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Agricultural Biotechnology and the Poor in Developing Countries

INTRODUCTION

The poor can be helped by improving the conditions or environment in which they live, lowering the costs of what they consume, and increasing their incomes. In the developing world, if agricultural biotechnology can be directed towards such changes it can benefit the poor. Directing biotechnology requires a clear identification of the poor, where they live, what they consume, how they generate their income, how biotechnology could improve their living conditions, how it could reduce the costs of what they consume, and how it might increase their income. I briefly discuss identifying the poor and their needs, and then concentrate on the potentials of biotechnology.

THE POOR

Poor people are everywhere, from the streets of New York, London and Calcutta to the rural outback of Texas, Nigeria and Brazil. Statistics about the poor are inadequate and the definitional basis for those statistics are questionable, but, still, we know that poverty is an overwhelming problem in the developing world. 'More than one billion people in the developing world are living in poverty. *World Development Report 1990* estimates that this is the number of people who are struggling to survive on less than $370 a year' (World Bank, 1990). A total of 42 nations with a population of 5.8 billion people were in the lowest income group with per capita incomes of $545 or less in 1988. Many of those are in Africa, but the most populous are in Asia, including China and India. Population growth rates are slower in most countries of Asia than in most of Africa and per capita income growth rate faster, but Asia is nonetheless expected to have about 800 million poor in the year 2000, compared to 260 million in Sub-Saharan Africa and about 100 million in the rest of the developing world.

The poor lack assets (wealth), have low incomes, low consumption levels, and live in primitive conditions. Within poor countries the poor live in the worst conditions and have the lowest levels of health. The obvious potential of biotechnology for improving human health suggests that may be a priority

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area for its application in the developing world, but one may contrast that with the great potential for improving health through the application of known, low-cost, public health measures in most developing countries. Even in the area of health research, there is a continuing need to increase emphasis on diseases that are important in developing countries (Commission on Health Research for Development, 1990). Although the complex issues related to health and biotechnology for developing countries are recognized, space limitations preclude further discussion of that issue.

Analysts point out that the application of biotechnology in the industrialized world will create substitutes for agricultural goods now produced in the developing world, undercut export markets and thereby reduce developing country incomes. Trade policies have similar effects. As with health, the value of these points is recognized, but they are not discussed: this paper concentrates on the way in which biotechnology should be directed to make positive contributions to the poor in the developing world. The most obvious need of the poor is for higher income: how can biotechnology be used to that end? The needs of the poor would be better met if the things they consumed were available at lower real costs: how can biotechnology be used to reduce the costs of what the poor now consume and would consume if their real incomes were higher?

Increasing Incomes for the Poor

Low incomes are the result of either low productivity by the self-employed or, among those employed by others, low wages, generally in combination with inadequate duration of employment. The poor self-employed work with very few of their own capital resources, generating income essentially from their labour input. If biotechnology is to raise the productivity of the poor self-employed, their enterprises must be identified, the factors that limit their labour productivity must be identified and some strategy to overcome such limitations must be followed. Strategies which require the self-employed individual to make capital investments are biased against the poor, by definition. It may be possible to offset such biases by policy or institutional means, but those go beyond the scope of directing biotechnology, which is the focus of this paper.

Self-employment enterprises include agricultural, hunting, gathering, handicraft, service, and other types of activities. Crop and animal enterprises are important among these, but agriculturalists probably over-estimate their importance for total income. For example, a comprehensive, careful study of a Philippine village, in the middle of the most intensive rice-growing area of that country, showed that 42 per cent of average family income came from rice, the balance from other agricultural enterprises (14 per cent), labour earnings (28 per cent) and transfer payments (15 per cent) (Hayami, 1978).

Most poor do not own land and they are employed by others (in the Philippine village study cited above the landless received 61 per cent as labour earnings and 33 per cent as transfer payments). If biotechnology is to raise the income of the poor, it must increase either wage rates or employment opportu-

nities, or both. That is, it should increase the demand for labour and should not create substitutes for labour. Biotechnology can increase the demand for labour by increasing the productivity of labour-intensive enterprises and by creating new labour-intensive enterprises. Examples include making crop production possible on land that previously was not usable, or making it possible to grow crops in a season when previously it was not possible.

