Biotechnology Research and Third World Agriculture

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Developing countries are naturally attracted to the potential applications of biotechnology research in solving problems of hunger, energy supply, and improving the quality of life. The priorities of the different countries vary widely, however. The National Institute of Biotechnology and Applied Microbiology in the Philippines, for example, has accorded priority to research on (i) biofuels; (ii) nitrogen fixation; (iii) food fermentation; (iv) plant hydrocarbons; (v) antibiotics, vaccines, and microbial insecticides; and (vi) biomass production. The National Biotechnology Board of India has chosen genetic engineering, photosynthesis, tissue culture, enzyme engineering, alcohol fermentation, and immunotechnology as areas of immediate interest. Nearly every developing country has plans or programs for harnessing the tools of biotechnology for national development. It is important, therefore, that a realistic understanding of the problems and potentials associated with biotechnology research become widespread. Since food is the first among the hierarchical needs of man, I discuss here some priorities in biotechnology research as related to agriculture.

The major pathways to productivity improvement will have to be increased yields and a greater intensity of cropping. Multiple cropping is possible in the tropics and subtropics because of the abundance of sunshine throughout the year. The major constraint will be water availability, although most developing countries are making major investments in bringing more land under irrigation. For both higher productivity and increased intensity of cropping, a greater nutrient supply will be needed. Many of the soils in Southeast Asia and Latin America suffer from mineral stress. Hence, plant nutrition, soil and plant health care, and irrigation require concurrent attention. At the same time, steps will have to be taken to expand the area under cultivation through the reclamation of poor soils. In South and Southeast Asia, about 86.5 million hectares could be made more productive if problems of salinity, alkalinity, and other adverse soil conditions were rectified. Rice varieties tolerant to some of the adverse soil factors have already been bred (Table 1).

Developing countries must improve production and consumption simultaneously. In many of them, this will be possible only if the cost of production is kept low. Few countries provide extensive farmer and consumer subsidies. Since energy in the form of fertilizer, irrigation and tillage, and postharvest technology operations is an important component in the cost of production, fossil fuel requirements will have to be reduced. Thus, the challenge to those in charge of technology development is to bring about a continuous improvement in the productivity of major farming systems per unit of land, water, time, and energy without detriment to the long-term production potential of soil. Biotechnology can help in this task, and by taking rice as an example I will illustrate the scope for integrating recent advances in biotechnology with the techniques already in use.

Biotechnology Applications in Rice Production

In its study on *Agriculture: Toward 2000*, the FAO (*1*) has projected the need for an additional production of 300 million tons of paddy (threshed, unmilled rice) between 1974–1976 and the end of the century. The rate of growth in world demand for rice during the 1980's is expected to be of the order of 2.9 percent a year. In contrast to the other cereals, the demand for rice will probably remain overwhelmingly for direct use as human food. If past trends in demand and production continue, the gross import requirement of rice of the developing countries will rise from 8.3 million tons of paddy in 1974–1976 to 33 million tons in 2000. Through an expansion in the area under irrigation and through productivity improvement, it should be possible for developing countries to meet 200 million tons (paddy) of the additional demand through greater home production (Table 2). For this purpose, there is need for an optimum blend of technology, services, and public policies.

It takes several years of breeding and selection work for useful genes from a suitable donor strain of rice to be incorporated into a commercially popular variety. The breeding of the rice variety IR36, which now occupies an area of over 10 million hectares in Asia, took about 7 years. Seed production on a scale necessary to cover large areas takes another 2 to 3 years. Thus, it takes about 10 years from the time a cross is made to the time it makes a widespread impact, even when two to three crops can be grown in a year. Through such techniques as "rapid generation advance," even four crops of rice can be produced with some strains in a year (*2*).

Raising the Ceiling on Yield

The potential and actual experimental rice yields under two levels of incident solar radiation, representing the wet and dry seasons in monsoon Asia, are indicated in Fig. 1. The term "favorable conditions" refers to the conditions under which diseases, insects, water, fertilizers, and cultural practices do not limit rice growth and yield. The data suggest that further increases in yield, by 2.2 tons per hectare for the wet season and 3.5 tons per hectare for the dry season, would be realistic targets.

