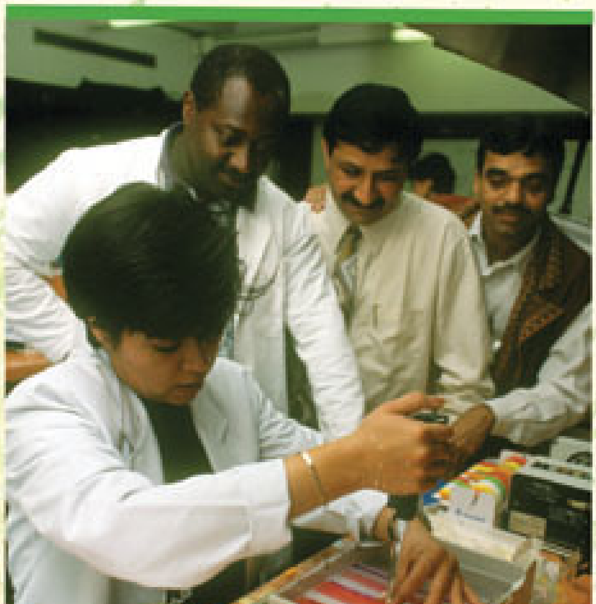
The Asian Maize Biotechnology Network (AMBIONET):

A Model for Strengthening National Agricultural Research Systems



Carl E. Pray
Department of Agricultural, Food & Resource Economics
Rutgers University

USAID
FROM THE AMERICAN PEOPLE

CIMMYT

The Asian Maize Biotechnology Network (AMBIONET):

A Model for Strengthening National Agricultural Research Systems

Carl E. Pray
Department of Agricultural, Food & Resource Economics
Rutgers University
Cook Office Building
55 Dudley Road
New Brunswick NJ 08901
USA

Acknowledgments
Editing: Mike Listman.
Layout/design: Eliot Sánchez.

USAID FROM THE AMERICAN PEOPLE

This study was generously supported by USAID, through linkage funding.

CIMMYT® (www.cimmyt.org) is an international, not-for-profit organization that conducts research and training related to maize and wheat throughout the developing world. Drawing on strong science and effective partnerships, CIMMYT works to create, share, and use knowledge and technology to increase food security, improve the productivity and profitability of farming systems, and sustain natural resources. CIMMYT is one of 15 Future Harvest Centers of the Consultative Group on International Agricultural Research (CGIAR) (www.cgiar.org). Financial support for CIMMYT's work comes from the members of the CGIAR, national governments, foundations, development banks, and other public and private agencies.

Correct citation: Pray, C. 2006. The Asian Maize Biotechnology Network (AMBIONET): A model for strengthening national agricultural research systems. Mexico, D.F.: CIMMYT.

Abstract: This report reviews the impacts of the Asian Maize Biotechnology Network (AMBIONET), organized by the International Maize and Wheat Improvement Center (CIMMYT) with funding from the Asian Development Bank to strengthen the capacity of public maize research institutions in China, India, Indonesia, Philippines, Thailand, and Vietnam to produce high-yielding, disease resistant, stress tolerant maize cultivars. It was found that, during its lifetime (1998-2005), AMBIONET clearly benefited researchers and institutions in participating countries, as well as CIMMYT. In addition, there was good progress toward developing improved cultivars. Asian farmers are just beginning to gain from the work, but their future benefits will likely pay for AMBIONET's relatively modest expenditures many times over.

ISBN: 970-648-138-9
AGROVOC descriptors: Zea mays; Plant breeding; Biotechnology; Breeding methods; Research methods; Disease resistance; Yield increases; Research institutions; China; India; Indonesia; Philippines; Thailand; Viet Nam; Asia
AGRIS category codes: F30 Plant Genetics and Breeding
F01 Crop Husbandry
Additional Keywords: AMBIONET
Dewey decimal classification: 633.15950

Printed in Mexico.

Contents

Tables and Figures

1. Executive Summary

Supported by the Asian Development Bank, the Asian Maize Biotechnology Network (AMBIONET) included molecular biologists and maize scientists and was organized in 1998 by CIMMYT and the national agricultural research systems (NARSs) of China, India, Indonesia, Philippines, and Thailand. Vietnam joined during the second phase of the project, which started in 2002. The network ended in 2005.

The objective of AMBIONET was to strengthen the capacity of key public maize research institutions in Asia to produce maize cultivars that would be higher yielding, resistant to diseases, and tolerant to abiotic stresses. The research capacity building component focused on the use of molecular markers and molecular breeding.

The major research question of this study was: in a climate of shrinking funding for the CGIAR centers, were these AMBIONET projects a good use of CIMMYT's limited resources? To answer this question we looked at three components:

1. Is the Asian maize breeding capacity stronger than it would have been in the absence of AMBIONET?
2. Are the research programs that are part of AMBIONET likely to develop technology that will improve the income and well-being of resource-poor farmers in Asia?
3. Is CIMMYT's research program stronger because of AMBIONET?

The primary method to answer these questions was through interviews conducted over November 2003-August 2004 with many NARSs and CIMMYT scientists involved in AMBIONET and with public sector scientists and officials in private firms outside the network. We also developed a questionnaire that was completed by the AMBIONET coordinator for each country. Finally, we reviewed the reports and some published papers of the AMBIONET team and of other networks.

The main findings are:

1. Although AMBIONET was developed and expanded in two projects funded by the Asian Development Bank; the resources provided to AMBIONET by ADB and CIMMYT in the two projects were quite small: US$2.4 million from ADB and about US$1.3 million in kind from CIMMYT.
2. Despite the limited resources invested, maize research in Asia was strengthened, particularly at the institutes participating in AMBIONET in China, India, Indonesia, and Vietnam. AMBIONET also strengthened the research of individual scientists in the Philippines and Thailand, even though it was less successful at building research institutions.
3. Much of AMBIONET's research focused on the problems of small farmers. Good progress was made toward developing improved, disease resistant lines that can be used in breeding programs. It is too early to tell whether the breeding priorities pursued were the best to obtain maximum social benefits.

4. Farmers are just starting to benefit from AMBIONET research. The size of future benefits is difficult to predict, but the benefits will probably cover the costs of AMBIONET expenditures many times over.
5. CIMMYT has also benefited from this program. It has gained knowledge about Asian maize germplasm and knowledge and molecular markers relating to drought and important diseases. AMBIONET has helped CIMMYT move toward its goals of stronger maize research programs and improved technology for the poor in developing countries.

This report is organized as follows. Section 2 is a history of AMBIONET and the research inputs that it provided. Section 3 develops a framework for impact assessment based on the biotechnologies and their possible impact. Section 4 examines the impact of AMBIONET on Asian research capacity. Section 5 presents an analysis of the impact of AMBIONET on research outputs and productivity. Section 6 describes the way increased research outputs and productivity could benefit farmers and the possible level of potential benefits from AMBIONET research. Section 7 reviews the evidence on the impact of AMBIONET and looks at some alternative futures for the network.

2. History and Structure of AMBIONET

History

The AMBIONET project built on two previous Asian biotechnology networks. The first was the Rockefeller Foundation Rice Biotechnology Program. This program started in 1984 as a comprehensive research, capacity building, and technology transfer program that included the entire spectrum from fundamental research to plant breeding and socio-economic evaluation of potential benefits. Between 1984 and 1999 the Rockefeller Foundation allocated almost US$100 million to this program. Part of the money went to laboratories in high-income countries to develop techniques and knowledge that could be used for the molecular biology, genetic engineering, and molecular breeding of rice. The other large part of the money went to fund capacity-building and research at institutes in developing countries, primarily in Asia. In addition networking activities like annual meetings of participants and a rice biotechnology newsletter were developed to improve communication among participating scientists.

This program was a major success in terms of capacity building. The 1999 evaluation of this program stated (Mohan et al. 1999):

> "As far as the capacity building in rice biotechnology capacity in low income countries (LICs) is concerned, the impact of the Rice Biotechnology Program has been profound, often with spin-off benefits to other crops. Many individuals have benefited from both formal training and research grants while we estimate the combination has had potentially a major impact in about 46% of the Rice Biotechnology Program supported LICs institutions. However, we believe that major challenges still exist in many institutions in ensuring that such individual and institutional biotechnology capacity results in useful contributions to final products, the primary problem being of forging effective interactive linkages with rice breeders and development oriented agencies."

The program was less successful at developing "products" in the form of new technology for farmers. The impact as of 1999 was an impressive list of intermediate products including an immense amount of knowledge about rice genetics, many new research tools, and improved lines of rice. According to Mohan et al. (1999): "…as a result, work on the rice genome has become a model for other cereal crops." Many transgenic rice varieties and hybrids with resistance to insects, disease, herbicides, and improved nutritional qualities have been developed by scientists, but no transgenic rice lines have been commercialized, primarily because of biosafety regulatory procedures, which are driven in part by consumer concerns about the safety of genetically modified products. Some disease resistant, non-transgenic rice varieties developed using marker assisted selection (MAS) were being tested for commercial release when the Rockefeller Program was evaluated in 1999.

The second program upon which AMBIONET built was the Asian Rice Biotechnology Network (ARBN). International Rice Research Institute (IRRI) scientists, with funding from the Asian Development Bank and German foreign aid, set up the ARBN in 1993. It grew with a second phase which started in 1997 and a third phase which lasted from January 1999 to 2002. The initial project aimed to address the fact that many biotech research centers were started with well-trained people, lots of equipment, and funding from Asian governments and the Rockefeller Foundation, but few of these centers did much research and or produced new knowledge or technology. IRRI scientists and their NARSs colleagues felt that some type of on-going relationship with IRRI biotech scientists and other research centers was needed; that NARSs scientists should be able not only to take training courses, but also to use the techniques learned while working alongside an IRRI scientist. The latter would provide subsequent trouble-shooting assistance for the national program researchers, once they returned their home institutions. The ARBN also provided enzymes or facilitated repairs for advanced equipment, when such products or services were unavailable locally, and helped the national scientists to keep current with the literature and maintain contact with colleagues.

The first ARBN project was funded by ADB and concentrated on strengthening selected public research labs, biotech scientists, and rice breeders in India, Indonesia, and the Philippines. Later projects expanded the program to 10 institutes in 6 countries. The research focused on biotic stresses; specifically, bacterial blight, tungro, blast, and gall midge. ARBN had a full-time scientist/manager and scientists at IRRI who backstopped the manager. The first phase of the project was primarily capacity building. The second phase comprised collaborative research and some capacity building with newer partners. The third phase was mainly networking and maintenance of research. Approximately US$100,000 was invested in the labs of each of the early partners. The project sponsored many training courses and financed research projects at the collaborating institutes. A lab at IRRI received network partners for extended periods of research. The IRRI lab also furnished access to expensive, sophisticated equipment that partners needed only occasionally.

AMBIONET was modeled fairly closely on ARBN. CIMMYT had a long history of training and supporting maize breeders and other maize scientists from the center's regional office in Bangkok. In the mid-1990s CIMMYT closed that office, but tried to continue to support maize breeders in the region by proposing an Asian maize network to be funded by ADB. The agency declined to fund that network, so in 1997 CIMMYT put together the proposal for AMBIONET. Like ARBN the aim was to strengthen public maize breeding through applied biotechnology. To join AMBIONET, countries had to have some biotech research capacity, as well as be clients of ADB. The institutes in each country were selected to ensure that the biotechnologists and plant breeders worked closely together on applied research problems. In each country a biologist and a plant breeder were selected as joint team leaders. On the advice of Rockefeller and ADB and due, in part, to the limited budget, the project did not include a large central laboratory for AMBIONET. The Bank also decided not to fund genetic engineering research, because of concerns in the agency about potential health hazards. AMBIONET was accepted and the project started in early 1998.

The Structure of AMBIONET

The first AMBIONET project included China, India, Indonesia, the Philippines, and Thailand. The Asian Development Bank project that funded it was called "Application of Biotechnology to Maize Improvement in Asia." The objectives and scope of the first project were (CIMMYT 2001):

> "To build and support the capacity of national maize improvement programs in five Asian countries to apply biotechnology for variety improvement, with the goal of increasing maize productivity through the development of high yielding cultivars that are resistant to disease and tolerant to abiotic stresses. The scope of the project includes training, collaborative research, and information sharing through the Asian Maize Biotechnology Network.
>
> The project focused on the application of molecular markers to develop improved maize varieties that have high yield, resistance against diseases, and tolerance to abiotic stresses. Primary research areas were the genetic characterization of maize lines, and mapping and marker-assisted selection for resistance to downy mildew, sugarcane mosaic virus (SCMV), and maize rough dwarf virus (MRDV), in addition to tolerance to drought and low nitrogen conditions."

David Hoisington, head of the Applied Biotechnology Center at CIMMYT, was the scientific advisor and administrator of the project. Luz George, who had worked for the Asian Rice Biotechnology Network, was hired in late 1998 as AMBIONET coordinator in Asia, located at IRRI in the Philippines, with chief responsibility for project implementation. A maize breeder and a molecular biologist from public research institutes were identified as team leaders in each project country. In 2000 a sixth team located at the Sichuan Agricultural University in southern China was added.

The objectives and scope of the second project (2002-05) added enhanced nutritional qualities and banded leaf and sheath blight (BLSB) as research areas. At this time institutes in Vietnam joined AMBIONET.

The AMBIONET was funded by a three-way partnership among the Asian Development Bank, CIMMYT, and national partners. The first project was funded primarily by ADB, which contributed US $1.4 million over four years, and by CIMMYT, which made an in-kind contribution of scientific advice and training of about US $400,000. The national partners were budgeted to contribute about US $200,000. In the second project ADB provided US $1 million over three years. CIMMYT was to contribute in-kind services of about US $900,000. The national partners were budgeted to contribute US $720,000 in in-kind resources, and it was hoped that the private sector would contribute US $180,000 over the three years of the project.

