improved Cultivars

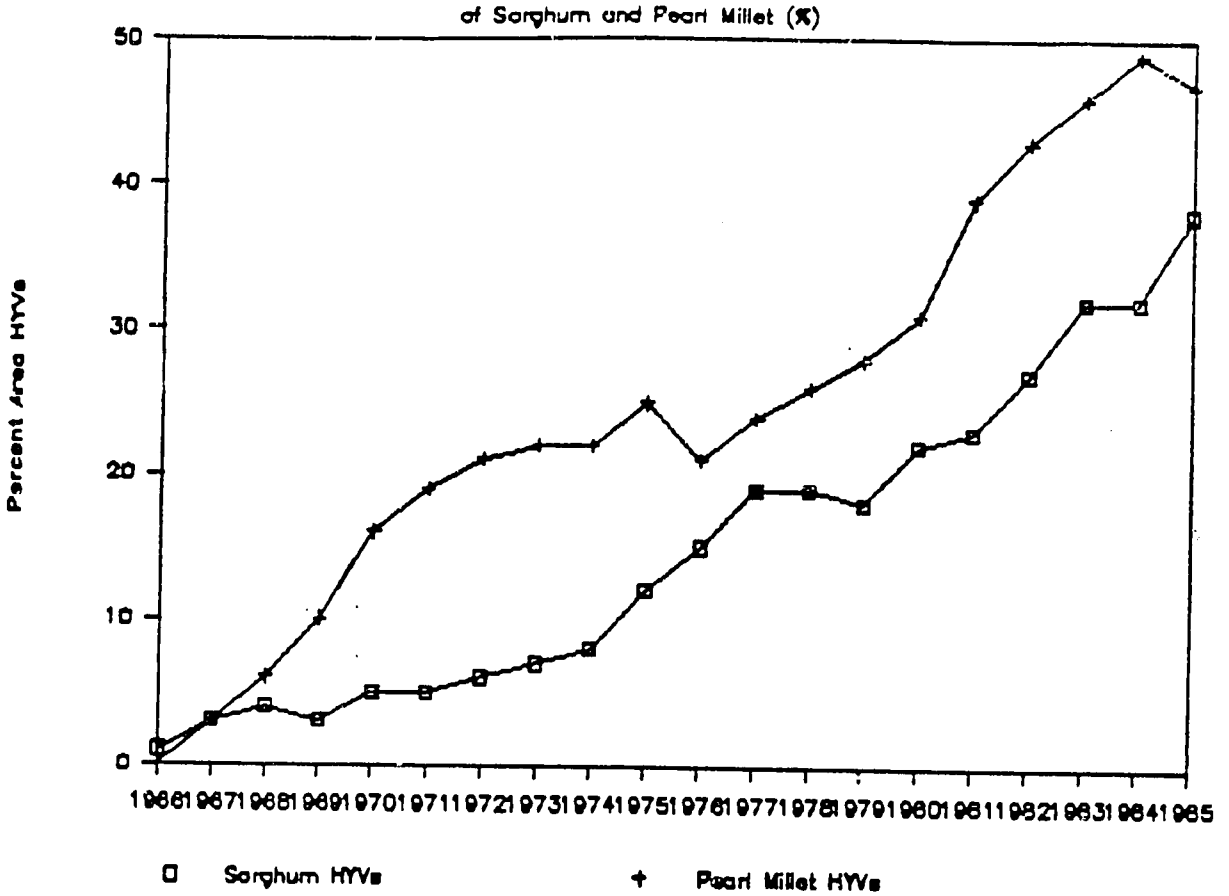

Table 1 . Summary Studies of Agricultural Research Productivity

Study	Country	Commodity	Time Period	Annual Internal Rate of Return (%)
Index Number				
Griliches, 1958	USA	Hybrid corn	1940-1955	35-40
Griliches, 1958	USA	Hybrid sorghum	1940-1957	20
Peterson, 1967	USA	Poultry	1915-1960	21-25
Evenson, 1969	South Africa	Surgarcane	1945-1962	40
Barletta, 1970	Mexico	Wheat	1943-1963	90
Barletta, 1970	Mexico	Maize	1943-1963	35
Ayer, 1970	Brazil	Cotton	1924-1967	77+
Schmitz and Seckler, 1970	USA	Tomato harvester, with no compensation to displaced workers	1958-1969	37-46
		Tomato harvester, with compensation of displaced workers for 50% of earnings loss		
Ayer and Schuh, 1972	Brazil	Cotton	1924-1967	16-28
Hines, 1972	Peru	Maize	1954-1967	77-110
Hayami and Akino, 1977	Japan	Rice	1915-1950	35-40[a] 50-55[b]
Hayami and Akino, 1977	Japan	Rice	1930-1961	25-27
Herdford, Ardila, Rocha, and Trujillo, 1977.	Colombia	Rice	1957-1972	73-75
		Soybeans	1960-1971	60-82
		Wheat	1953-1973	79-96
		Cotton	1953-1972	11-12
Pee, 1977	Malaysia	Rubber	1932-1973	none
Peterson and Fitzharris, 1977	USA	Aggregate	1937-1942	24
			1947-1952	50
			1957-1962	51
			1957-1972	49
Wennergren and Whitaker, 1977	Bolivia	Sheep	1966-1975	34
Pray, 1978		Wheat	1966-1975	44
	Punjab (British India)	Agricultural research and extension	1906-1956	−48
	Punjab (Pakistan)	Agricultural research and extension	1948-1963	34-44
Scobie and Posada, 1978	Bolivia	Rice	1957-1964	23-37
Pray, 1980	Bangladesh	Wheat and rice	1961-1977	79-96
Regression Analysis:				30-35