The estimated potential yields were calculated with the assumption that the amount of incident solar energy during the grain-filling period and the efficiency of energy use by a crop ultimately determine the yield. In Australia and parts of the United States much higher levels of solar energy are available than those in Asia.

The 6- and 9-ton yields per hectare were chosen for the experiment station's yields because these yields can be easily produced with a good variety and appropriate management. Higher yields have been obtained under exceptionally favorable conditions or with the use of special treatments such as CO_2 enrichment before or after heading.

Energy-use efficiency is expected to decrease as the level of incident solar

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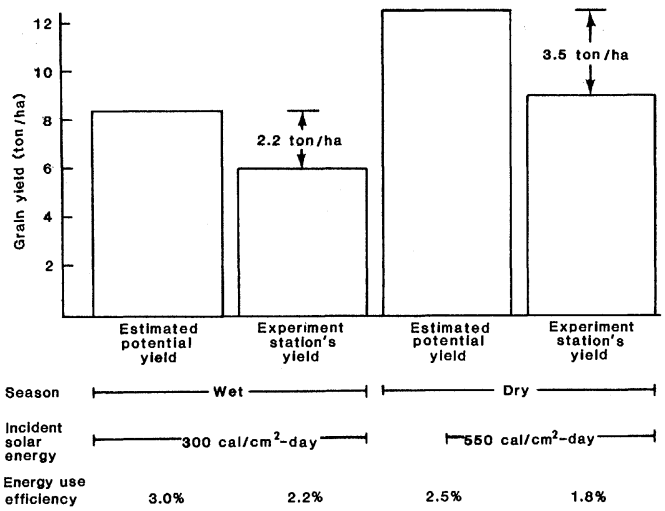


Fig. 1. Estimated potential yields and experiment station's yields of rice during wet and dry seasons.

energy increases. The highest recorded values are 3.7 percent by Murata *et al.* (*3*) and 3.3 percent by the Japanese Committee for the International Biological Program (*4*), but these were obtained for the vegetative growth stage. During the ripening period, senescence is unavoidable and hence the energy-use efficiency is lower than during the vegetative stage. Differences in energy-use efficiency between the estimated potential yields and experiment station's yield are 0.7 and 0.8 percent.

Bridging the Gap Between Actual and Potential Yields

The physiological factors that must be considered in reducing the gap between actual and potential yields are indicated below.

1) In the past, slower initial growth was correlated with higher yields because old varieties were tall and susceptible to lodging. With short-statured and lodging-resistant varieties, fast initial growth is one requirement for maximum crop photosynthesis. In theory, the land should be covered with leaves as early as possible; the leaves should be erect to increase crop photosynthesis.

2) Respiration during darkness has two components: growth (photo) respiration and maintenance respiration. Although photorespiration can not be changed unless biochemical pathways are modified, rice varieties that have lower rates of maintenance respiration can be selected.

3) Total elimination of photorespiration in rice may increase net photosynthesis by 50 percent.

4) Reduction in maintenance respiration and photorespiration should increase leaf photosynthesis.

5) Sink size is generally a limiting factor in rice yields under favorable conditions. To increase sink size, the number of spikelets per shoot and grain size must be increased simultaneously. Attempts to achieve this objective are being made in the Plant Physiology Department of the International Rice Research Institute (IRRI).

6) In a physiological sense, greater partition of assimilates into spikelet formation before heading will result in a larger sink size. Young spikelets compete for assimilates with flag leaf and culm. This process is probably under hormonal control. In terms of morphology, short culm and small flag leaf favor greater partition of assimilates in spikelets.

7) Increased sink size should be coupled with increased harvest index. Modern *indica* varieties have a harvest index of about 0.5. This could be increased to 0.6.

8) Slow senescence assures active photosynthesis during the grain-filling period and contributes to increased lodging resistance. Leaf sheath contributes to the breaking strength of the shoot by 30 to 60 percent.