Research capacity building was to be achieved through a combination of collaborative research projects, training, networking, and in some cases the provision of equipment or assistance in identifying suppliers. Varietal development research was done by national programs in collaboration with CIMMYT, which contributed training, information, DNA markers, germplasm, and other scientific and technical backstopping. AMBIONET provided the research focus and facilitated collaboration. Molecular markers were used in (1) fingerprinting, particularly characterizing maize germplasm in genetic diversity studies; (2) mapping, which is the identification and characterization of genomic regions involved in the expression of target traits; and, ultimately, (3) marker-assisted selection (MAS), also know as molecular breeding, which is maize improvement using selection for genomic regions associated with target traits.

The AMBIONET research agenda was developed by the national breeders and biologists working with CIMMYT biotechnology scientists (Table 1).

Projects focused on the improvement of locally-adapted lines for country-relevant traits. Components on diversity and downy mildew, which were relevant to all or most of the countries, were pursued through a sub-network of research projects.

Priorities were set primarily according to supply-side considerations: how difficult the problem was to solve and the capacity of NARS researchers. AMBIONET scientists chose research projects that they believed had prospects for quick success, both to encourage NARS partner scientists and to show other scientists and funding agencies the value of biotechnology tools. For example, diversity studies in hybrid breeding populations—classifying them into groups from which breeders could choose lines to develop higher-yielding hybrids—constitute a relatively straightforward use of genetic fingerprinting. All partner institutions had the scientists and equipment needed to accomplish them, and the information generated could be useful to conventional plant breeders.

Developing markers for disease resistance and using them in MAS is more complicated and would take longer to produce results. Participants started working on diseases about which much was known and for which resistance was controlled by a small number of genes. It was expected that they would make progress by the end of the first project and they did.

The last target was drought tolerance. This was thought to be the most important problem throughout Asia (and elsewhere), particularly for small-scale farmers who lack irrigation. Drought tolerance is genetically much more complicated than resistance to most diseases. Many traits contribute to drought tolerance at different stages of plant growth, and most of these traits are controlled by many genes. As a result the AMBIONET team decided that larger, more advanced research programs, such as those of China and India, would start working on drought immediately. The others would wait until they had built up their biotech capacity through work on diversity and diseases.

Table 1. Summary of AMBIONET research activities, 1998-2003 (x = started in phase I; xx = started in phase II). Participating institutes are listed below.

Country	NARSs	Maize diversity	Virus	Downy mildew	Banded leaf and sheath blight	Drought tolerance	Low nitrogen tolerance	Quality protein maize
China-North	CAAS	x	x			x		xx
China-South	SAU	x			xx	x		
India	IARI	x		x	xx	x		
Indonesia	ICERI/IABGGRI	x		x	xx	xx		xx
Philippines	USM	xx		x		xx		xx
Thailand	DOA	x		x		x	x	xx
Vietnam	NMRI/AGI	xx				xx		xx

CAAS: Chinese Academy of Agricultural Sciences
SAU: Sichuan Agricultural University
IARI: Indian Agricultural Research Institute
ICERI: Indonesian Cereal Research Institute
IABGRRI: Indonesian Agricultural Biotechnology and Genetic Resources Research Institute
USM: University of Southern Mindanao
DOA: Department of Agriculture
NMRI: National Maize Research Institute
AGI: Agricultural Genetics Institute
Source: CIMMYT 2001

During the second project, quality protein maize (QPM)[1] was added as a target trait, because CIMMYT had good markers for protein quality and good lines of maize with this characteristic. The AMBIONET scientists thought it would be relative easy to add QPM to good, local maize lines. In addition, as success was achieved in producing markers and resistant lines for downy mildew and viruses, the network moved on to BLSB, which was a more important disease than downy mildew or viruses.

Not every country worked on every project, because in some countries a particular disease was not a problem or researchers had not developed the capacity required.

Research priorities could have been improved by considering the economic significance of the problem, the time and difficulty of delivering the science-based solutions to the poor, and the availability of alternative technologies for addressing the problems. However, given the short period of ADB funding and the need to provide some initial results which could be used to justify a second phase of the project, the priorities chosen may have been the best.

Table 2. ADB AMBIONET budget categories.

Categories	Phase I: 1998-2001 (revised budget)	Phase II: 2002-2005
Project coordinator	210,000	210,000
Travel	140,000	80,000
Research work, equipment and materials	420,000	190,000
Training NARSs scientists	230,000	140,000
Disseminating results and technical support	215,000	175,000
Administrative support	185,000	110,000
Contingencies	0	95,000
Total	1,400,000	1,000,000

Source: CIMMYT 2001.

The major budget categories of the ADB money are found in Table 2. A major component of the project and one of the keys to its success was the appointment of the project coordinator, Luz George. Her duties included:

- Act as the communication node among the network participants.
- Monitor the progress of country teams and assist in troubleshooting.
- Plan and organize annual meetings, workshops, and training activities.
- Facilitate the procurement and distribution of equipments/supplies.
- Supervise the AMBIONET service lab.
- Conduct training and research of relevance to the network and publish papers.
- Produce technical progress reports and grants proposals.
- Publish the network newsletter.
- Design, development, and maintain the network's web site.

In addition to these tasks, she led network research programs on genetic diversity and downy mildew in collaboration with CIMMYT and NARSs, and published several high-quality journal articles.

The biggest category was initially for NARS. This declined during the second phase, partly because most NARS labs had the equipment they needed by then. Funding to each individual program was quite limited (Table 3). In interviews, NARS team leaders emphasized the importance of AMBIONET's flexibility, which offered different types of assistance to different institutes. For example, in India, B.M. Prasanna, of the Indian Agricultural Research Institute, emphasized the importance of being able to buy equipment for his lab. In contrast, for Shihuang Zhang, head of the

[1] QPM looks, tastes, and grows like normal maize, but its grain contains nearly twice the levels of lysine and tryptophan, essential amino acids for protein synthesis in humans and many farm animals.

Chinese group, one of the most important uses of the money was to hire post-doctoral fellows with experience using molecular marker techniques. In Indonesia, access to some of the key chemicals was a major constraint, and AMBIONET funds and assistance addressed those needs and enabled researchers there to progress.

The research programs were also supported by the AMBIONET service lab, located at IRRI. The lab purchased and delivered equipment and supplies in the region, and conducted research to fill gaps and benefit the whole network. In a 25 August 2004 email, George gave several examples of the role the lab played:

> "….in our network-wide research to identify QTLs for DM resistance, we consolidated and analyzed the individual country data, conducted additional work to locate linked markers in the strongest QTL [which happened to be expressed in all locations] which the countries can then use in marker assisted selection. Another example of work in the service lab is the development of standard alleles and kits which we distributed to the network countries. By using the standard alleles and standardized protocols, the different countries could combine their genetic diversity data. The importance of this is that, by merging datasets, there is no duplication of effort (if teams want to see the relationship of their inbred lines with those of another country or CIMMYT, there is no need to fingerprint the lines of others anymore, one can simply combine the specific country data with others)."

Training programs were another large component of the budget. The first of these training programs was designed by CIMMYT and aimed to put the participating breeders on equal footing with the molecular biologists with whom they would serve as joint team leaders for country programs. It provided an overview of molecular markers and related techniques, and particularly their role in plant breeding. The course also described how to assemble a molecular marker laboratory for maize breeding and detailed associated costs.

Other training programs responded to specific NARS needs and enabled them to carry out their part of the project research agenda. A list of all courses is found in Appendix Table 1. This list includes workshops and country training programs on maize and downy mildew fingerprinting, QTL mapping, functional genomics, and genetic diversity. The last regional workshop was on grant writing. The skills that scientists gained were utilized in their research programs. As a result of this and other network contributions, participants used similar techniques and research protocols, facilitating region-wide collaboration and sharing of results.

Table 3. Research inputs from AMBIONET.

	China-North	China-South	India	Indonesia	Philippines	Thailand	Vietnam
Research funding for national programs Phase I (US$'000)	80	20	80	80	80	80	0
Research funding for national programs Phase II (US$'000)	27	27	27	27	27	27	27
AMBIONET training programs (number attending)	17	47	14	21	23	19	3
AMBIONET annual meetings (number attending)	20	9	9	25	25	24	7
On-site visits by CIMMYT staff	6	7	12 to 14	11	11	13	4

Source: Survey by author and CIMMYT 2004.

Annual meetings comprised an integral part of the capacity building process. There participants assessed and reinforced new skills when they reported their results, with questions and suggestions from other teams and the CIMMYT staff. CIMMYT staff and the project coordinator spent time for each country team for more detailed feedback. Presentations by CIMMYT scientists covered new techniques and advances in knowledge on genetic diversity, biotic stresses such as downy mildew and viruses, abiotic stresses such as drought and low nitrogen, and grain quality. Future plans and collaborative research were discussed.

Visits by the project coordinator and CIMMYT staff provided additional support. In the initial stages of each institute's participation, George and Hoisington visited and helped identify the best equipment, chemicals, and training programs needed. Visits from other experts were arranged to solve specific problems. For example, the CIMMYT maize pathologist might be sent to help the local collaborators identify a pathogen or set up the related experiments.

Finally, scientists from one country spent time working in the labs of other AMBIONET partners. Several Indonesian scientists received training at the University of the Philippines, Los Banos (UPLB), in the first phase of project. In Phase II, Indonesian scientists spent a month working and learning in Prasanna's lab in India.

This project did not provide money for degree training, but supported the thesis research of AMBIONET participants, such as Marcia Pabendon and M. Azrai (Indonesia, MSc theses) and Dedi Ruswandi (UPLB, the Philippines, PhD thesis).

International teams collaborating in research projects on downy mildew resistance and genetic diversity took advantage of the network and the diversity of research locations available through it to do work that could not have been done in any single country, as well as benefiting from the scrutiny and advice of other scientists on their work.

3. Framework for Impact Assessment

The major goal of AMBIONET was to increase the capacity of maize research in Asia to produce improved maize varieties for the poor. The major focus of AMBIONET's capacity building was molecular breeding. To assess the impact of AMBIONET, this study first had to determine whether collaborating maize breeders in these countries improved their capacity to develop useful cultivars over what that capacity would have been without AMBIONET. Is their capacity and skill greater than it was in the past? If so, then has it improved the maize varieties and their economic value?

Assessing the impact of a project on research capacity is a difficult task. The research capacity of a scientist or institution depends on the intellect, skill, and training of scientists, the state of knowledge in their field, the ability to obtain the tools that are needed for their research, and the availability of information, germplasm, etc. Indicators of research capacity include tangible products such as multiple plant varieties, molecular markers, research tools, publications, research awards, and patents. Equally important indicators are scientists' assessments of their own growth in research capacity and their assessment of their colleagues' growth due to this program. Has it influenced their research priorities? What can they do now that they could not do before they joined AMBIONET? Has AMBIONET made it easier or less expensive for them to do their research? Is it easier to get scientific information and short-term training, now that they are members?

To understand the potential impacts, a brief description of conventional and molecular breeding is necessary.

Conventional breeding

Plant breeders define and characterize their target environment. Next they identify the characteristics that farmers need in crop varieties to improve their incomes and well-being. These crop traits may include higher yield, improved resistance to pests or diseases, or improved nutritional characteristics. They may also have differing requirements for cultivar or variety types; say, for example, hybrids vs. open pollinated varieties (OPVs).[2] They then collect sources of genetic variation for these characteristics, conduct recurrent selection or other breeding methods to improve the populations collected, cross them if necessary, and select the genotypes—inbred lines or subsets of the population—that possess the desired characteristics. The selected genotypes are used to produce hybrid varieties or OPVs. These varieties are tested for several years to eliminate genotypes with undesirable traits, and seed of the selected genotypes is produced and marketed to farmers. OPVs are constructed by any of various approaches, including selection of a sub-set of plants or families from a source population, or

[2] Hybrids are produced by crossing carefully selected, highly-inbred lines. With proper management, they can show outstanding performance in the first generation, but this performance drops off in subsequent filial generations. Farmers must purchase fresh seed each season from the company that controls the inbred parents, to get the full advantages of a hybrid. Improved OPVs generally perform at a lower level, but farmers who save the seed for sowing in subsequent seasons will not notice such a steep drop-off in performance as with saved seed of hybrids. OPVs may thus be preferable for farmers who lack the disposable income to invest regularly in hybrids or the inputs that hybrids require to yield their best.

combining several pure-lines which have useful characteristics. Experimental OPVs also must be tested, multiplied and marketed. The entire process to produce hybrids or OPVs commonly takes 8 to 10 years.

Breeding with molecular tools

One of the major goals of crop biotechnology has been to make plant breeding more efficient. Molecular markers were used in AMBIONET to increase the efficiency of breeding in two ways. First, genetic fingerprinting was used to assess the genetic purity of inbred lines, which theoretically should be completely inbred and hence true-breeding. This helped inform breeders whether the lines they were using had become contaminated, and if so, to correct this problem. This helps make their program more efficient and really helps other breeders or seed companies who use their lines. Second, fingerprinting provides information about the genetic distance between different groups of lines. In general, crossing lines separated by a greater genetic distance will result in more vigorous, higher-yielding hybrids. Experienced maize breeders know which genetic stocks combine well, and they perform carefully-planned trials to predict which lines will combine to achieve excellent hybrid vigor, but for newer breeding programs and inexperienced breeders, information about genetic distances among lines can be especially valuable when initiating a breeding program and making preliminary choices among dozens or even hundreds of potential parent lines for hybrid formation. Finally, experienced breeders find this type of information helpful for deciding how to efficiently incorporate lines from CIMMYT or other countries into their breeding programs.