Reducing consumption costs of the poor

Among the developing world's poor, the products of agriculture – food, fodder, fibre and fuel – generally absorb the largest fraction of total income. No global data exist, but in countries as diverse as Indonesia, Côte d'Ivoire and Peru about 70 per cent of poor households' spending is for food (World Bank, 1990). Many poor suffer from malnutrition and, although some malnutrition is observed among groups at all levels of income, the rate of food consumption generally rises sharply as incomes rise above the lowest levels. Technology holds out the promise of increasing agricultural production and reducing the real price of basic agricultural commodities in the developing world by increasing the efficiency with which they are produced, if it can be directed and focused on appropriate problems.

Cereals, roots, tubers and legumes contribute 60 per cent of the food protein and over 60 per cent of the energy of developing world people, with rice alone contributing over 25 per cent (FAO 1980). This is in sharp contrast to North America and Europe, where cereals, roots, tubers and legumes contribute only 30 per cent. Comparisons within countries show that consumption patterns of the poor differ considerably from those of the wealthy. It follows that, if one is to direct biotechnology towards food consumed by the poor, those commodities must be clearly identified. This is the first task of those who would use biotechnology to benefit the poor.

THE IMPACT OF TECHNOLOGICAL CHANGE

Research on the effect of technical change in agriculture has established that, when technological improvements are made in the production of a basic food crop such as rice, for which demand is price inelastic, the largest fraction of benefits accrues to consumers, assuming product prices are relatively free to respond to markets. If that downward adjustment of price is frustrated by government policy, then the benefits of the technological change may be absorbed by producers. This is true in high-income countries (Cochrane, 1958) as well as low-income countries (Hayami and Kikuchi, 1981). The impact on producers who also consume some of what they produce, which is the case in most developing countries, has also been analysed and is reviewed below (Hayami and Herdt, 1977).

Disaggregated effects of technological improvement

A technological improvement is a decline in the amount of input per unit of output and hence in unit cost of production, all other things held constant. One of the most important factors determining whether farmers benefit from a new technology is whether they adopt it. When widely adopted over the long run, technical improvement affects the earnings of all land and capital used in agriculture and hence affects both adopters and nonadopters. Technical change also affects non-farmers, both rural and urban, and labourers who work for farmers.

Table 1 illustrates the impact of a technological improvement in rice production that is suitable for one agro-ecology but not for a second. The impact on individuals depends on their relationship to rice production and consumption. Seven groups are defined. Group 1 consists of rice consumers who do not produce rice. They are not affected by farm prices received or rice production costs, but, because the price of rice they consume falls with a technological improvement, their welfare improves. Groups 2 and 4 include producers located in the agro-ecology for which the technology is suitable and who adopt the technology. After the technological improvement they receive lower prices for the rice they sell but also have lower costs of production. Whether they gain depends on the relative change in costs and prices, and cannot be determined *a priori*. Net buyers gain because they buy rice at lower prices, but because some changes increase benefits while others reduce them, the net impact on groups 3 and 6 are also indeterminate. Groups 5 and 7 lose from the technical change because the price of rice they sell declines and they get no benefits from the technology because they either cannot (7) or do not (5) adopt. One may divide each of the groups in Table 1 into a poor and non-poor component, thereby focusing more sharply on the issue of the poor, but using Table 1 or an expanson of it requires much empirical work (Binswanger, 1980).

TABLE 1 *Impact of a technological improvement in rice production applicable in agro-ecology 1 but not 2, which leads to a fall in market price*

Group	Impact on price received	Impact on rice production costs	Impact on rice consumption costs	Net impact on welfare
1. Consumers, non-producers	0	0	–	+
Producers in agro-ecology 1 (technology suitable)				
2. Net buyers who adopt	–	–	–	?
3. Net buyers, non-adopters	–	0	–	?
4. Net sellers who adopt	–	–	0	?
5. Net sellers, non-adopter	–	0	0	–
Producers in agro-ecology 2 (technology not suitable)				
6. Net buyers	–	0	–	?
7. Net sellers	–	0	0	–

Note: The effect on variables in column headings are decrease (–), increase (+), no effect (0), or indeterminate (?).

EMPIRICAL STUDIES OF TECHNICAL CHANGE IN RICE

As indicated above, adoption is necessary to obtain benefits as a producer. There was concern in the 1960s and 1970s about whether farmers with limited resources would adopt new technology (for example, Falcon, 1970). Since then, many empirical studies have shown that, although adoption of semi-dwarf rice varieties in the first one or two years after their introduction was concentrated on larger farms, adoption thereafter spread generally throughout the farming population in agro-ecologies for which the new technologies were biologically well adapted (Ruttan, 1977; Barker and Herdt, 1985; Herdt and Capule, 1983).