9) Maintenance of a healthy root system is important not only for water and nutrient uptake but also for (i) production of cytokinin, a plant hormone responsible for senescence and (ii) better anchorage of the crop stand to prevent root lodging.

10) Stiff culm must be considered in addition to short plant stature. Increased importance of lodging resistance can be clearly illustrated in the following way. With a harvest index of 0.5, 8.2 tons of straw supports 8.2 tons of grain (estimated potential yield); total biomass becomes 16.4 tons. When the harvest index is increased to 0.6, 5.5 tons of straw will have to support 8.2 tons of grain. Thus, straw must be much stiffer even though total biomass production is less (5.5 + 8.2 = 13.7 tons). Special attention should be given to this characteristic since lodging resistance is much lower in recent varieties such as IR36, IR42, and IR50 in comparison with IR8.

The possible applications of biotechnology to rice improvement are indicated in Table 3. Even though basic techniques were known in the past, the application of these techniques to crop improvement is a new avenue of research.

For genetic engineering to be useful for the improvement of higher plants such as rice, further advances in tissue and cell culture techniques are indispensable. This is because modification of single cells is the end of research in microorganisms, but it is just the first step in higher plants. In higher plants, cells must be modified, multiplied, and regenerated into the whole plant. In addition, the modified traits must be manifested in the whole plant and retained for succeeding generations. In tissue and cell culture, two problems require intensive research: (i) understanding the mechanisms of genotypic differences in plant regeneration and methods to overcome such genotypic differences, and (ii) methods to regenerate plants from long-term cultured callus and cell suspension culture. Without answers to these problems, the usefulness of tissue and cell culture, and hence genetic engineering, may remain restricted to a very narrow range of materials and problems.

Some Immediate Applications of Biotechnology Research

1) Among the various techniques used in tissue and cell culture, induction and selection of useful mutants at the cellular level is probably the most promising approach to rice improvement. At IRRI, work on salt tolerance and aluminum toxicity tolerance is now under way. Work on rice with a high lysine and high protein content will soon be initiated.

2) Low photorespiration has been studied at several laboratories in the world. At present, tissue culture is used to reduce the photorespiration rate of tobacco plants. Photorespiration inhibitors are also being studied in several laboratories.

3) Tissue culture has been used to increase the lysine content of rice (*5*). The results indicate that there is an overall increase in the protein of such rice but only a slight increase in the lysine content.

4) Disease resistance can be increased by tissue culture when particular toxins are directly involved in the disease development. Application of tissue culture to sheath blight resistance will soon be initiated at IRRI.

5) Embryo culture has been used in studies of interspecific hybridization at IRRI. Because of its simplicity, the technique may be useful in some instances where postfertilization abnormalities impair embryo development.

6) Anther culture may not be useful in rice breeding unless further advances are made in plant regeneration and pollen culture. In China several rice varieties have been produced by anther culture but these are *japonica* varieties. Plant regeneration problems hamper usefulness of anther culture in most *indica* varieties.

7) The incorporation of nitrogen-fixing genes into rice by genetic engineering is the most ambitious project. We now know that at least 17 genes are involved in the nitrogen fixation system. We still do not know if manipulation of such a large number of genes will be possible.

Biological nitrogen fixation in rice. Wetland rice has been grown without nitrogen fertilizer for centuries. Long-term fertility experiments in both temperate and tropical regions indicate that rice crops grown without nitrogen fertilizer absorb about 50 kilograms of nitrogen per hectare. Most of this nitrogen comes from biological nitrogen fixation. The major nitrogen-fixing agents in wetland rice soils are (i) free-living blue-green algae, (ii) blue-green algae symbiotic with a water fern *Azolla*, (iii) heterotrophic nitrogen-fixing bacteria associated mainly with the roots of rice, (iv) heterotrophic nitrogen-fixing bacteria growing on plant residues, and (v) rhizobia in symbiosis with aquatic legumes. The problems associated with biological nitrogen fixation in rice culture have been discussed elsewhere (*6, 7*).