The second way AMBIONET attempted to increase breeding efficiency was through marker-assisted selection (Table 4), involving several steps from the identification of markers to the production in farmers' fields of new varieties with a desired trait. Examples include resistance to viruses in China and to downy mildew in India—two AMBIONET molecular-assisted breeding projects that advanced the most in developing improved varieties.

The first step in marker-assisted selection is to identify a resistant line that can be crossed with a susceptible one to produce a population of plants differing widely for resistance, from very susceptible to highly resistant. By studying the DNA of these different lines and using publicly available software, scientists seek to identify DNA segments that are uniquely present in resistant plants. The next step is to identify molecular markers precisely located on the flanks of the DNA segments associated with resistance. The markers must then be evaluated for other maize populations to confirm or validate that they are associated with the trait in a wide range of maize genotypes. This may take some time and if no resistant maize line can be found, it will not be possible to breed for resistance. In India, it took a year or two of screening varieties and inbred lines to select a good, downy mildew resistant line for use in this project. In China, inbreds resistant to SCMV had already been identified by the time AMBIONET started.

Once markers are identified and validated, they can be used to accelerate the process of selecting new and resistant lines among progeny of resistant-by-susceptible breeding crosses. Markers can also be used to screen existing breeding lines or other material for additional sources of resistance. Using molecular markers to select the lines with the desired trait can lead to the development of breeding lines that are then ready to be used in hybrid breeding programs.

Next, new OPVs or hybrids are developed. Both the Chinese and Indian AMBIONET teams chose to develop improved breeding lines and hybrids to demonstrate the value of molecular tools for breeding. The final stage in most countries is testing in government variety registration programs to make sure the hybrid's performance is equal or superior to that of currently-used varieties, which takes several years. While testing is going on, companies start producing commercial seed, which they market to farmers when they receive government approval.

Conventional breeding for disease resistance requires step 1—identification of lines with resistance (Table 4). Conventional breeding does not require step 2, but often does require steps 3 through 6—backcrossing, developing hybrids, government testing, and marketing. For certain traits, molecular markers may cut the time and the cost of steps 3 and 4 (Dreher et al. 2003). If the cost savings are greater than the cost of step 2, then MAS is clearly superior. If markers are already available, then step 2 is eliminated and any cost savings in steps 3 and 4 will be cost savings for the project.

For improving many economically important traits of maize, there is no advantage to using molecular tools. Hoisington et al. (1998) suggest two conditions under which MAS will be more cost-effective than conventional breeding:

1. "If the heritability of the trait being selected for is high but costly field conditions are required to ensure its expression…A good example is resistance to certain viruses, which obviously will not express in locations where the virus does not occur….
2. If environmental effects are high, the trait being selected for will tend to have low heritability, making classical selection inefficient. In such cases marker-assisted selection could improve selection efficiency, even though the percentage

Table 4. Steps in marker-assisted breeding for disease resistance in maize, with examples from India and China.

Activity	Years required	SCMV, Northern China	Downy mildew, India
1. Identification of sources of resistance to the disease.	0 - 2	CAAS team had resistant and susceptible lines when program started in 1998, identified Huangzao 4 as SCMV resistant line.	NAI116 and four CIMMYT lines identified by AMBIONET-India team during 1999-2000.
2. Identify QTLs* and molecular markers associated with the target trait.	2	CAAS team in 2000 shows that Huangzao 4 has 2 major QTLs for SCMV resistance. CAAS team identifies markers closely linked to resistance genes/QTLs in 2001.	AMBIONET-India team identifies QTLs in collaboration with the CIMMYT and AMBIONET teams in Indonesia, the Philippines, and Thailand during 2001-2002; validates the major QTLs on different mapping populations during 2002-2003.
3. Marker-assisted backcrossing for transfer of disease resistance into elite lines for use in commercial breeding.	2 – 3	Using Huangzao 4 and a line with good combining ability, researchers developed CAR 107, resistant to SCMV, by MAS in 2003.	Major QTLs for downy mildew resistance transferred to CM139 from the donor parent NAI116 during 2003-2004; identified improved lines of CM139 in 2004.
4. Breeders use resistant line(s) to develop new hybrids or improved versions of their best hybrids.	2 – 3	CAAS developing model hybrids – ready for commercialization in 2006; 16 other government institutes have been given resistant lines to use in their breeding programs.	Collaboration with SAUs and other ICAR institutes to develop disease resistant hybrids – possible hybrids in 2006-2007.
5. Government varietal trials and seed companies produce seed.	2 -3	Trials could be complete in 2008.	Multi-location All-India Coordinated Maize Trials for approval of the disease resistant hybrids (2007-2009).
6. Seed companies market the seed with the trait.		Possibly by 2008.	2010.

* QTL = quantitative trait loci; these are genome regions that contain genes associated with traits of interest.

of phenotypic variance controlled by the QTL (quantitative trait loci) would be low. A good example is drought tolerance, which appears to be controlled by several genes and whose expression is frequently confounded by environmental variables that are difficult to control….”

Molecular-assisted breeding also can help breeders to “stack” or “pyramid” multiple genes for resistance to a disease or pest, thereby reducing the likelihood that the resistance in that variety will soon be overcome by the evolving pest or pathogen.

Pathways to farmers

There are a number of pathways by which the gains in research efficiency from AMBIONET might be translated into gains for farmers. These are shown in Figure 1. First, in step 1 in Table 4 AMBIONET breeders may identify lines that can be used directly as inbred parents for producing good hybrids. The lines could go to public plant breeding institutes that develop the hybrids, whose seed is multiplied and sold to farmers. The lines could also go directly to private companies with breeding programs, which would develop the hybrids, produce the seed, and sell it to farmers. A line with useful characteristics may also be crossed with valuable commercial lines and the progeny used as inbreds by public or private seed producers. AMBIONET partners may also develop their own hybrids and provide the inbred parents to public or private seed companies for sale to farmers.

Figure 1 illustrates different paths by which improved germplasm can eventually reach farmers and plots some of these pathways in India and China. The different levels of the AMBIONET collaborating institutes and the different structures of the seed industries in these countries also illustrate how the paths to commercialization are different in different countries. The AMBIONET teams in North China (CAAS) and in India developed commercial hybrids only to demonstrate a new concept. They primarily develop techniques and lines for use by plant breeders in public universities, government research institutes, and local private companies. They move these products out to breeders through collaborative research, training programs, and germplasm dissemination programs. In contrast the Indonesia, Thai, and Vietnamese AMBIONET teams already formed part of government maize

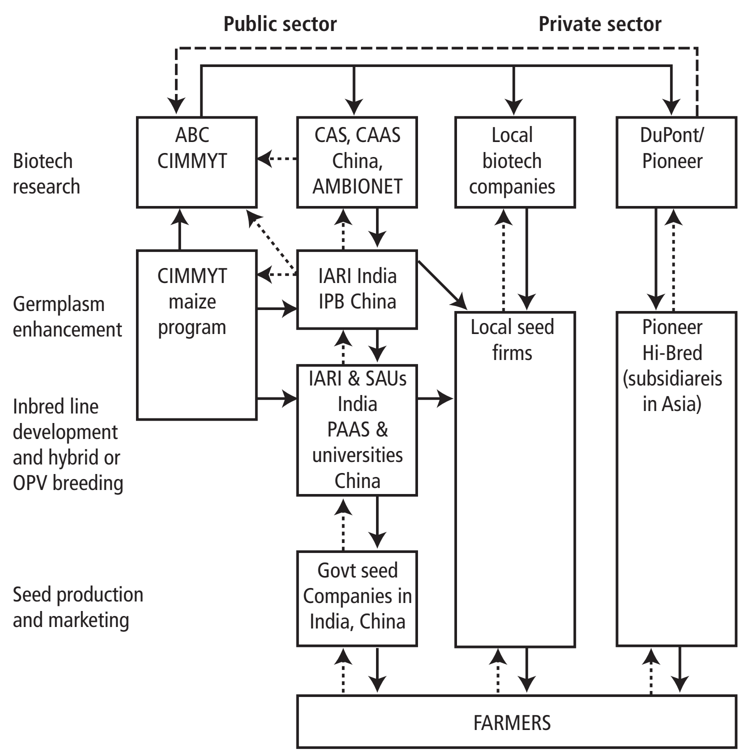


Figure 1. Pathways for marketing germplasm. Solid lines show the flow of techniques and technologies and dashes show the flow of information.

breeding programs; that is, those countries did not have different public institutes for germplasm enhancement and breeding. They put the techniques directly to work in breeding programs; collaboration with other institutes or large training programs were not necessary.

The role of seed companies also varies greatly between countries. Most countries have three types of companies: government owned companies, multinationals, and local seed companies. Government seed companies typically take hybrids or OPVs that have been developed by the public sector, multiply the seed, and sell it. Some local seed companies have small biotech programs and conventional breeding programs that use inbred lines developed by the public sector. Small companies often use finished hybrids from the public sector. Large multinationals like Monsanto and Pioneer may occasionally get some useful germplasm from CIMMYT or national programs, but often their own stress-tolerance breeding research is more advanced.

Methods of impact analysis

One possible impact from molecular breeding is to reduce the cost of research. Precise figures on the costs of conventional breeding versus those for molecular breeding are very difficult, time consuming, and expensive to produce. Obtaining them was outside the scope of this small project. Other types of impact are the economic benefits from developing varieties more rapidly than in the absence of AMBIONET, or developing varieties with more durable resistance to pests and disease. To measure these impacts, we have to compare the value of AMBIONET varieties with the value of similar varieties that would have been developed in the absence of AMBIONET.

Figure 2 shows a hypothetical example of the costs and benefits of AMBIONET. The white bars are the costs of research, which are shown as negative values. In this example we assume that the costs savings in some parts of the research process are offset by cost increases in others. The striped bars represent the value of increased net income that farmers gain by adopting pest or disease resistant varieties developed using conventional plant breeding. The size of these bars would be the economic surplus from adoption of the new varieties calculated using the methods described by Alston, Norton, and Pardey (1995). The benefits rise as more farmers adopt the technology, but then they fall after 2013 in this example, because pests start to evolve around the genetic resistance

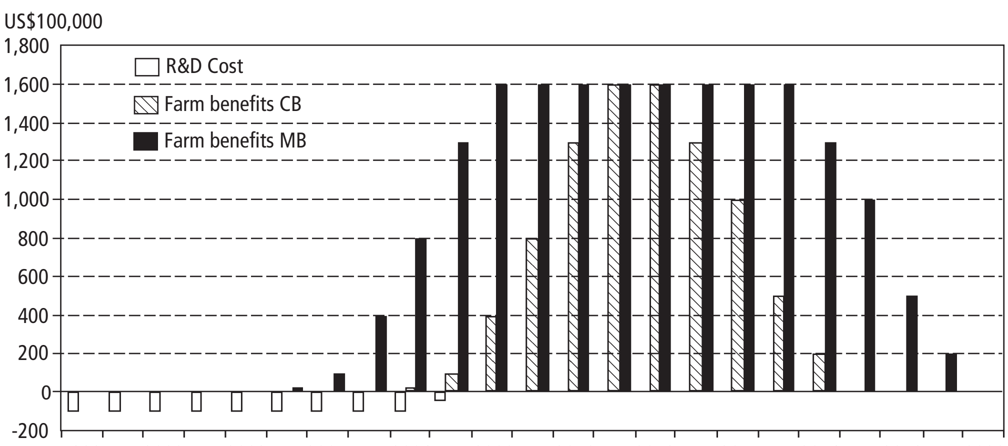


Figure 2. Hypothetical example of costs and benefits from molecular breeding.

and yields from this cultivar start to decline. The solid bars are the benefits that farmers gain if the same characteristic was developed three years earlier using molecular approaches. They are higher than the striped bars until 2012, when both are equal. The solid bars could be higher later if the AMBIONET collaborators stacked a number of different sources of resistance into one cultivar, thus ensuring a longer period of resistance. The benefits from AMBIONET calculated in the present study are the differences between the solid and striped bars—the extra money farmers would earn from cultivars produced through AMBIONET, in comparison with what they would have earned if they waited for the conventional varieties.

If some of the new maize cultivars developed based on AMBIONET outputs are now being used by farmers, it is possible to use the standard methods of measuring social costs and benefits (Alston, Norton, and Pardey 1995) to calculate the value of these cultivars to society. To do this, data on the yield increases or reductions in crop losses due to adoption of stress resistant hybrids are needed. In addition, data on the area sown to new hybrids are needed, as well as data on the farm-level price of maize. If new cultivars are not yet in the field but a reasonable estimate could be made about potential yield increases or reductions in losses as well as the area of adaption, the future benefits from biotechnology could also be calculated.

AMBIONET could also have had several other important impacts, such as pulling more public and private money into maize research. Governments and companies respond to technological opportunities and the new tools might have induced added funding for research on the problems of resource-poor maize farmers, which tend to be neglected. Second, lessons from AMBIONET may now be finding their way into the training of graduate students who will be the future breeders in their countries. Third, scientists play important roles in the development and implementation of policies and regulations surrounding biotechnology, biosafety, and intellectual property rights. If scientists from the network subsequently contributed to formulating or applying those policies, they could bring valuable perspectives on other countries' activities and what might be done in collaboration with other research institutes, including those of the CGIAR. These impacts are not readily quantifiable but can be described.