A recent thorough review of the equity effects of new technology by one of its early critics concluded that the major defect of the 'green revolution' rices is that they were not equally well suited to all areas (Lipton and Longhurst, 1989). A new set of studies comparing the impact in areas where new rices were widely adopted with areas where they were not shows that the new varieties increased the demand for labour in the adopting areas and that interregional migration, both seasonal and permanent, occurred, with the consequence that wage rates tended to rise in the non-adopting areas as well as in the adopting areas (David and Otsuma, 1989; Hossain, 1988; Jateliksono, 1987). That research also shows that irrigation and other physical factors are much more important than farm size and tenure in determining adoption of semi-dwarf varieties and that returns to land tend to rise in the adopting areas and fall in the non-adopting areas.

The effect of a technical change on individuals, whether poor or non-poor, will depend on the magnitude of changes in production costs, product prices, input use and input prices. The net effect of changes will differ individual by individual, depending on consumption patterns and the resources and enterprises each controls. In addition to the attributes noted in Table 1, some individuals may work as labourers, others may receive the residual earnings from rice land, and others may supply inputs required by the new technology. All these attributes will affect the impact of a technical change. The aggregate effect on the 'poor' in a country will also depend on the number of people in each group. Thus it is impossible to predict the size and magnitude of impact on the poor from a technological change in agriculture, whether it arises from biotechnology or from some other source, although it is clear that consumers will gain and non-adopting farmers will lose when market prices are allowed to reflect the cost-reducing effect of the technological improvement.

Decision makers in any particular country who wish to direct biotechnology at the needs of the poor in their country will need to operationalize the above general comments by empirical analyses that identify:

(1) the health problems of the poor,
(2) major commodities consumed by the poor,
(3) enterprises controlled by the poor,
(4) constraints that limit productivity of those enterprises, and
(5) constraints that can be addressed by biotechnology.

THE POTENTIALS OF BIOTECHNOLOGY

To help direct biotechnology it is important to have an understanding of the basics of biotechnology (see NRC, 1987; Walgate, 1990; Messer and Heywood, 1990). Too few social scientists or economists have been willing to gain such an appreciation. Biotechnology does not directly affect such agriculturally important factors as the physical composition of soil, the strength of metals, the access to financial assets, the distribution of land, the regulations governing international trade, or the phases of the moon! It does offer a number of new ways to modify the genetic compositions of living organisms – plants, animals and micro-organisms. All of its potentials and limitations derive from that capacity.

Mankind has been changing the genetic code of the living organisms it uses since the beginning of time, at first simply by choosing to use some plants and animals rather than others, more recently by deliberately breeding plants and animals. In agriculture, biotechnology can be directed towards creating genetically improved crops, genetically improved animals, or genetically modified micro-organisms that produce something used in crop or animal production. In order to keep the discussion manageable, I concentrate on crops biotechnology. Two sets of techniques are important: recombinant DNA and tissue culture.

Recombinant DNA

Recombinant DNA, which (theoretically, at any rate) enables the transfer and activation of genes from any living organism to any other living organism, lies behind the explosion of scientific and commercial interest in biotechnology. Related biotechnology techniques offer great potential, but recombinant DNA or genetic engineering is the key: 'The essence of genetic engineering is the ability to identify a particular gene – one that encodes a desired trait in an organism – isolate the gene, study its function and regulation, modify the gene, and reintroduce it into its natural host or other organism' (NRC, 1987).

Identify a particular gene This apparently simple statement is rather misleading. Genes cannot be physically observed, even with the most powerful of electron microscopes, because they are segments of DNA strands. Chromosomes, which are composed of huge amounts of DNA, can be observed; rice has 12, human beings have 46, but being able to see chromosomes does little to help identify a gene. Molecular biology has developed laboratory techniques, the main one being gel electrophoresis, to distinguish reproducibly the presence or absence of fragments of DNA with varying molecular weights. DNA is prepared by treating cells with restriction enzymes which cut the DNA of each chromosome into many, many pieces. Some fragments contain genes or fragments of genes and many other fragments which either have no function or have unknown functions.

One that encodes a desired trait Traits are just what they sound like: observable or measurable characteristics that make an organism what it is.

Simple human examples are hair colour, number of fingers, or the capacity for 'perfect pitch'. By observing the DNA of progeny of individuals with and without a particular trait, it may be possible to identify the fragment of DNA associated with the trait of interest. Biologically, what a gene does is to provide the instructions or code required to produce a given protein. Each gene encodes a different protein. Proteins are extraordinarily versatile molecules that make up most of a cell's structure and ensure that cells do whatever it is they are intended to do.