Lang, 1963	Japan	Aggregate	1880-1938	35
Griliches, 1964	USA	Aggregate	1949-1959	35-40
Latimer, 1964	USA	Aggregate	1949-1959	not significant

Source: Ruttan 1982

Table 1 – *Continued*

Study	Country	Commodity	Time Period	Annual Internal Rate of Return (%)
Peterson, 1967	USA	Poultry	1915-1960	21
Evenson, 1968	USA	Aggregate	1949-1959	47
Evenson, 1969	South Africa	Sugarcane	1945-1958	40
Barletta, 1970	Mexico	Crops	1943-1963	45-93
Duncan, 1972	Australia	Pasture Improvement	1948-1969	58-68
Evenson and Jha, 1973	India	Aggregate	1953-1971	40
Cline, 1975 (revised by Knutson and Tweeten, 1979)	USA	Aggregate	1939-1948	41-50[c]
		Research and extension	1949-1958	39-47[c]
			1959-1968	32-39[c]
			1969-1972	28-35[c]
Bredahl and Peterson, 1976	USA	Cash grains	1969	36[d]
		Poultry	1969	37[d]
		Dairy	1969	43[d]
		Livestock	1969	47[d]
Kahlon, Bal, Saxena, and Jha, 1977	India	Aggregate	1960-1961	63
Evenson and Flores, 1978	Asia – national	Rice	1950-1965	32-39
			1966-1975	73-78
	Asia – International	Rice	1966-1975	74-102
Flores, Evenson, and Hayami, 1978	Tropics	Rice	1966-1975	46-71
	Philippines	Rice	1966-1975	75
Nagy and Furtan, 1978	Canada	Rapeseed	1960-1975	95-110
Davis, 1979	USA	Aggregate	1949-1959	66-100
			1964-1974	37
Evenson, 1979	USA	Aggregate	1868-1926	65
	USA	Technology oriented	1927-1950	95
	USA	Science oriented	1927-1950	110
	USA	Science oriented	1948-1971	45
	Southern USA	Technology oriented	1948-1971	130
	Northern USA	Technology oriented	1948-1971	91
	Western USA	Technology oriented	1948-1971	95
	USA	Farm management research and agricultural extension	1948-1971	[illegible]