Blue-green algae. The literature on blue-green algae in rice soils was reviewed in 1980 (*6*). The inoculation of soils with blue-green algae is widely practiced in Egypt, India, and Burma. Preparation of the inoculum has been developed as a small-scale village biotechnology. The average increase in rice yield achieved by inoculation has been estimated at 16 percent over uninoculated controls (Table 4).

Little is known about the relation between inoculation and grain yield, but studies of the availability of algal nitrogen and the ecology of blue-green algae have been initiated at IRRI. Although it is relatively easy to prepare and transport inocula of the free-living blue-green algae, the establishment of such algae is rather sporadic. Little is known about the conditions that lead to the success of inoculation or about the factors that govern the survival of the organisms.

Few investigators have attempted genetic engineering in the blue-green algae. Only a limited number of strains are free from bacteria and no vector of gene information has been found. Research in the following areas is urgently required: (i) strains that have been collected and selected for environmental adaptation as well as nitrogen fixation; (ii) methods for encouraging the growth of desirable organisms and discouraging the growth of undesirable algae and predators; (iii) low-cost sources of such plant products as neem (*Azadirachta indica*) seed, which can be used to control predators; (iv) means of gene transfer, such as protoplast fusion, in the blue-green algae.

Nitrogen fixation with Azolla. The possibility of using *Azolla* as a nitrogen-fixing green manure crop suitable for rice culture has been recognized by many researchers, agricultural administrators, and peasants. *Azolla pinnata* can fix a maximum of about 3 kg of nitrogen per hectare daily and *Azolla filiculoides*, 10 kg per hectare. *Azolla* has been used in China and northern Vietnam for centuries. Recently, trials of these species as green manure crops have been made in other Asian countries. Studies conducted by the International Network of Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) (*8*) showed that the increase in rice yield brought about by one crop of *Azolla* was equivalent to that obtained by applying 30 kg of nitrogen as urea (Table 5).

In the southern Philippines, the *Azolla* technique has been used successfully in areas amounting to several thousand hectares. Farmers in these areas find that two crops of *Azolla* (before transplanting and after the harvest of rice) can replace chemical nitrogen fertilizer. IRRI maintains six species of *Azolla* and

Table 1. Performance of rice varieties or lines that tolerate problem soils (*19*).

Soil problem	Variety or line	Yield (ton/ha)
Salinity	IR50, IR5657-44	3.6
Alkalinity	IR36, IR4595-4	3.6
Strong acidity	IR42, IR4683-54	4.2
Peat	IR42, IR8192-31	3.1
Aluminum toxicity	IR43, IR6115-1	3.8
Phosphorus deficiency	IR52, IR8192-200	4.4
Zinc deficiency	IR36, IR8192-31	2.9
Iron deficiency	IR36, IR52	2.8

Table 2. Area, yield, and production of rice (paddy) in developing countries (*1*).

Land and water class	Harvested area (million hectares)		Yield (ton/ha)		Production (million tons)	
	1974–1976	2000	1974–1976	2000	1974–1976	2000
Rain fed	62.6	57.8	1.5	2.1	95.4	123.8
Irrigated	36.5	64.8	2.7	4.1	97.6	264.9

Table 3. Possible applications of biotechnology research to rice improvement.

Research technique	End result
Tissue and cell culture	
Induction and selection of useful mutants at the cellular level	Salt tolerance
	Aluminum toxicity tolerance
	High lysine and high protein
	Low photorespiration
	Disease resistance
	Low oxygen tolerance
Embryo culture	Intra- and interspecific hybridization
Anther and pollen culture	Reducing breeding time
Protoplast fusion	Interspecific and intergeneric hybridization
	Hybrid rice improvement
	Azolla improvement
Genetic engineering	Incorporation of nitrogen-fixing genes

screens strains for use in the tropics. Because of its high protein content, *Azolla* is also a potential food source for farm animals and fish and can be used by farmers with small landholdings.