To assess the impact of the project, we reviewed information in published and unpublished documents about AMBIONET. For an overview of what the project provided and its impact on Asian research capacity, we interviewed Hoisington and George. Because the network is relatively recent and because of the inherent difficulty of measuring research capacity, in-depth case studies were conducted with participating researchers in China, India, and Indonesia, prior to the termination of the project. Using a semi-structured questionnaire, we interviewed scientists about AMBIONET impacts on their research agendas, what they received from the project (inputs), how the project affected their research methods, and whether it increased their efficiency. The scientists were also asked if the project was developing new technology for farmers and when the technology would be available. Finally, the scientists were asked about the sustainability of their research—had the project helped them obtain more resources from other sources? Colleagues of participating scientists and research administrators were also interviewed to obtain their assessment of the impact of AMBIONET on the collaborating scientists.

Measures of research inputs and outputs were gathered from a questionnaire completed by all country collaborators; this was supplemented by information from project reports, online databases, and interviews. Research inputs included research expenditures and numbers of scientists before and after AMBIONET, inputs from AMBIONET, and inputs from other sources. Research outputs included publications, new molecular markers, new techniques for using those markers, new OPVs and hybrids developed using MAS, and reductions in breeding time due to MAS. The data were analyzed for indications that AMBIONET increased maize breeding funding, influenced research priorities, or increased research productivity. To identify the impact of this project, research inputs and outputs in maize breeding before and after the beginning of the project were compared.

Initially, we had hoped also to compare the inputs and outputs of project scientists with non-AMBIONET peers in the same institutes, which would have required interviews with the non-network scientists. However, resources were lacking to do this systematically. We were able to speak to some participants from the Asian Rice Biotech Network in the Philippines, India, and Indonesia, and some wheat biotech scientists in China. In addition we interviewed private sector maize scientists in most countries.

4. Impact on Asian Maize Research Capacity

Based on the interviews and survey data, it is clear that AMBIONET has increased the maize research capacity of these countries. This impact is not always possible to quantify, because in many cases the increase is not yet visible in numbers of scientists, budgets, or new varieties. This section combines the numbers that do exist and quotes and comments from the interviews to make the case that AMBIONET has really done an impressive job making research exciting and productive for maize scientists in Asia.

Asian maize research before AMBIONET

Maize plant breeding research in Asia started before World War II in India, China, and several other countries. Applied research and technology transfer by government institutions and private firms expanded in the 1950s throughout Asia, when many countries attempted to copy the hybrid maize revolution in US agriculture. Government maize research financed both by national governments and donors continued to expand in the 1960s and 1970s but private research was very limited. CIMMYT began to play an important role supporting Asian maize research programs (except China) in the 1970s. China was by far the most successful in introducing and adapting hybrid technology, in part because most of their maize was grown in temperate regions similar to the U.S. In Southeast Asia US hybrids could not survive the diseases and pests – particularly downy mildew. Most national maize programs in Asia other than China and Burma placed more emphasis on open pollinated varieties (OPVs) than hybrids.

In the 1980s and 1990s, public sector maize research continued to grow, but the growth was slow in most Asian countries. In China, maize breeding research grew rapidly during the 1990s at the provincial and sub-provincial levels. In countries such as Thailand, the Philippines, and India, private sector research grew very rapidly, as both multinationals and private seed companies increased their investments in Asian maize research.

The structure of maize research in Asia when AMBIONET started (1998) is shown in Table 5. In India and Thailand more scientists worked in the private sector than in the public sector. In Indonesia and the Philippines, the private sector was closing in on the public sector in numbers of scientists and probably outstripped the public sector in annual research investments. Public research dominated only in the transitional economies of Vietnam and China.

Table 5. Public and private-sector maize research institutes and scientists, 1997/98.

	Public sector		Private sector	
	Number of agencies	Number of scientists (FTEs)	Number of agencies	Number of scientists (FTE)*
China-South	65	270	1	na
India	27	56	28	74
Indonesia	1	13	1	11
Philippines	12	50	7	34
Thailand	4	35	6	40
Vietnam	2	68	5	1
Asia	116	505	49	166
Asia (excluding China)	51	235	48	166

Source: CIMMYT Asia Maize Impact Survey 1998-99.
*FTE = full-time equivalent.

Biotechnology research on maize in Asia started around 1990. Chinese government scientists at CAAS have been working to develop Bt maize since then. Central China Agricultural University started using molecular markers in the mid-1990s. Basic research on transposans in maize was conducted at the Central University of Hyderabad, India, since about 1990. Some Indian agricultural universities, general universities, and the IARI conducted research on transgenic maize in the 1990s. The Chinese and Indian governments invested heavily in basic research laboratories for plant, animal, and human biotechnology; a small amount of that went to maize research. The governments of Thailand, the Philippines, Indonesia, and Vietnam started investing substantial amounts of money in plant biotech research but not much went specifically on maize.

In the late 1990s a number of companies started to investigate the potential of transgenic maize in Asia. So far this investment has started to payoff only in the Philippines, where Bt maize is starting to spread to farmers. Bt maize has been in government field trials in China since 1999, in India for the past several years, and in a number of countries in Southeast Asia. In addition herbicide tolerant maize is in government field trials in the Philippines, Indonesia, and Thailand.

Impact of AMBIONET on NARSs' research priorities

One clear impact of AMBIONET has been to increase the number of scientists working on maize germplasm enhancement and breeding. One of the early criticisms of biotechnology was that it pulled resources away from conventional plant breeding, rather than helping plant breeding become more effective. There was concern that biotech research was too basic and would not provide technology that farmers needed. AMBIONET seems to have increased the resources devoted to enhancing maize genetic variability in China and India and maize breeding programs in all of the countries. In China the number of plant breeding programs was increasing in the public and the commercial sector. According to Zhang, the CAAS Institute of Plant Breeding in Beijing did not have a strong program to increase the genetic diversity of maize germplasm before AMBIONET, and that is precisely what AMBIONET was able to strengthen. In Indonesia all crop programs have had difficulty attracting young people to plant breeding, but there were many maize scientists in other disciplines. The Indonesian maize program used AMBIONET money to finance research that attracted bright, young scientists from plant pathology, agronomy, and other disciplines to plant breeding that used molecular tools. In the Philippines, the breeder at the University of Southern Mindanao had been doing rice breeding before he joined the AMBIONET team.

The network also led biotech scientists to change their focus from basic to applied research. For example, Prasanna changed from academic research on maize landraces in Northeast India to research on the actual disease and drought problems of subsistence and commercial maize producers. Biotech scientists who used AMBIONET money to pursue research in isolation from plant breeders in the first phase were not asked to join the second phase of AMBIONET.

Perhaps even more important has been the impact of inducing biologists to work on maize. With the exceptions of Li and Prasanna, the biologists on AMBIONET teams were previously not working on maize. CAAS recruited Tian from the wheat biotech program, Wanchen Li at SAU in Southern China had worked on silkworm genetics, and Sutrisno in Bogor worked on rice.

The project also appears to have changed breeders' priorities somewhat from traits like yield, which are complex and controlled by many genes, to traits such as resistance to biotic stresses, controlled by a few genes. The Indonesian maize breeders reported that before AMBIONET they focused on yield, acid soils, and resistance to the main pests and diseases. After joining AMBIONET they focused more specifically "on increasing genetic resistance of maize to downy mildew and the molecular study of genetic diversity of Indonesian inbred lines." It is not clear whether this is a more effective use of research resources or not.

Financial resources

Participation in AMBIONET is clearly related to increasing budgets. Before AMBIONET, the budgets of all the programs except Vietnam's were decreasing or stable. After joining AMBIONET, all programs except the maize program of Thailand (which suffered because of the Thai fiscal crises) increased their budgets (Table 6). During the same period almost all of the budgets of their colleagues in similar programs declined or were stable.

Part of the increase in collaborators' budgets was due to AMBIONET funds, part of it was due to increases in institutional funding by their governments, and another part was through grants from their governments (Table 6). Funding for partners' research came primarily from their government departments: specifically, ministries of agriculture or education. Traditionally they had not obtained support through competitive grants. Most grants were small, but they were still significant because they were competitive grants. In China and Indonesia grants came from non-traditional sources, specifically the ministries of science. This represents a new source of funding, rather than just reorienting existing agricultural research money.

The Chinese and Indian case studies show how major programs were built based on AMBIONET. In part this is a result of their governments viewing science as an engine for economic growth and designating biotechnology as a major area for investment. With the help of AMBIONET, scientists there took advantage of the opportunities offered by the national governments.

In an interview at the AMBIONET annual meetings in Chiang Mai, Thailand, 2003, Shihuang Zhang, leader of the Chinese team, said: "AMBIONET came along at the ideal time for us. We were able have some of our young people trained and start our lab. Then in 1998 and 1999 China changed the way research was funded. We had to compete for funds and we were able to get big projects for molecular breeding." The Chinese

Table 6. Direction of research funding and competitive grants in AMBIONET.

Survey question	China-North	China-South	India	Indonesia	Philippines	Vietnam	Thailand
Before AMBIONET, budget was....	Down	Stable	Stable	Stable	Down	Up	Stable
Your budget during AMBIONET went....	Up	Up	Up	Up	Up	Up	Down
Budget of comparable programs?	Stable	Stable	Down	???	Down	Up	Down
Grants from national/international grants programs	US$30,000	US$33,735	Yes	Yes (some)	US$43,000	US$15,000	US$5000/year
Sources of grants	Natural Science Foundation, MOST	Natural Science Foundation, Sichuan Dept. of Ed.	Indian Council of Agricultural Research	International Fund for Science (Sweden), Ministry of Research & Tech.	Dept. of Ag., Philippines	Govt. of Vietnam	Thai. Govt.

Source: Survey by author.

team at CAAS used the initial money, equipment, training, and advice from AMBIONET to start the fingerprinting, mapping, and markers lab. AMBIONET money was used to hire Xinhai Li, PhD in maize genetics and breeding from Northeastern Agricultural University in Harbin who had worked as a postdoctoral fellow using molecular markers at Central Agricultural University in Wuhan, and Quinzhen Tian, who had worked on molecular markers in wheat at CAAS. Under Zhang's leadership, these scientists and others converted the Institute of Plant Breeding's maize program into China's major maize molecular breeding and enhancement program. This initial combination of breeding and molecular biology capacity, the early output of this lab, and its links to international scientists at CIMMYT gave it a competitive advantage at a time when the research funding in China was changing from institutional funding to competitive grants.

The China AMBIONET team obtained a series of increasingly large competitive grants from the government. They received a small grant from the Chinese Natural Science Foundation and the Ministry of Science and Technology (MOST) for US $24,000 in 2000, for maize germplasm improvement. The grant was for 4 years and 16 institutes. They were then able to obtain US $1.2 million to continue their germplasm improvement project. Some of the research financed by this grant used molecular markers. In 2003 MOST financed a much larger project to commercialize crops developed using molecular breeding. The total funding was US $4.9 million, of which this group received US $363,000 to work on maize. The rest is spread between different important commodities in China. The last grant—the first large project specifically for molecular breeding and commercialization—seems to reflect a change in government policy on biotech research; previously, public investments went largely for genetic engineering. The shift may be due to the success of molecular breeding in maize, wheat, and rice; to effective lobbying by Zhang and his colleagues; and to increasing consumer concerns about genetic engineering.

In India, AMBIONET had similar impacts on Prasanna's lab and research budget, among other things enabling him to be the only person from the Genetics Department of IARI to have a lab at IARI's Biotechnology Center. He became co-principle investigator for AMBIONET-India with N.N. Singh, also head of IARI's maize breeding program and a long–time CIMMYT partner. When Prasanna started working with AMBIONET, he had a lab and limited, antiquated equipment, but no reliable electricity or modern equipment. Through Singh he obtained money from the Directorate of Maize Research to redo the electrical system. He used US $40,000 from the first AMBIONET project and US $10,000 from the second to buy or update equipment. He also recruited IARI grad students to work in his lab.

The capacity of Prasanna's lab to conduct sophisticated research and to do training and short courses has enabled the group to win two new projects approved by the Indian Council of Agricultural Research (ICAR) in October 2004:

1. A molecular breeding project involving a network of 12 ICAR institutes and a budget of US $866,000 for 12 crops. Of this US $55,000 is for maize research and training at Prasanna's institute.
2. Prasanna's work with AMBIONET has given him functional genomics skills, allowing him to obtain an ICAR-approved grant of US $400,000 for maize functional genomics research and the purchase of the new equipment needed.

Human capital

The scientific capacity of research institutes increases through the addition of new scientists or by increasing the capacity of current scientists, via training and/or learning-by-doing. Only the Chinese and Philippines labs of AMBIONET reported increases in the number of scientists (Table 7). In Indonesia and Vietnam, the number of scientists remained the same. The Indian lab lost one permanent staff to retirement, while the Thai program lost people to administrative positions. What does not show up in these numbers of permanent staff is that in both India and China the actual number of people involved in research is augmented by graduate students. Both CAAS and IARI give postgraduate degrees in the agricultural sciences. Prasanna at IARI had Indian, Vietnamese, and Iranian students working with him from the beginning of the AMBIONET program. Since the start of AMBIONET he has had five MSc students and five PhD students, three of whom are still working on PhD theses. AMBIONET paid for their research expenses.

In North China the lab has gone from no graduate students to 18 students who are in CAAS PhD programs or from other agricultural universities around China. When AMBIONET-China country coordinator Shihuang Zhang visited Prasanna's lab he said: "I saw all these young people in his lab and I thought I should take this back to China. Our universities have many graduate students but they do not have enough money to support research. On the other hand, under recent reforms, my institute is cutting back on paid staff. So we opened our doors and have the students work with us, and in turn we help them prepare their theses. Perhaps this approach is already popular elsewhere, but for China this is very new and very useful."