Source: Robert E. Evenson, Paul E. Waggoner, and Vernon W. Ruttan, Economic Benefits from Research: An Example from Agriculture," *Science*, 205 (September 14, 1979), pp. 1101-7. Copyright 1979 by the American Association for the Advancement of Science.

a. Returns to maize research only.

b. Returns to maize research plus cultivation "package."

c. Lower estimate for 13-, and higher for 16-year time lag between beginning and end of output impact.

d. Lagged marginal product of 1969 research on output discounted for an estimated mean lag of 5 years for cash grains, 6 years for poultry and dairy, and 7 years for livestock.

Sources for Table 10.3: The results of many of the studies reported in this table have previously been summarized in the following works.

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In addition to the studies listed in the table, there have been several other important research impact studies in which results are reported in a cost-benefit rather than an internal rate of return format.

TABLE 2. RATES OF RETURN TO RESEARCH

	Method	Commodities	MIRR	IRR
Pakistan	Production Function	Crops and Livestock	64.5%	
	Index No.	Wheat	60-67%	55-62
	Index No.	Maize	19-27%	15-23
Indonesia	Productivity	Rice	100+	
Bangladesh	Productivity	Crops	200	
	Index No.	Crop		32-37%
North India	Duality	Crop	60-70%	
Res. & Ext.	Duality	Crop	72%	

Source: Pray and Ruttan (1985)
MIRR = Marginal Internal Rate of Return
IRR = Internal Rate of Return

TABLE 3. HYV WHEAT, RICE AND MAIZE IN ANE REGION
(as % of total area of each crop)

	HYV WHEAT					
	1970	1975	1980	1982	1983	mid80s
Bangladesh	11	59	97	96	--	100
India	39	75	73	81	79	85
Nepal	49	84	89	85	90	87
Pakistan	50	69	83	91	--	85
Egypt	na	na	na	36	55	58
Morocco	5	na	na	na	30	50
Tunisia	5	21	37	41	37	36

	HYV RICE				
	1970	1975	1980	1982	1983
Bangladesh	5	15	21	25	--
Burma	4	8	43	51	49
India	15	32	45	48	54
Indonesia	13	43	63	65	72
Nepal	6	17	26	36	36
Pakistan	5	39	43	46	--
Philippines	51	66	75	79	--
Sri Lanka	12	54	74	91	--
Thailand	0	7	12	(1981)13	--

	MAIZE	
	IMPROVED 1985	HYBRID 1985
Burma	34	0
India	36	13
Indonesia	25	1
Pakistan	28	2
Philippines	26	1
Thailand	70	8
Egypt	64	10

Sources: Wheat and Rice 1970-83; Dalrymple (1986).
Wheat mid-80s; unpublished estimates from CIMMYT.
Maize; CIMMYT (1987)

TABLE 4. RESEARCH EXPENDITURE BY TYPE OF INSTITUTION, 1985.
(Millions of U.S.$s)

	India	Philippines	Thailand	Indonesia	Malaysia	Pakistan	Bangladesh
Private Research	16.7	4.4	4.4	2.0	10.5	.8	.1
Government Ag.[a] R&D	248.0	7.0	78.6	62.0	44.4	56.2	8.0
International[b] Centers	22.1	22.6	-	-	-	-	-

[a] These numbers are not consistent on their inclusion or exclusion of capital expenditures. The Philippines does not include capital expenditures, Pakistan does, and some of the others are unclear.
[b] Only part of this research is specifically on Indian or Philippine problems.

Sources: Private Sector; Survey.
Public Sector; India, 1983; India (1984)
Philippines, 1984; Sardido.
Thailand, 1984; Rungruang Isarangkura (1986)
Indonesia, 1984; Nestel (1985)
Malaysia, 1980; Oram.
Pakistan, 1984; Pakistan (1986)
Bangladesh, 1985; ISNAR.