Azolla requires a high level of phosphorus in the soil, low temperatures (preferably lower than 30°C), and plentiful water. Insects can seriously damage the fern, particularly in the tropics, and must be controlled. Areas that meet these requirements are somewhat limited in rain-fed tropical rice culture. *Azolla* must be maintained throughout the year as a vegetatively growing plant and must be transferred and inoculated in the fresh state. *Azolla* forms sporocarps (male and female organs) that can be used for germplasm maintenance and propagation, but the conditions to induce these artificially are not known and artificial mating has not been successful. If *Azolla* species could be crossed by methods of asexual recombination, such as by protoplast fusion, strains of the organism could be improved. Protoplast fusion could also be tried between *Azolla* and *Anabaena* (Fig. 2).

Nitrogen fixation associated with wetland rice. Direct evidence of nitrogen fixation by bacteria associated with plant roots has been obtained for wetland rice, as well as for the grasses *Digitaria* and *Paspalum*. The amount of nitrogen fixed by heterotrophic bacteria associated with wetland rice may range from 5 to 10 kg per hectare. Nitrogen-fixing bacteria of various species accounted for up to 90 percent of the heterotrophic bacteria isolated from the stems and roots of wetland rice.

Table 4. Average increase in rice yield achieved by inoculation of soil with blue-green algae in field experiments. Modified by Roger and Kulasooriya (*5*).

	Grain yield in control plots (kg/ha)	Increase over control after inoculation	
		Percentage	Grain yield (kg/ha)
Mean	3016	16.1	485
Number of data	30	87	87

Bacteria (*Azospirillum*) isolated from rice roots have been cultured and inoculated into the roots of rice crops, but their effects on growth and nitrogen fixation have been variable. Cultivars vary in their ability to support nitrogen fixation in the root zone, and screening for varieties that stimulate high rates of nitrogen fixation would be one way to increase fixation by this mechanism.

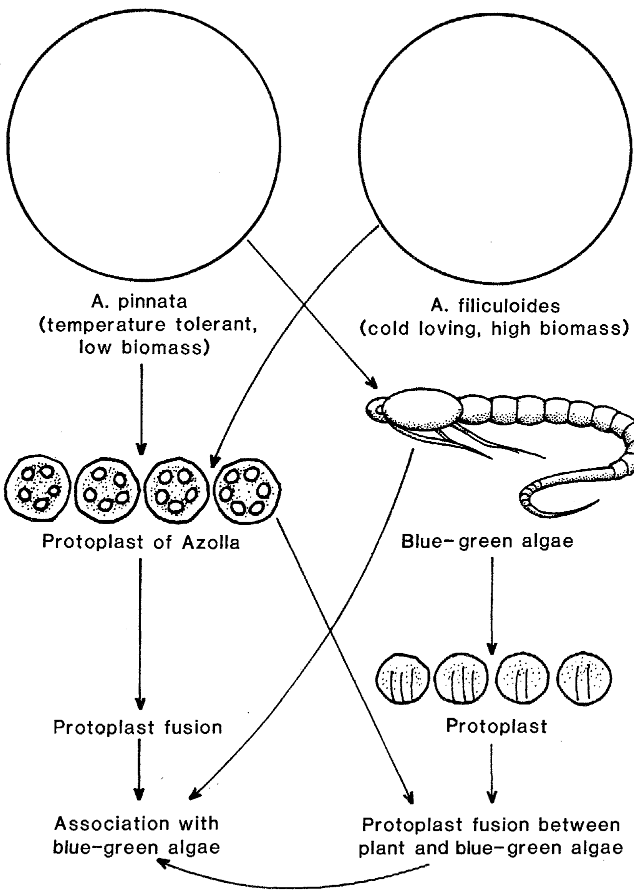


Fig. 2. Potential applications of protoplast fusion in *Azolla*.

Convincing data pinpointing the importance of nitrogen fixation in the root zone of non-nodulating plants are very limited. Data establishing the actual involvement and dominance of *Azospirillum* in nitrogen fixation around plant roots in soil are scarce. Little is known either of the physiology of the mechanism or of the plant characteristics that would support it more efficiently.