Even more important than the number of scientists has been the growth of maize scientists' knowledge and research skills. The scientists in these programs have higher degrees in more basic areas of science. This is particularly clear in the Chinese case. At the time AMBIONET started, a number of senior scientists were retiring. These scientists had made major contributions to Chinese agricultural development, including the introduction and development of single-cross maize hybrids that boosted yields in the 1980s and 1990s. They were knowledgeable and skilled breeders, but few had PhDs or training in molecular biology. In contrast, four of the young scientists who have joined the maize section of the Institute of Plant Breeding with AMBIONET support have PhDs in genetics or plant breeding and at least two have post-doctoral research experience in molecular markers and mapping.

In Indonesia, both the degree training and research experience of scientists have been important. Four young scientists from the maize research system in Maros, Suluwesi, have obtained MSc degrees in plant breeding from Padjadjaran University and one from the University of the Philippines, Los

Table 7. Scientists and technicians in the AMBIONET teams before and after joining AMBIONET.

	China-North	China-South	India	Indonesia	Philippines	Vietnam	Thailand
Number of scientists before joining AMBIONET	2	6	2	8	1	30	5
Number of scientists after joining AMBIONET	5	8	1	8	4	30	3
Number of technicians before joining AMBIONET	1	6	3	No info	0	10	3
Number of technicians after joining AMBIONET	5	7	2	No info	3	10	1
Increase in number of scientists	3	2	-1	0	3	0	-2
Increase in number of technicians	4	1	-1	No info	3	0	-2

Source: Survey by author.

Banos (UPLB). The research of the two Padjadjaran students used molecular markers and was financed by AMBIONET. They continued their work at the biotechnology laboratories in Bogor, while the Indonesian maize program and AMBIONET equipped the labs in Maros. In addition, a faculty member from Padjadjaran University, Bandung, West Java, obtained a PhD at UPLB working on an AMBIONET-financed project in molecular breeding.

The contributions of AMBIONET to the skills of participating scientists through short courses and actual work in advanced labs probably equals or exceeds degree training in importance (Table 8). At the beginning of AMBIONET, Prasanna and Desiree Hautea (Philippine team leader in AMBIONET Phase I) were the only partner scientists with training in the use of molecular markers, knowledge acquired during a course at CIMMYT in the early 1990s. The country teams assembled the few scientists who had experience, if they could. In China some young scientists with post-doctoral experience were available. In other cases, scientists trained by Rockefeller or ARBN in the use of markers for rice helped the program get started. Frequently, the institutes hired people and sent them for training. Indonesian scientists who had worked in ARBN got the project started, while other scientists went for training in the Philippines. The first researchers sent for training did not stay with AMBIONET, so others trained with Prasanna (see below). In short, almost all scientists who actually did the work, except a few in China and India, had to be trained in AMBIONET mapping and marker training programs.

In addition to formal training, longer training programs, where scientists from one program worked in another AMBIONET lab, were important. The Indonesian team sent two of their young scientists to Prasanna's laboratory in New Delhi, India. Indonesian scientist Firdaus Kasim reported this to be extremely useful, particularly for his colleagues Marcia Pabendon and M. Azrai, who went for one month to a genomics workshop for Indian scientists. "Prasanna showed our scientists how to do downy mildew and genetic diversity research. He was a very good teacher—strong in genetics and statistics. After they came back they made a lot of progress." Prasanna provided the second set of lines that Pabendon fingerprinted in diversity studies and also 400 primers (markers) for downy mildew resistance. The groups remain in close contact through email.

Table 8. Participants in training programs by country.

Course, location, year	China North	China South	India	Indonesia	Philippines	Vietnam	Thailand
Molecular Marker Applications to Plant Breeding, Mexico, (1998)	4		3	2	4		4
DNA fingerprinting, Thailand (1999)	2		2	2	2		2
Utilization of DNA-based Markers for Crop Improvement and Candidate Genes, Thailand (2000)							10
The Master Class in Molecular Plant Breeding, Australia (2000)				1			1
QTL Mapping Workshop, Philippines (2001)	3	3	2	5	6		4
Genetic Diversity, Thailand (2002)			3	4	4		5
Proposal development workshop, Thailand (2003)	3	1	1	3	3	2	4
In country training on SSR Protocols					2		
In country training on Data encoding & analysis					5		
Molecular marker technologies, Vietnam						10	
Laboratory exchange visits	3	2	1	3	5	1	1
Total	**15**	**5**	**13**	**20**	**30**	**13**	**31**

Source: Survey.

Strength through the network

All participants interviewed commented on the value of collaborative research with other national programs and CIMMYT. Being forced to present results to peers from other countries energized the young scientists in China and India and the senior scientists in Indonesia. They received constructive criticism, learned about how others overcame problems, and arranged follow-up visits to their programs by researchers from CIMMYT or other countries.

Hautea emphasized the cumulative impact of research that allowed young scientists to shuttle between NARS and CIMMYT labs and to develop contacts with other scientists. The first step for most in AMBIONET Phase I was a training program involving actual research in an advanced lab. This gave participants the confidence that they could apply the techniques, as well as contacts for continuing consultation when they needed assistance. Collegial links and exchange of information and feedback were re-enforced at the annual meetings. Research steps that could not be carried out successfully in national program labs could be done at CIMMYT or in the AMBIONET service lab at IRRI.

At Bogor, Indonesia government scientists listed several other advantages of networks. Technicians or scientists from CIMMYT could come to Bogor to help solve problems. Consumable supplies—particularly imported chemicals—could be ordered through the AMBIONET Support Lab at IRRI for much lower prices and with much less hassle. Machine repairs could often be done at IRRI more quickly than by sending the apparatus to a factory in the US or Europe.

When the Chinese team encountered a technical problem, they contacted CIMMYT for assistance by phone, email, or, on occasion, through direct visits. Zhang cited an example of the latter, in an incident pertaining to virus resistance. The Chinese researchers thought they had identified sugarcane mosaic virus (SCMV), but the sample tested differently from SCMV elsewhere; some local scientists said it was actually maize dwarf mosaic virus (MDMV). CIMMYT maize pathologist Dan Jeffers traveled to China with AMBIONET support and confirmed that the disease was SCMV. Upon his return to CIMMYT, he developed a new method for inoculating plants with SCMV to test lines and populations for susceptibility. The method is still used in China and represented an important breakthrough in research to develop virus resistant maize.

Impact on research capacity outside AMBIONET partner institutions

AMBIONET partners are starting to contribute to the research capacity of other institutions in their countries, through training and collaborative research. Thesis research funded and numbers of students and scientists who received short-term training from AMBIONET teams are shown in Table 9. The Chinese and Indian institutions, which have major graduate training programs in their institutes, support PhD and MSc thesis research. The graduates are taking jobs in other universities and government research institutes using the molecular marker techniques learned from AMBIONET partners. The programs also teach these techniques to graduate students. Sichuan Agricultural University reports that about 350 students have been introduced to the techniques. The AMBIONET teams are also spreading the techniques to other breeders, both for maize and other crops, through short-term training programs. The Indian team seems to have done the most short-term training. The Chinese institutes provided training to private sector scientists. The Thai and Indonesian programs have supported a few theses or training courses (they do not belong to institutions with teaching responsibilities).

Table 9. Thesis research and short-term training supported by AMBIONET teams.

	China-North	China-South	India	Indonesia	Philippines	Vietnam	Thailand
Thesis research							
MSc	8	9	5	2	0	3	0
PhD	2	3	5	0	0	1	0
Short-term training courses							
Number of students	10	350	100	4	100	150	0
Number of public sector scientists working on maize	15	20	20	0	3	10	0
Number of public sector scientists working on other crops	0	20	30	0	10	15	0
Number of private sector scientists	12	3	0	0	0	0	0

Source: Survey by author

The CAAS team has provided training in marker use to public and private scientists through a series of short-term programs. Two scientists from private firms (Denghai Seed Co. and Tunyu Seed Co.) and one scientist from another public institute have worked in their labs for several weeks, in preparation for setting up their own labs. The CAAS team has provided the companies and institutes with a list of equipment and chemicals needed and have helped them buy equipment and supplies. Denghai Seed Co now has an operating genetic fingerprinting lab which the author visited. PhD and MSc students from all over China are conducting their thesis research in the lab of the CAAS team (four students were from Xinjiang Agricultural University, three from Shenyang Agricultural University, and three from the Northeast Agricultural University in Harbin), many with AMBIONET funding.

The Indian government is now establishing networks modeled loosely on the AMBIONET, ARBN, and the Rockefeller Foundation Rice Biotechnology Network to reinforce their formal training programs. Prasanna is involved in a maize genomics project that will provide training, backstopping, and a central lab facility for a network of government research institutions working on maize functional genomics.

Private firms in the AMBIONET countries are beginning to use molecular breeding technologies. Most interested are local companies whose maize breeding programs are too small to justify the investment in molecular markers. This includes companies with annual sales as high as US $20-40 million, such as MAHYCO in India, the Denghai Seed Company and Tunyu in China, and Dominguez in the Philippines. The multinationals have their own MAS programs more advanced than the AMBIONET work.

The Denghai Seed Company was investing in this technology to strengthen their control over the inbred parents of their maize hybrids. They were fingerprinting all inbred lines for which they were obtaining plant variety certificates, to help establish their ownership in the courts. They currently have more certificates on maize than any other company, and they also have taken more legal action than other companies to enforce their certificates. Their leader Li Denghai reported in June 2004 at his headquarters near Qingdao that stronger property rights through plant breeders rights had allowed him to increase revenues from maize sales dramatically and augment investments in maize breeding from US $2.5 million in 2000 to about US $12 million in 2004.

Maize is not a major crop for MAHYCO, but it does have a small breeding program to develop hybrids for farmers with marginal water resources. Brent Zehr, head of MAHYCO's research program, said in a 29 July 2004 email:

> "The one area where we have used DNA markers has been in fingerprinting our parental lines, so that we can better understand underlying genetic diversity and develop heterotic group clusters in order to make more informed crossing decisions. This is well established in hybrid maize programs globally; and DNA markers in this crop are published such that it is relatively easy to perform the tests in-house."

In response to the follow-up question: Have you seen the work that Prasanna of IARI has done in this area and if so, was it helpful to your program? Zehr replied: "Yes, we had seen the work a few years back, and had decided to utilize some of the same markers, as his work included Indian based germplasm. So I would say that it helped give us some direction for initiation of the work. Beyond that, we have developed further marker profiles and taken directions that are useful for our goals in breeding of hybrid maize."

5. Impact on Research Output and Productivity

For maize in Asia, the ultimate goal of CIMMYT and the national AMBIONET programs is to develop new cultivars that improve the well-being of the poor. Thus, AMBIONET research will hopefully result in new varieties for farmers and consumers that improve their diets, health, and incomes. Developing a new maize variety typically takes at least 8 to 10 years, after which in most Asian countries it goes through several years of government testing. Following this, new cultivars take a while to spread to farmers and increase their incomes and the availability of food. Even if this process is accelerated a bit through molecular breeding, it is still early to expect a project that started late in 1998 to have produced new cultivars or impact on farmers. The project has, however, produced knowledge, research tools, and lines of maize that will contribute to the development and spread of new cultivars and the improved well-being of farmers.

Progress toward improved cultivars

Interviews and questionnaires have revealed that, despite the short life of the project, each step of molecular breeding has produced new lines or hybrids, and that there is substantial progress toward developing disease resistant and QPM cultivars using MAS. Most partners have established a program that can be the basis for developing higher-yielding hybrids and drought tolerant cultivars in the future. There is evidence of improved research tools, such as useful new molecular markers, and additions to knowledge about maize in the form of refereed journal articles. Both will help increase the efficiency of future research.

AMBIONET programs contributed to the development of improved OPVs and hybrids for farmers through four pathways (Table 10). The first pathway leads directly from genetic diversity studies. Information developed in those studies

Table 10. Pathways from AMBIONET research to improved cultivars.

Contribution of AMBIONET to breeding material	Research institutes using AMBIONET lines and names of new hybrids/OPVs	Intended impact/benefits	Year of approval or expected approval
1. Information about combining ability leads to new hybrids.	South China: hybrids SAU 23 and SAU 27.	Higher yield.Higher yield.	2002 (SAU 23). 2004 (SAU 27).
2. Lines identified in studies to develop QTLs.	Thai Department of Agriculture: hybrids NS 72 and NSX 982013.	DM resistance. DM resistance + higher yield.	2001 (NS 72). 2003 (NSX 982013).
	India: University of Agricultural Sciences, Bangalore; Composite NAC3002. Hybrids under development.	DM resistance.	Expected 2006.
3. Resistant lines identified and incorporated into lines with good combining ability using markers.	Breeders at public research institutes and universities.	DM resistance.	
	China: CAAS, 16 institutes are using lines.	SCMV resistance.	
	AMBIONET team develops resistant lines that can be used in Indonesia, Thailand, and the Philippines.	DM resistance.	2011?
4. Hybrids and OPVs developed using MAS.	IARI producing hybrid to demonstrate molecular breeding.	DM resistance.	2010.
	CAAS producing hybrid to demonstrate molecular breeding.	SCMV resistance.	2008.
	Indonesia maize research program and Padjadjaran university.	Stacked DM resistance and QPM.	Unknown.

was used to choose parents of hybrids with better combining ability. The other three pathways come from molecular breeding programs. The second pathway was the identification of lines for use in research to produce molecular markers. These lines and combinations of lines could be used in conventional breeding programs to produce commercial hybrids. The third pathway used lines identified by AMBIONET teams as having disease resistance using molecular markers and then backcrossing the lines identified to other lines with good combining ability. The resulting progeny are given to breeders to produce finished hybrids. The fourth pathway is when the AMBIONET teams produce finished hybrids or OPVs developed through backcrossing and MAS programs and provide these to seed companies.