Table 5 Private and Public R&D by Commodity in the Philippines.
(millions of pesos)

	Private (1985)	Public (1984)
Rice	20	15
Corn	30	6
Sugarcane	3	29
Coconut	2	11
Tobacco	2	19
Fruits and Veg	19	3
Other Crops	3	27*
Livestock	5	17

Source: Pray, 1987.
* Half of this is root crop research.

TABLE 6. TRENDS IN R&D EXPENDITURES

		1971	1974	1977	1980	1980	1984
		(000 1980 US $)				(millions constant local currency)	
Indonesia	GOI	8688	8023	42229	33200	41	29
	External					16	33
	Total					57	62
Philippines		5499	6844	8637	9533	82950	47608
Thailand		11740	11463	23547	21600	1004	1654
India	State					4605	10398
	Federal					9594	12783
	Total	66108	66868	103855	120167	14199	23181
Bangladesh		2348	2677	15735	27613	229	334
Sri Lanka		6340	5731	4244	5057		
Nepal		2163	2229	2556	2634		
Pakistan		4696	4776	38528	29899		
Morocco		6574	6112	8633	8026		
Egypt		24067	21015	22325	23717		
Tunisia		2428	3874	5320	6764		
Jordan		427	852	869	849		

Sources: 1971-1980; Judd et al (1988)
1980-84; Indonesia; Nestel (1985)
Philippines; Gomez (1986)
Thailand; Rungruang (1986)
India; India (1984)
Bangladesh; ISNAR.

TABLE 7. AID/ANE BUREAU R&D EXPENDITURES

	1982	1985	1987
Bangladesh	9021	6509	4059
India	4212	351	5924
Nepal	2535	318	704
Pakistan	1200	1803	3822
Sri Lanka	3365	495	2206
Burma	800	0	357
Philippines	4565	1083	502
Thailand	2260	263	515
Indonesia	13027	4748	2689
Asia Regional	200	28	0
Asia Total	41185	15598	20778
Egypt		13521	7065
Jordan		466	1166
Morocco		4317	5697
Tunisia		681	1027
ANE Regional		0	1013
Near East Total		18985	15968

Sources: 1982; Pray and Ruttan (1985)
1985 and 1987; Cummings (1988)

Table 8 Research Targets and Institutions

Research Targets	Level of Research	Institutions	
		Major actors	Minor Actors
Basic food grains	Strategic	General Universities Agricultural U's NARS, CGIAR	
	Applied	NARS, CGIAR	Private R&D
	Adaptive	NARS Farmers organizations private companies	Private R&D
Diversification	Strategic		
	Applied	NARS, Private R&D Farmers organizations	CGIAR
	Adaptive	NARS, Private R&D Farmers organizations	
Sustainability Natural Resources	Strategic	General Universities	
	Applied	NARS, Agricultural U's	Private R&D
	Adaptive	General Universities	Private R&D

Table 9 Policies Influencing Private R&D

Main Determinants	Economic and Technical Factors Affecting Main Determinants	Government Policies
Expected Demand for:		
Farm products	Income growth, income elasticities, export demand, demand elasticity	Commodity price policies Export policies
Manufactured Inputs	Modernization of agriculture	Input price controls, credit policies, govt. supplies
Processed goods	Income growth, income elasticities, export demand, demand elasticity	Food, beverage, drug, textiles price and export-import policies
Appropriability	Nature of technology	Public R&D
	Firm size	Anti-trust policy
	Market structure	Anti-trust policy
	Characteristics of competing firms	Patents, plant breeders rights Enforcement of rights
Technological Opportunity	Private local R&D	Patent and trade secret legislation Enforcement of rights Public R&D
	Foreign Technological developments by: 1. same firm 2. other firms 3. foreign public R&D	MNC policies Technology import policies
	Quality and cost of Scientific inputs	Output of public Universities R&D Subsidies Imports of R&D equipment

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