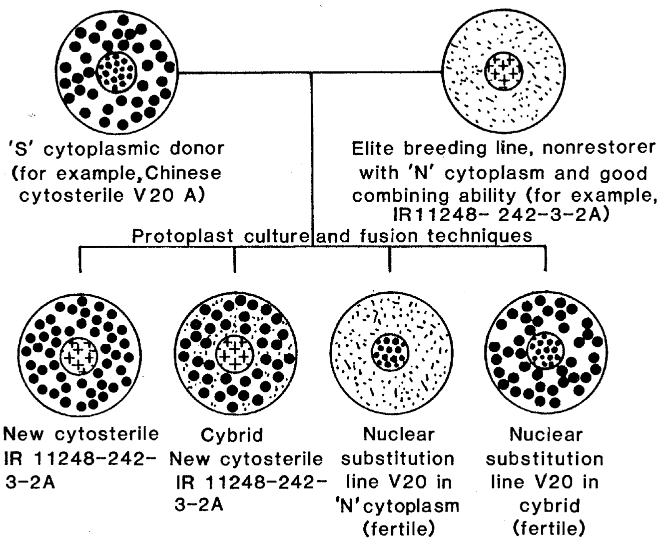
Sesbania rostrata and *Aeschynomene indica* are aquatic leguminous plants that form stem nodules. Because of the stem nodules, nitrogen fixation by *Sesbania rostrata* is less inhibited by ammonium nitrogen than is fixation by ordinary root-nodule bearing leguminous plants. *Sesbania sesban* is widely used in the tropics for intercropping with rice. However, because of its height, *Sesbania* competes with rice at a later growth stage. It is therefore planted at a late stage of the first crop of rice and used as a means of fertilizing the second crop. *Sesbania*, which is already used in Vietnam, could be further exploited if collections were made of other species and strains.

None of the nitrogen-fixing systems mentioned thus far are appropriate as sole sources of nitrogen in rice cultivation. Combinations of possible sources must be used based on a clear understanding of the relative importance of each nitrogen-fixing agent under different environmental, cultural, and social conditions.

The final goal of research on the biotechnology of nitrogen fixation is to minimize the dependence of farmers on chemical nitrogen fertilizers. Scientists at IRRI believe that strengthening the currently known systems of biological nitrogen fixation would be the most feasible way to increase nitrogen availability for rice. Since the living rice root is inhabited by 10^7 to 10^9 cells of bacteria per gram of dry weight, the introduction of *Nif* genes by genetic engineering techniques is worth attempting. Most of the heterotrophic bacteria isolated from rice roots have some nitrogen-fixing ability, and this could probably be increased.

Another encouraging feature is that most of these rhizobacteria have the ability to utilize hydrogen gas. Because paddy fields produce hydrogen from organic matter, the ability of the dominant nitrogen-fixing rhizobacteria to use hydrogen as an energy source would mean that the roots of wetland rice would participate in the recycling of energy.

Protoplast fusion. The various uses of protoplast fusion have recently been summarized (*9*). The University of Nottingham and IRRI are jointly undertaking



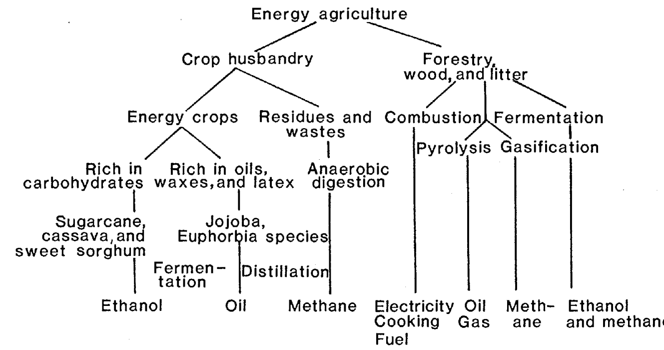


Fig. 3 (left). Use of protoplast culture and fusion techniques to develop new cytoplasmic male sterile lines in rice. Fig. 4 (right). Different aspects of research related to energy agriculture.

research on protoplast fusion in rice and *Azolla*. The People's Republic of China has nearly 6 million hectares under hybrid rice. These strains are based on cytoplasmic male sterile lines identified in varieties adapted to temperate conditions. It is now necessary to develop speedily male sterile lines and restorers (lines that can restore pollen fertility in crosses with a male sterile line) in varieties with good combining ability that are adapted to tropical conditions. Heterosis in root growth and early seedling vigor will also have to be studied, and for this purpose it is proposed to combine the tools of somatic and sexual genetics. It will be necessary to use anther culture for production of haploids in order to maintain the chromosome number at the diploid level (Fig. 3).