The only technologies related to this program that have reached farmers were developed through the first two pathways. Chinese scientists from SAU in Sichuan developed two new hybrids, SAU 23 and SAU 27, based on their studies of genetic diversity. SAU scientists took advantage of the information about genetic distance based on the fingerprinting data of their lines and the lines of other maize programs in China to identify and cross inbreds that were the greatest genetic distance apart. This allowed them to obtain greater hybrid vigor and higher yields. The Vietnamese team has identified two hybrids that resist lodging and possess drought tolerance; they are refining them, based on information from the diversity studies.

The Thai hybrids were developed from lines identified at the beginning of the research to locate QTLs for downy mildew resistance. While screening for resistant and susceptible parents to make a mapping population for resistance QTLs, they found a line—NEI 9202—that had good resistance and other good commercial characteristics. This line was probably based on downy mildew resistance screening programs carried out by earlier generations of Thai breeders with CIMMYT assistance. The current breeders were able to use this line as a parent of two commercial hybrids: NS 72, released in 2001; and NSX 982013, grown by farmers for the first time in 2003. Seed of the NSX hybrid was multiplied and marketed by government agencies and sown on about 5,000 hectares this year (Pichet email). It replaced NS 72 and other hybrids because it yields 10% more than NS 72.

One of the Indian research stations that is collaborating with the Indian AMBIONET team has used the downy mildew resistant line, NAI 116, which the Indian AMBIONET team identified as a parent for a molecular mapping population, to develop improved hybrids and OPVs. The University of Agricultural Sciences, Bangalore's Regional Research Station at Mandya, and the Agricultural Research Station at Nagenahalli developed a downy mildew resistant composite NAC3002 using NAI116 as a parental line. They are also developing hybrids using this line. NAC3002 is being tested in advanced field trials and will probably will be released in the next few years (Prasanna email, 02 September 2004).

The two groups of cultivars under development using pathways three and four (backcrossing and MAS) that are closest to being commercialized are downy mildew resistant cultivars in South and Southeast Asia and SCMV resistant cultivars in China. Table 4 shows the progress that the Chinese and Indian programs have made towards developing commercial cultivars. Several years ago they identified disease resistant lines and reported their names—NAI 116 and Huangzao 4—and sources in journals, so that public and private sector breeders could use them.

The lines had serious limitations—NAI 116 will only pollinate at cool temperatures and Huangzao 4 had poor combining ability—so AMBIONET teams backcrossed them with better inbreds for commercial uses. As part of this, they used molecular markers they had developed to screen the segregating material for resistance. They made the selected material available to other public sector breeders in India and to public and private sector breeders in China. In India the lines were being used by AMBIONET partners. As of June 2004, 16 government research institutes and no private institutes had requested SCMV resistant lines from the AMBIONET-China lab.

The CAAS and Indian AMBIONET teams are also producing disease resistant hybrids using MAS. CAAS plans to have SCMV resistant hybrids ready for commercialization in 2006 and IARI plans to have downy mildew resistant hybrids ready in 2006 or 2007. These hybrids will then be tested for several years in multi-location trials for yield and pest and disease resistance, before they can be sold to farmers. Thus, at the earliest these hybrids would be available to farmers in 2008 in China and 2010 in India.

The Indonesian, Philippine, and Vietnamese AMBIONET teams worked on downy mildew resistant hybrids and OPVs using the lines and molecular markers developed in AMBIONET. In addition, the Indonesian AMBIONET team was close to releasing a QPM line, originally from CIMMYT, that they had selected and tested in Indonesia.

Many teams produced considerable data about their own inbred lines and the genetic relationship of those lines to other maize lines from CIMMYT and Asia. Interviews with Asian and CIMMYT breeders showed this information was influencing Asian breeders' thinking and making their programs more effective.

Increasing knowledge, improving research tools

The other important AMBIONET output is knowledge about maize and maize breeding. This knowledge takes tangible form in research tools, presentations at meetings, and publication in academic journals, but much of it is intangible. One of the few quantitative measures of knowledge in a research program is the number of articles published in refereed academic journals. Table 11 shows that the number of articles in national journals published by AMBIONET partners increased or stayed the same in all countries, except Thailand and Vietnam. In addition, only a few of the AMBIONET scientists had previously published articles in international journals, but now all but the two newest programs, Vietnam and the new Philippines team at the University of Southern Mindanao, have international publications.

Table 11. Numbers of journal articles published by AMBIONET partners.

	China-North	China-South	India	Indonesia	Philippines	Vietnam	Thailand
National journals for 5 years before AMBIONET	8	10	5	3	3	10	4
National journals after joining AMBIONET (adjusted for 5 years*)	15	35 (58.3*)	5	3	3 (7.5*)	7 (17.5*)	0
International journals for 5 years before AMBIONET	0	0	3	0	1	0	0
International journals after joining AMBIONET (adjusted for 5 years*)	5	3 (5)	13	1	0	0	2

* We adjust publications by assuming the output per year will be the same throughout the period of time after joining AMBIONET and then multiply output per year by five. When the survey was done the founding teams had been on board for 5 years, south China for 3 years and the new Philippines team and Vietnam for 2 years.
Source: Survey by author.

With leadership from Luz George and David Hoisington, AMBIONET partners published articles on downy mildew resistance in *Theoretical and Applied Biotechnology* (George et al. 2003) and *Euphytica* (George et al. 2003). The team used a set of common markers, common research procedures, and a common set of maize lines, and conducted multilocation field research to identify QTLs and DNA markers for downy mildew resistance. Similar studies on maize genetic diversity were published in *Theoretical and Applied Biotechnology* (George et al. 2004)

In developing disease resistant cultivars, the AMBIONET teams have generated a set of tools that will be useful to maize breeders wherever downy mildew and SCMV are a problem (CIMMYT 2004):

> "Teams used molecular data from a cross previously mapped by CIMMYT, combined with phenotypic data produced in five locations in India, Indonesia, Philippines, and Thailand, to identify genes for downy mildew resistance. Five quantitative trait loci (QTL) that significantly influence downy mildew resistance were identified, three of which explain up to 50% of the phenotypic variance for reaction to downy mildew disease. With genetic linkage maps constructed in the AMBIONET-China lab and phenotypic data from Beijing, researchers identified five QTLs conferring resistance to sugarcane mosaic virus, explaining up to 27% of the phenotypic variance."

Research productivity

Was the increase in output of publications due mainly to the increase in scientists and resources previously described, or did the scientists produce more per person? Figure 3 shows that in most countries research productivity, as measured in publications per scientists, has increased. Three programs—those of South China, India, and Indonesia—raised their publication productivity after joining AMBIONET. North China increased published output substantially from 8 to 20, and the number of articles in international journals went from 0 to 5, but the number of scientists also expanded rapidly from 2 to 5, so productivity appears to be constant. If international journals are weighted more heavily than national journals, then the productivity of the North China program also went up. If we use the productivity measures adjusted for the number of years in AMBIONET, Vietnam's productivity also goes up. In the Philippines, productivity goes down despite the increase in articles, due to the fact that the number of scientists in the new team at USM grew from one to four. The Thailand team has only public plant breeders at the moment, and their job is to produce varieties rather than journal articles. So, it is not too surprising that Thai productivity declined slightly.

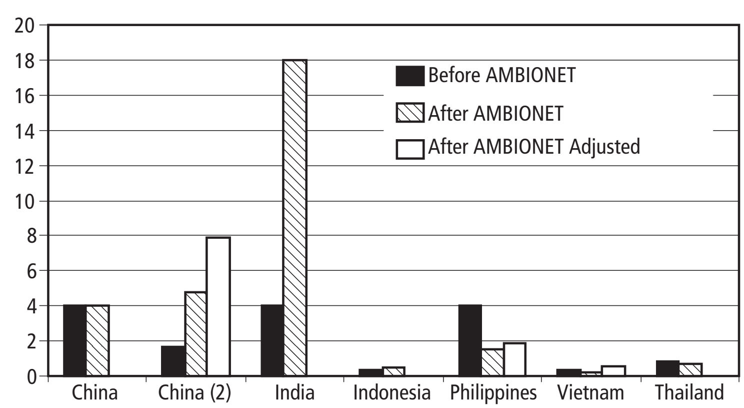


Figure 3. Research productivity: journal articles per scientist.
Note: National and international journal articles from Table 12 were added together and then divided by the number of scientists reported in Table 7.

As formerly mentioned, comparing the results between countries is misleading because different types of institutes have different research goals and different methods of measuring scientists' numbers, and were members of AMBIONET for different lenghts of time. For example, the Indian program had only two permanent scientists in the lab when AMBIONET started and one scientist during the second phase. These scientists worked with a number of other scientists in other institutions and with a number of graduate students to produce the journal articles. In contrast almost all of the maize scientists in Indonesia work in the collaborating lab and so cannot collaborate with many scientists outside of their labs. Thus, the differences in productivity between Indonesia and India are not as great as they would appear, judging from the graph. Programs in South China, Vietnam, and the Philippines did not have a full five years to produce articles, so Figure 3 presents adjusted productivity measures for those countries. The unshaded bar shows adjusted productivity measured in output/ scientist, assuming that their output per year after AMBIONET continued at the current level, and multiplies output per year times five (see Table 11 above).

6. Impact on Farmers

Will the technologies developed by AMBIONET partners improve the well-being of the poor? This chapter argues that it is likely. When the new cultivars are marketed, they are likely to provide substantial benefits and rapidly pay off the investments of Asian governments, ADB, and CIMMYT in AMBIONET.

Potential value of new varieties from AMBIONET

The potential social benefits of higher-yielding, downy mildew and virus resistant, drought tolerant cultivars are significant. Measuring the increase in yield due to new, higher-yielding, stress-resistant hybrids is relatively straightforward conceptually: one simply measures the value of increased yield per hectare due to use of a new hybrid or OPV and multiplies that by the number of hectares sown. The first data on the increased yields of a hybrid due to better choices of inbred lines or stress resistance will be experiment station yield comparisons, but is it is possible to make a rough estimate of the size of some of the benefits. The starting point for measuring the potential yield increases from disease resistance or stress tolerance is the value of the losses that now occur from these stresses. It is difficult to measure the extent of losses or their frequency, but we have two sources of information. The first is government agriculturalists and scientists who have studied past disease and drought incidence. The second source is the farmers who are affected. The estimates of losses reported by Dalmacio (2000) and Zhang (1998) have been gathered in Appendix Table 2. Estimates from farmers are available from a recent research priority setting exercise conducted by CIMMYT (IFAD-CIMMYT study).

The next challenge is to estimate how much of this loss could be averted using the improved lines from AMBIONET and when these savings will take place. These estimates require assumptions about:

1. What cultivars these characteristics will be bred into, who will do the breeding, and when.
2. Who will produce and market the seed of the new varieties and when.
3. How rapidly farmers will adopt these varieties.
4. How much of the loss will be averted and what the value of that quantity will be.

The simplest set of assumptions is that the government institutes of the AMBIONET teams will develop new cultivars and pass then through the variety registration process. Then government or private seed companies will multiply and market the seed, and farmers will buy the seed because of the obvious benefits to them.

Unfortunately (or fortunately), the world is more complicated than that. As Table 12 shows, almost all maize hybrids outside the transitional economies of China and Vietnam were developed by the private sector, and even in China hybrids from private firms are popular in the north. As discussed above, lines with the new traits are likely to go to local seed companies with breeding programs, after the traits have been bred into lines with good combining ability that are relatively easy to use in the private breeding program. Or, small seed companies with limited breeding capacity could wait until the government institute has actually developed resistant hybrids through MAS and then start multiplying and selling the seed.

Actual and potential impact of AMBIONET activities

CIMMYT scientists recently went through an exercise where they interviewed farmers in representative villages about their average yield losses from various constraints (IFAD-CIMMYT study). These estimates were reviewed by NARS and CIMMYT scientists to assess how realistic farmers' estimates were, to provide information on how widespread the losses were, to calculate the value of the losses, and then to discuss maize research priorities. In these studies downy mildew was identified as a serious problem in only a few regions (Table 13). At the bottom of the table the losses from SCMV were estimated. In India and Vietnam the farmers who were interviewed did not experience large losses from downy mildew.

These losses seem very consistent with those reported by the private sector and in academic studies. Geekay Bhatia, a scientist from Pioneer Hi-Bred in India, said in an email (June 2004): "…the private sector (Pioneer, Cargill) introduced hybrids with good tolerance to DM and later other private companies came up with DM tolerant products. Over time, with the widespread planting of resistant hybrids, mainly in Karnataka and Andhra, incidence of DM was restricted to some parts of southern Karnataka and Tamil Nadu and that to late-planted crops only." In addition, seeds of most commercial crops is treated with the fungicide metalaxyl, which provides further protection from downy mildew. Sam Dalmacio, plant pathologist for Pioneer Hi-Bred in the Philippines, said in June 2004: "I believe downy mildew is still a problem in some places in Mindanao where farmers save their seeds from F1 hybrids. And recently there were reports of downy mildew outbreaks in Cotabato where F1 hybrids have been infected….There have been severe incidences of downy mildew in South Sumatra, Indonesia, in the past, particularly in Lampung area."

It is possible to illustrate the potential benefits from the disease resistance research at AMBIONET by making several assumptions. The losses from downy mildew and SCMV are assumed to be the losses shown in Table 13 and as a result are only for Indonesia, Thailand, the

Table 12. Number of maize varieties developed and marketed in Asia by public and private sector, 1990-98.

	Public sector		Private sector			
			National		Multinational	
	Improved OPVs	Hybrids	Improved OPVs	Hybrids	Improved OPVs	Hybrids
China-South	3	34	na	Na	0	0
India	20	17	0	73	0	29
Indonesia	6	12	na	Na	1	22
Philippines	33	6	0	18	0	21
Thailand	1	8	0	5	0	29
Vietnam	5	26	na	Na	0	11

Source: Gerpacio.