Protoplast fusion and hybrid cell regeneration will be used in the interspecific hybridization of *Azolla*. Attempts will also be made to bring about fusion between cells of *Azolla* and *Anabaena*.

Tissue culture techniques. Tissue culture techniques are needed that could become standardized methods for breeding perennial plants such as coconut, rubber, and quick-yielding fuel trees. In coconut, for example, there are diseases of unknown etiology such as *cadang-cadang* in the Philippines and root wilt in India. In the midst of severely infested coconut palms, healthy palms with a high yield potential also occur. Since coconut requires cross pollination, it is difficult to maintain desirable genotypes. Vegetative propagation of disease-resistant and high-yielding palms through tissue culture would be of particular value.

Bamboo species exhibit rich variability in nature. They have a number of domestic and industrial uses and in countries such as India, bamboo pulp provides the raw material for 66 percent of the paper produced in the country. Out of a total of nearly 1000 species of bamboo known, over 100 occur in India, with the most important commercial species being *Dendrocalamus strictus* and *Bambusa arundinacea*. Most Indian bamboos flower only at intervals ranging from 12 to 48 years. They usually die after seeding. The factors that trigger gregarious flowering or promote sudden senescence are not known. McClure (*10*) recommended the use of tissue culture techniques to understand problems in bamboo flowering and propagation. A similar recommendation was made at the workshop on "Bamboo Research in Asia" (*11*). Bamboo flowering in the state of Mizoram in the eastern Himalayas is usually associated with famines arising from drought and rodent damage. Studies by Mohan Ram and Hari Gopal (*12*) have indicated that the explosive growth in the rodent population in the years when bamboos flower profusely is dependent on the availability of abundant nutritious food in the form of bamboo flowers, reduced cannibalism, decreased time gap between pregnancies, and a disturbed prey-predator balance.

That bamboo breeding and propagation can be greatly speeded up through the appropriate use of tissue culture techniques has been demonstrated by Mehta *et al.* (*13*), who used such techniques to accelerate embryogenesis in the test tube in *Bambusa arundinacea*, which normally flowers only once in 30 years.

Genetic engineering. There has been an impressive increase in published material on different aspects of genetic engineering research as applied to crop improvement (*14, 15*). It is clear that we need more knowledge of the structure and organization of genetic information in plants together with a better understanding of gene regulation and expression. Somatic cells isolated from a plant can provide valuable sources of genetic variation. If we could gain a better understanding of cell differentiation and organ development, cellular totipotency could be put to many uses. Peter Day (*16*) has suggested that a start can be made in analyzing the comparatively

Table 5. The effect on grain yields of *Azolla* incorporation compared with application of chemical nitrogen fertilizer. Data from (*8*).

Treatment	Grain yield ton/ha (index)	
	1979	1980
No nitrogen	2.6 (100)	3.2 (100)
Nitrogen (30 kg/ha) from urea*	3.2 (122)	3.8 (123)
Nitrogen (60 kg/ha) from urea*	3.7 (141)	4.2 (139)
Azolla grown before transplanting	3.2 (122)	4.0 (123)
Azolla after transplanting and incorporation	3.1 (118)	3.9 (123)
The same as No. 5, but not incorporated	3.1 (119)	4.0 (123)
Nitrogen (30 kg/ha) plus *Azolla* before transplanting	3.7 (143)	4.4 (140)
Nitrogen (30 kg/ha) plus *Azolla* after transplanting	3.5 (134)	4.4 (135)
Azolla before and after transplanting	3.6 (139)	4.2 (137)
Number of sites	13	19

*Total split between two or more applications.

small genomes of chloroplasts and mitochondria by sequencing their DNA's and cataloging the proteins and enzymes they code for.