Table 13. Estimates of losses from downy mildew (DM) and sugarcane mosaic virus (SCMV).

Country	Region	Disease	Average loss (%)	Value of loss (US $ millions)
Indonesia	Lampung	DM	5	10
Philippines	South & Central Mindanao	DM	10 – 20	21
Thailand	Upper North & Northeast	DM	10 – 30	11
China	NE, N, NW & Yellow River	SCMV	0.2 – 2	44

Source: CIMMYT 2004.

Philippines, and China. It is assumed that half of these losses can be eliminated by the adoption of resistant cultivars from the AMBIONET program, new cultivars will be introduced in the years shown in Table 10, and that it takes five years after cultivars' introduction to reach a 50% level of coverage. Figure 4 shows the costs and the returns to AMBIONET disease research up to the year 2015. The costs of the disease resistance research were assumed to be about half of AMBIONET's actual costs, which include ADB funds and in-kind contributions from CIMMYT and NARSs. This was about US $250,000 per year during the first phase and US $500,000 per year for the second phase. The benefits to farmers will surpass the costs to the program around the year 2008 and rapidly reach US $40 million.

Some gains could presumably have been made in the absence of AMBIONET; conventional breeders would have identified resistant hybrids at some point anyway. However, for illustration purposes we have assumed that AMBIONET sped the discovery and development of these traits by five years. The benefits from conventional breeding are shown as the light bar in the figure. The actual benefit attributable to AMBIONET would be the difference between the light and striped bars. This is still a substantial number: US $15 million in 2010 and hitting a maximum of US $27 million in 2012. The internal rates of return from the investment of in AMBIONET using these projections exceed 40% percent. The Net Present Value of the investment of a dollar in this project in 1998, assuming an interest rate of 10%, was US $30, or US $15, assuming 15%. If AMBIONET impacts achieve the level projected here, it will have been a very good investment for ADB, CIMMYT, and the NARSs.

To return to reality, it is useful to remember that benefits to farmers have actually occurred in two places: Thailand and Southern China. Assuming that, on average, yields on the 5,000 hectares scientists report as sown to the improved hybrids would have been reduced 10% by downy mildew, and the value of the new hybrids to farmers was US$186,000, one year pays for most of the AMBIONET investment in Thailand. Scientists from South China estimate that their hybrids were grown on 50,000 to 100,000 hectares in 2004. Assuming a 5% yield increase over previous hybrids, previous yields of 5 t/ha, and prices of US$10/kg, the benefits would be between US $1.25 and 2.5 million.

Whether the disease resistant hybrids are actually approved for commercialization will depend on whether they perform better in terms of yield, insect resistance, and other characteristics, relative to the check hybrids used in government trials. If the hybrids pass this hurdle and are approved for commercial use, the next question is how many farmers will adopt them. This will depend on farmers' perception of the price of the seed, the

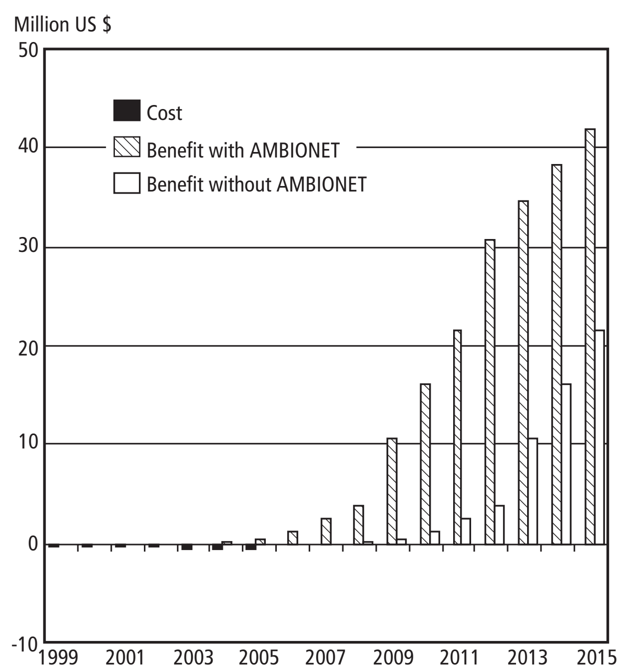


Figure 4. Costs and potential benefits of disease resistance research conducted as part of AMBIONET.

yield advantage of the hybrid, the grain quality, and price of grain relative to farmers' current hybrids or varieties. It will also depend on how risk-averse farmers are. Disease resistance is almost never main criteria farmers' for choosing hybrids; yields are almost always the main factor. In addition to farmers' perceptions of benefits and risks of new hybrids; seed company decisions about how much seed to produce and how to market a new hybrid will also influence how fast it spreads.

According to surveys with farmers, scientific studies by scientists, and the perception of the AMBIONET teams, drought generally inflicts the greatest damage of any biotic or abiotic stress. To illustrate the large impact of reducing drought, we have taken the example of India, where most maize is grown under inadequate irrigation. Small farmers in the CIMMYT survey (2004) estimated that drought reduced yield substantially; in most places by one-third. Thus, the benefits of addressing this problem could be huge. Even if drought tolerant cultivars spread to only one-third of maize-growing areas—which is realistic—the benefits could reach as much as US $100 million.

In addition to increasing production by reducing losses from disease and drought, AMBIONET will also hopefully lead to increased yields through more efficient conventional plant breeding. A better understanding of the genetic diversity of breeding lines and their combining ability by public plant breeders could increase the efficiency of current breeding programs and their ability to integrate new exotic material into current lines. Ensuring that inbred lines are homozygous increases the efficiency of the public or private plant breeding programs that make use of the lines. An even 1% increase in annual yield growth could easily increase benefits to Indian farmers by US $10 million annually.

Has AMBIONET been a good investment? By the end of the second ADB project, CIMMYT, ADB, and the NARSs will have invested about US $6 million in AMBIONET. It is still too early to estimate the size of the payoffs, but the simulated benefits from reducing disease and drought-occasioned losses, along with yield increases, would quickly pay off the investment. Payoffs to farmers are just starting, with some downy mildew resistant hybrids in Thailand and higher-yielding hybrids in southern China. These will soon be followed by downy mildew resistant OPVs in southern India. The first cultivars developed through MAS will be virus resistant varieties in China, which should reach farmers in about 2008, followed by downy mildew resistant hybrids in India in 2010. Increased yields through improved conventional breeding programs could start to appear fairly soon. Both CIMMYT scientists and I felt that the Indonesian conventional breeding program had benefited greatly from the genetic fingerprinting exercise and that the team's productivity might have increased the most from AMBIONET support.

Will the technology reach the poor?

In all AMBIONET countries private firms are the main source of purchased seed and the most efficient way that new technology spreads to farmers. However, one potential barrier to the rapid spread of AMBIONET hybrids and varieties to farmers—particularly the resource-poor—is that the private sector has to make profits to survive. This means that private firms focus on traits needed by commercial farmers and almost exclusively on the development and sale of hybrid cultivars. Asian farmers outside of China and Thailand primarily plant their own saved seed or OPVs (Table 14). Thus, the AMBIONET teams and other public breeders either have to try to disseminate their improved varieties through

Table 14. Area planted to maize, by maize type, based on estimates of national public-sector researchers (adjusted using FAO area data), selected Asian countries and region, 1997.

	Farm-saved seed	Area planted to improved germplasm: OPVs	Hybrids varieties	Total modern	Total maize area (adjusted FAO)
			(000 ha)		
China (non-temperate)	41.1	485.4	3,587.1	4,072.6	4,113.7
India	3,190.4	1,432.4	1,888.2	3,320.6	6,511.0
Indonesia	1,036.9	1,417.1	1,002.4	2,419.5	3,456.4
Philippines	1,728.6	324.1	648.2	972.4	2,701.0
Thailand	3.9	180.7	1,115.4	1,296.1	1,300.0
Vietnam	305.7	101.0	280.3	381.2	686.9
Asia	6,595.4	4,305.0	8,670.8	12,975.8	19,571.3
			(percentage of maize area)		
China (non-temperate)	1.0	11.8	87.2	99.0	100.0
India	49.0	22.0	29.0	51.0	100.0
Indonesia	30.0	41.0	29.0	70.0	100.0
Philippines	64.0	12.0	24.0	36.0	100.0
Thailand	0.3	13.9	85.8	99.7	100.0
Vietnam	44.5	14.7	40.8	55.5	100.0
Asia	33.2	21.8	44.9	66.7	100.0

Source: Gerpacio, R.

inefficient government seed companies and hope that farmers will spread the varieties to other farmers, or try to persuade private companies to incorporate the traits into their hybrids. The latter path does not necessarily exclude small-scale farmers from the benefits of public research; in China all farmers are small-scale farmers, and in India some local companies like MAHYCO develop hybrid maize for farmers with limited water resources and many small-scale farmers buy this hybrid maize seed. In addition there is probably a process similar to the "creolization" described in Mexico by Bellon and Risopoulos (2001), where the useful trait from commercial hybrids and OPVs are bred into local varieties by farmers and small seed companies.

The problem is even greater in the case of the traits that AMBIONET partners chose to address — traits that would improve the income of resource-poor farmers. They succeeded in choosing traits important to the poor: downy mildew is not a problem for most commercial farmers, who purchase metalaxyl-treated seed. Nor is drought a concern in the irrigated or good rainfall areas where wealthier farmers work. This means that the traits are less attractive to seed companies targeting commercial farmers.

A further problem in some countries is the weak relationship between AMBIONET and the private sector. Government institutes are often reluctant to share their lines with the private sector and AMBIONET did little to change this situation. Still, most private companies try to monitor the work of the public scientists and make use of some of technology developed.

In the Philippines there are informal relationships between public and private scientists. Scientists in both sectors were trained and worked at UPLB, and public sector scientists are leaving the university for the private sector all the time. In Asia, the closest relationship between the public and private sectors is in China. There are long-term relationships between public sector breeders and private seed companies that go back to when they were all public sector and worked on breeding and collaborative testing of new hybrids and other products. As mentioned above, the Chinese AMBIONET team has trained scientists from two companies for several weeks in their lab on DNA fingerprinting and use of molecular markers in breeding. They also assisted in buying equipment and supplies for the private lab.

AMBIONET research did focus attention on meeting needs of the poor. However, the real issue in many countries is, if new, superior cultivars are developed for the poor, will the government seed system or the private sector make use of them and spread them to the poor? At present, the best that AMBIONET collaborators can do is to incorporate the traits they have identified into attractive commercial cultivars and make them easily available to both public and private seed suppliers.

Research priorities

Two sets of research priority decisions influenced the direction of AMBIONET. Neither was based on a formal study of farmers' needs. The first was ADB's decision not to fund research to develop transgenic maize. Given the considerable consumer resistance to genetically modified maize and the difficulty in getting permits for commercialization from the biosafety regulatory authorities everywhere in Asia except the Philippines, this looks like a good decision.

The second decision concerned which non-transgenic research projects to pursue. Choices of research priorities and techniques were essentially supply driven—the least expensive projects with the highest probability of success—and focused on downy mildew and virus resistance and then drought and QPM, despite the fact that those traits might not be characteristics, like increased yield or improving drought tolerance, most important to all farmers and most useful to resource-poor farmers. The sequence of research in each country and in the region was also supply-driven, from least expensive and most likely to be successful to most expensive / most difficult.

There are potential problems with this method of priority setting. To set research priorities so that they give the highest social rates of return on investment, policy-makers need three types of information: (1) scientists' best estimates about what science can do and what it would cost; (2) estimates of social benefits from the technology that could be developed, if the science were successful; (3) society's judgment about what is important; that is, is it better to maximize total social returns or should improving the income and welfare of the poor be given extra weight? The AMBIONET priority-setting process explicitly used the first information by gathering the best judgment of leading maize breeders and biologists in Asia and CIMMYT. I was not able to find out about other scientific opportunities they failed to take, such as other available molecular markers that they did not use.

The second type of information—measurements of possible social benefits by social scientists based on experimental data and farmers' perceptions of their needs—was not collected. This is not too surprising, given that such studies take resources, the budget for the project was quite small, and social scientists from CIMMYT were in the process of conducting a more general study on constraints to maize production in Asia. There was some implicit criticism from private sector plant breeders interviewed about AMBIONET's priorities. Scientists from companies with major maize breeding programs in India said that they no longer had downy mildew as a breeding objective, since they had already developed resistant lines and could fall back on the fungicides. Likewise, Chinese maize breeders did not believe that the viruses addressed by Chinese AMBIONET teams were economically important. They also had little interest in research on QPM. Most major international companies are placing emphasis on drought tolerance, and so they did agree that this was a major research priority with potentially high payoffs.

The divergence in private and public priorities may be due to the fact that AMBIONET is explicitly trying to work on problems of the poor, whereas the private sector targets better-off commercial farmers. The poor may have less access to fungicides for protection from downy mildew. They may also depend more on maize as a source of protein and would benefit from QPM, if they could get access to it. So, if we put more weight on the needs of the poor, AMBIONET's priorities may have the highest payoff. In addition, if network research programs provided efficient steps for scientists to learn to use markers focused on big economic problems like drought, they may have been justified. However, the questions of the private companies suggest that at least some type of economic study quantifying the possible benefits of the research projects might have been useful.

7. Conclusions: Impacts and the Future

The goals of AMBIONET were to strengthen the research capacity of key public maize research institutions in Asia, and thereby to improve their ability to develop improved maize cultivars for poor farmers in Asia. Despite the fact that AMBIONET was a small investment (about US $2.4 million from ADB and US $1.3 million from CIMMYT), the network was successful in increasing research capacity, increasing research output, and initiating the development of technology that should benefit small farmers and consumers.