Research in energy agriculture, which includes the development of quick-yielding fuel trees, can help to arrest deforestation and soil erosion in the tropics and subtropics (Fig. 4) (*17*). Many questions need to be answered. For example, can we produce annual varieties of bamboo by crossing bamboo with sugarcane or other appropriate crops? Leguminous shrubs and trees provide considerable opportunities for improvement. Winged bean (*Psophocarpus tetragonolobus*) is a very promising multipurpose legume (*18*). The International Research Institute for Winged Bean, recently established in Sri Lanka, is likely to initiate a research program to develop erect and self-standing strains of this plant.

Research Priorities

In the choice of problems for research, it is obvious that we should select those that defy solution through already available techniques. Solving a problem rather than worshipping a tool should be the goal. Developing countries recognize the need to avoid technological obsolescence and to profit from the most recent advances in technology. To be effective in advancing the frontiers of production, technology has to be compatible with specific ecological, socioeconomic, and sociocultural factors. At the same time, technologies that can help to purchase time and that will facilitate quantum jumps in production and prosperity are of particular interest to developing countries. Biotechnology has raised considerable hopes in this respect.

The following institutional structures may be helpful in realizing goals in applied research.

Setting up international and regional "brain banks." The International Bank for Reconstruction and Development (World Bank) and the Asian Development Bank were established mainly for rendering financial support to worthwhile development projects. We now need to give thought to the organization of "brain banks" from which countries can receive objective and up-to-date advice on technology choice and transfer. This has become particularly important in the context of the growing commercialization of skills and know-how and of the increasing secrecy around the knowledge base of discovery. To be successful, the brain banks will need the support and guidance of leading scientists and technologists who share Albert Einstein's concept that "Concern for man himself and his fate must always form the chief interest of all technical endeavors in order that the creation of our minds shall be a blessing and not a curse."

Institutional twinning. Appropriate institutions in developing and developed countries could expand twinning arrangements to maximize the benefits from their complementary strengths. This would be helpful in purchasing time and sharpening priorities. The program of the Board for International Food and Agricultural Development of USAID is an important step in this field.

Investigator-initiated tie-up. In addition to interinstitutional collaboration, there should be scope for individual scientists in developed and developing countries to collaborate on projects of mutual interest. Simplified administrative procedures and appropriate financial support mechanisms would be needed to foster such collaboration.

Periodic seminars and workshops. The organization of seminars and workshops in developing countries in the frontier areas of science and technology under the joint auspices of the science academies of developed and developing countries would facilitate reviews of progress and help to clarify issues and determine priorities. Seminars should also be held for policy-makers and political leaders in order to familiarize them with the state of the art in biotechnology and help them make investment decisions based on a scientific understanding of the likely returns.

Research Resources

The major research resources needed for organizing effective national programs are: (i) trained manpower, (ii) chemicals and equipment, and (iii) information and literature. In manpower development, priority should be accorded to filling critical gaps in internal competence. Training and help are needed in the design of laboratories with adequate safety measures. Where possible, countries should be helped and encouraged to manufacture their own research supplies such as enzymes and radioactive chemicals. The information network should help in spreading knowledge not only on the scientific aspects but also on the legal (patent regulations and plant breeders' rights) and commercial aspects of biotechnology applications.

For imparting training and for information dissemination, suitable institutions on the model of INTSOY (International Soybean Program) could be promoted.

Several ideas, including the setting up of international and regional centers, are now being considered by the United Nations and other organizations. A modified version of the TOKTEN scheme (Transfer of Know-how through Expatriate National) would be immediately useful. The 6 years of experience gained under the UNDP-sponsored TOKTEN scheme was recently reviewed at a workshop held in Islamabad, Pakistan, in January 1982, and resulted in several useful recommendations. In my view, the TOKTEN scheme itself needs to be broadbased in some selected fields such as biotechnology so as to include not only expatriate nationals but also other appropriate experts.

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