Maize research in Asia has been strengthened, particularly at the institutes that took part in AMBIONET in China, India, and Indonesia. AMBIONET has induced more expenditure on maize research, increased the number of scientists working on maize, and strengthened the basic and applied research skills of Asian scientists. It has strengthened the research links between NARS scientists of different countries and between NARSs and CIMMYT. The strengthening of research institutes in the Philippines and Thailand has been less successful, but even in those countries individual scientists have had their research programs strengthened by AMBIONET.

We found evidence that AMBIONET is also strengthening research capacity beyond the collaborating institutes. The scientists of other government institutes and universities worked on PhD and MS theses financed and supervised by AMBIONET collaborators. Public sector scientists have received short-term training. AMBIONET has also become a model for some research networks in China and India attempting to do at the national level what AMBIONET did at the regional level. In addition, the research capacity of private firms in China and India was strengthened by AMBIONET.

AMBIONET also increased research output, as measured by publications, research tools, and improved lines and hybrids. This is the easiest type of output to document with quantitative evidence—in this case, numbers of publications. Most programs were able to publish in international journals for the first time, after joining AMBIONET. All programs increased the total number of papers published, except for Thailand's public plant breeding program, which in any case emphasizes the development of varieties rather than publications.

There was not yet enough evidence to be confident that the number or quality of new maize cultivars has been increased due to AMBIONET, but it was encouraging to find that a few cultivars based on research from this program are being grown by farmers. These first few cultivars were based on either the genetic diversity programs in southern China or on the disease resistant lines that were identified in Thailand while developing molecular markers (rather than being developed through molecular breeding). The second set of cultivars from AMBIONET associates are disease resistant cultivars in the pipeline in China and India. These were developed through molecular breeding and will be available to farmers in a few years.

Much of the AMBIONET research focused on the problems of small-scale farmers. AMBIONET has made good progress toward developing improved, disease resistant lines that can be used in breeding programs. Downy mildew is not a problem for commercial maize producers in most of Asia, because there are chemical seed treatments and some genetic resistance. It is a problem, however, for small-scale farmers who do not have access to commercial seed every year and who likewise need drought tolerance, because it is a key problem for smallholders in rainfed areas.

Using numbers from farmer surveys substantiated by expert opinion and experiment station data, it was possible to project the benefits from some technologies in a few countries. The adoption of downy mildew resistant varieties in Southeast Asia and virus resistant hybrids in China could easily pay for the costs of AMBIONET in a few years and give very high rates of return to the investment in research.

Whether the AMBIONET program could have had higher social benefits if participants had set different priorities is not clear. ADB's restriction that they not work on transgenic cultivars looks sensible in hindsight, given that only the Philippines has so far approved any transgenic maize. The emphasis on working on relatively less challenging problems at first also seems sensible, but much more analysis would have to be done (based on much speculation) to be confident that this particular strategy had the highest benefit-cost ratio.

AMBIONET's success in strengthening research is primarily due to the national governments who provided most of the funding and the scientists. The programs that have done best by some measures—the Chinese and Indian programs—are the ones who had the strongest research capacity initially and have rapidly growing financial resources for their research. Their research successes with AMBIONET led to more funding for the future. Both programs will have access to million-dollar grants for molecular breeding research.

The success of the project was due to a number of factors. The personal commitment and involvement in research and all other aspects of AMBIONET by George, Hoisington, and the other CIMMYT staff was one important reason for success. They were well trained, experienced scientists who committed an immense amount of time to the project. They got to know collaborating scientists and their institutions well and treated with respect the knowledge and skills that the NARSs' scientists brought to the table. The mix of disciplines, skills, and personalities of the Asian scientists in the network was another important factor. The CIMMYT leaders built on their contacts in Asia and on the experience of IRRI with the Asian Rice Biotech Network to identify people who were willing and able to collaborate. In a few cases they had to change collaborators, but in the end an impressive team of NARS scientists formed AMBIONET. The flexibility of the funding and the ability of AMBIONET to move it quickly to where it was needed was another important factor in making this project work.

Beyond the numbers and the questionnaires, the impressive thing about this project was the enthusiasm of the participants. There was Shihuang Zhang's quiet enthusiasm for the role AMBIONET played in introducing the young scientists in his research program to the international research community. Prasanna's enjoyment of competition with the Chinese team and equal enthusiasm for teaching Indian, Indonesian, Irani, and Vietnamese students about the tools of molecular breeding are worth note. Firdaus Kasim of Indonesia spoke highly of his research collaboration with Dedi Ruswandi and possible future international collaborations with Pichet of Thailand. Perhaps most impressive was the excitement of young scientists like Pabendon and Azrai in Indonesia talking about their research.

AMBIONET's success in improving the well-being of farmers depends not only on research output but perhaps even more on the ability of public extension to transfer public technology to farmers or the NARS scientists' ability to get private seed companies to make use of the technology they develop. The private sector organizations interested in AMBIONET and other public research activities are primarily the medium-sized Asian firms, such as MAHYCO in India and Domingo in the Philippines. The local branches of Monsanto and Pioneer had limited or no knowledge of AMBIONET. They do not use MAS in their breeding programs in Asia and the disease problems that AMBIONET addressed are not major concerns to them. Drought is an important problem for them, but research on this problem is being conducted by their central research programs and, in the case of Pioneer, with a collaborative research program at CIMMYT's headquarters.

Another measure of the project's success was the demand for participation. The participants were unanimous in their desire to continue the system, as might be expected. In addition many other countries were seeking to join and were willing to pay their own way or find donors to support their participation. At the annual meeting in Chiang Mai in 2003, AMBIONET collaborators were joined by three scientists each from Iran, Bangladesh, and Nepal.

The participants unanimously agreed that the network structure was important. The research projects provided the focal point for all activities, with the training programs, the annually meetings, and the technical backstopping contributing to the programs' success. The combination of collaboration, cooperation, and competition that I found at the annual meeting and in the interviews was impressive. This is the way good, collaborative research is supposed to work.

References

Alston, J., G. Norton, and P. Pardey. 1995. *Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting.* Ithaca: Cornell University Press.

Bellon, M.R., and J. Risopoulos. 2001. Small-scale farmers expand the benefits of improved maize germplasm: A case study from Chiapas, Mexico. *World Dev* 29:799-811.

CIMMYT. 2002. Project Completion Report of the Asian Maize Biotechnology Network RETA 5766: Application of Biotechnology to Maize Improvement in Asia. Submitted to the Asian Development Bank.

CIMMYT. 2004. Achieving Uncommon Things: Biotechnology Network in Asia. http://www.cimmyt.org/whatiscimmyt/recent_ar/D_Foster/achieving.htm. Accessed 12Apr06.

Dalmacio, S. "The importance of and growing concern for maize diseases in the Asian region." Presented at PCARRD, Los Banos, the Philippines, 2000.

Dreher, K., M. Khairallah, J-M. Ribaut, and M. Morris. 2003. Money matters (I): costs of field and laboratory procedures associated with conventional and marker-assisted maize breeding at CIMMYT. *Molecular Breeding* 11(3): 221-234.

George, M.L.C., W. Li, C. Moju, M. Dahlan, M. Pabendon, E. Regalado, M. Warburton, X.C. Xia, and D. Hoisington. 2004. Molecular characterization of Asian maize inbred lines by multiple laboratories. *Theor Appl Genet* 109:80-91.

George M.L.C., B.M. Prasanna, R.S. Rathore, T.A.S. Setty, F. Kasim, M. Azrai, S. Vasal, O. Balla, D. Hautea, A. Canama, E. Regalado, M. Vargas, M. Khairallah, D. Jeffers, and D. Hoisington. 2003. Identification of QTLs conferring resistance to downy°mildews of maize in Asia. *Theor Appl Genet* 107:544-551.

George, M.L.C., E. Regalado, M. Warburton, S. Vasal, and D. Hoisington. 2003. Genetic Diversity of maize lines in relation to downy mildew. *Euphytica* 135:145-155.

Gerpacio, R.V. (ed.). 2001. *Impact of Public- and Private-Sector Maize Breeding Research in Asia, 1966-1997/98.* Mexico, D.F.: International Maize and Wheat Improvement Center (CIMMYT).

IFAD-CIMMYT study on maize in Asia. The results of the study have been published in the series whose titles are listed below. All can be accessed, ordered, or downloaded from CIMMYT's web page (www.cimmyt.org) in the section "Publications/Maize Production Systems":

- Joshi, P.K., N.P. Singh, N.N. Singh, R.V. Gerpacio, and P.L. Pingali. 2005. *Maize in India: Production Systems, Constraints, and Research Priorities.* Mexico, D.F.: CIMMYT.
- Swastika, D.K.S., F. Kasim, W. Sudana, R. Hendayana, K. Suhariyanto, R.V. Gerpacio, and P.L. Pingali. 2004. *Maize in Indonesia: Production Systems, Constraints, and Research Priorities.* Mexico, D.F.: CIMMYT.
- Ekasingh, B., P. Gypmantasiri, K. Thong-ngam, and P. Grudloyma. 2004. *Maize in Thailand: Production Systems, Constraints, and Research Priorities.* Mexico, D.F.: CIMMYT.
- Gerpacio, R.V., J.D. Labios, R.V. Labios, and E.I. Diangkinay. 2004. *Maize in the Philippines: Production Systems, Constraints, and Research Priorities.* Mexico, D.F.: CIMMYT.
- Thanh Ha, D., T. Dinh Thao, N. Tri Khiem, M. Xuan Trieu, R.V. Gerpacio, and P.L. Pingali. 2004. *Maize in Vietnam: Production Systems, Constraints, and Research Priorities.* Mexico, D.F.: CIMMYT.
- Paudyal, K.R., J.K. Ransom, N.P. Rajbhandari, K. Adhikari, R.V. Gerpacio, and P.L. Pingali. 2001. *Maize in Nepal: Production Systems, Constraints, and Priorities for Research.* Kathmandu: NARC and CIMMYT.

Zhang, S.H. 1998. "Needs and priorities of maize breeding program for molecular genetics in China." Unpublished document, Chinese Academy of Agricultural Sciences, Beijing, China.

Appendix table 1. Summary of training courses and workshops.

Date	Place	Training/Workshop
Training Course		
9 Nov-4 Dec 1998	CIMMYT, Mexico	Training Course on Molecular Marker Applications to Plant Breeding
Regional Workshops		
Oct 1999	Kamphangsaen, Thailand	Regional Workshop on Maize and Downy Mildew Fingerprinting
May 2001	IRRI, Los Baños, Laguna, Philippines	Regional Workshop on QTL Mapping
May 2001	IRRI, Los Baños, Laguna, Philippines	IRRI-CIMMYT Functional Genomics Workshop
August 2002	Thailand	Genetic Diversity
November 2003	Thailand	Proposal development workshop
In-country training		
6-7 Mar 2000	Indian Agricultural Research Institute, India	Molecular Marker Applications to Plant Breeding
??	Vietnam	Molecular marker technologies
Annual Meeting		
27-30 Apr 1998	Bangkok, Thailand	First Annual Meeting
27-30 Apr 1999	Beijing, China	Second Annual Meeting
8-10 Mar 2000	New Delhi, India	Third Annual Meeting
10-11 May 2001	Los Baños, Philippines	Fourth Annual Meeting
2002	Indonesia	Fifth Annual Meeting
November 2003	Chiang Mai, Thailand	Sixth Annual Meeting

(b) AMBIONET Workshop on ‘QTL Mapping’ at IRRI, Philippines in May 2001

(c) AMBIONET Workshop on ‘Diversity Analysis’ at Thailand in August 2002

(d) AMBIONET Grant Writing Workshop at Thailand in November 2003

Appendix table 2. Losses from key diseases and drought in Asia.

Disease	Countries where problem	Country of example	Year	Estimated area of problem	Percent loss	Source
MRDV	China	China	1996	400,000 ha	20-30	Dalmacio
MRDV	China	China			30-50	Dalmacio
Viruses	China	China	1975	1,000 ha	50	Dalmacio
SCMV	Philippines	Philippines	1990		55-57	Dalmacio
Bacterial rot	India, China, Indonesia, Japan, Malaysia, Thailand, Philippines	India			80-85	Dalmacio
Bacterial rot		Philippines	1981		40	Dalmacio
Bacterial rot		Philippines	1985		20	Dalmacio
	Philippines	Philippines	1996		21	Dalmacio
Downy mildew	China, India, Indonesia, Japan, Nepal, Pakistan, Philippines, Thailand, Vietnam		1974-75		8 ?	Dalmacio
Downy mildew		Indonesia	1977		40	Dalmacio
Java downy mildew		Indonesia	1996	7,665 ha		Dalmacio
Banded leaf and sheath blight	India, Philippines, Vietnam, Indonesia					Dalmacio
Leaf blight and rot	Philippines	Philippines	1984		20	Dalmacio
Leaf blight and rot	Indonesia	Indonesia			11	Dalmacio
Fungal root and stalk rot	Philippines	Philippines	1995		13	Dalmacio
Fungal Root and stalk rot	Philippines	Philippines	1995		13	Dalmacio
Foliar diseases	Pakistan, India, Nepal, China, Japan, Indonesia					Dalmacio
Drought	China	China			30-40	Zhang
Stalk rot	China	China			10–20	Zhang
MRDV	China	China			10-15	Zhang
Asian corn borer	China	China			7 – 20	Zhang
Turcicum leaf blight	China	China	1974		20	Zhang

ISBN: 970-648-138-9

The Asian Maize Biotechnology Network (AMBIONET): A Model for Strengthening National Agricultural Research Systems

Carl E. Pray

CIMMYT[MR]

International Maize and Wheat Improvement Center
Apdo. Postal 6-641, 06600 Mexico, D.F., Mexico
www.cimmyt.org