Study its function and regulation Some useful traits are conferred by single genes, such as the toxin produced by *Bacillus thuringiensis*, which can kill insect pests. Many important traits are controlled by several genes, however, which makes working with such multi-gene traits orders of magnitude more complex than with single-gene traits. And to make the challenges even greater. Some of the most desirable properties of plants, such as drought-tolerance, high yield or hardiness, are the result of many traits working together, just as a good sportsman has good eyesight, endurance, strength, balance, timing and 'heart'.

Re-introduce the gene into another organism Before it can be transferred to another organism, a gene has to be cloned, or reproduced in large numbers. It is introduced into the DNA of a bacterium, the bacterium makes many 'copies' of the gene and itself multiplies millions of times, thereby multiplying the DNA and making it available in large quantities. The DNA is then introduced into cells of the organism which is to be changed, either by infection with the vector *Agrobacterium tumaefaciens*, which has the natural capacity to incorporate its DNA into plants, by shooting small particles through the cell wall using an explosive charge, by temporarily perforating the cell wall with electrical charges so the DNA can permeate it, or by treating the cell with a chemical substance for the same purpose. Millions of cells are treated and a small fraction take up the foreign DNA. Then, if the target organism is a plant, the cell is manipulated in such a way as to grow into a whole plant. If everything happens as planned, the transformed plant has the desired new trait.

DNA mapping The ability to cut DNA into segments and clone genes has made it possible to determine whether specific pre-identified segments of DNA exist in a given organism. If one has determined that the gene for a given trait falls on a given segment of DNA, then knowing whether that segment is present in a plant indicates whether the gene is present. Restriction fragment length polymorphism (RFLP) mapping and DNA probes make use of this capacity. DNA probes of plant pathogens can be used to detect the presence or absence of such pathogens on seeds, and to re-assure importing countries that seeds its plant-breeders may wish to import are pathogen-free.

Tissue culture

Tissue culture is the process of keeping tissue alive independent from the organism from which it was obtained, say in a test-tube. Plant tissue culture is a key part of plant biotechnology: it can be used to produce genetically modified plants itself, and is a necessary step in obtaining recombinant plants. Tissue culture is a generic term: many different tissues/organs can be cultured, including pollen cells (pollen culture), cells from the growing tip of a plant (meristem culture) and portions of ordinary leaves (somatic cell culture). The capacity to produce a whole plant from a cell differs for various plants and plant organs. Tissue culture is generally conducted in glass containers, that is *in vitro*.

Somaclonal variation Until ten or so years ago, the theory of genetics suggested that, if a single cell were induced to produce many cells, and some of those cells were induced to grow into whole plants, those plants would all be genetically identical. In fact, many are not, and the resulting variation is known as somaclonal variation. Some of the plants that result from the variation may have characteristics that are more desirable than others, so, in effect, somaclonal variation is one technique by which tissue culture can be used to induce genetic variation, much as the crossing operation in plant breeding generates variation.

Protoplast fusion As described in elementary biology, a single cell 'grows' by dividing, first into two, then into four and so on. (In this process, the DNA replicates so that the new cells each have identical DNA to the cell from which they were formed.) Almost the opposite can be made to happen: cells can be 'fused' together so that their respective chromosomes mix and, if the fused cell can be induced to produce a plant, it will have all or some genes from each 'parent cell'. If one begins with cells of, say, tomato and potato, the resulting plant would be expected to have characteristics of each crop. Plant cells have cell walls, so fusing them together is difficult, but removing or degrading their cell walls, and thereby making them into protoplasts, makes fusion possible. The technique works best with related species.

In vitro selection Somaclonal variation and protoplast fusion both generate many genetically modified cells relatively easily. Taking a large number of cells to the full plant stage is laborious and time consuming, and may be inefficient if most of the resulting plants do not have any especially desired characteristic. Subjecting the original millions of cells to carefully designed selection pressure *in vitro* can kill a large fraction of them, thereby reducing the number that have to be carried to maturity. If the cells that survive the selection pressure have the special characteristic that is being sought, then a significant savings in time and resources may be effected.

Micropropagation The clump of cells at the growing tip of a plant (the apical meristem) generally grows quite rapidly into a seedling that can mature into a complete plant. This process may occur so rapidly that plant diseases or

viruses (pathogens) present in the 'mother plant' are not in the meristem tissue and hence the plants produced by micropropagation are pathogen-free. Pathogens infect most plants grown by conventional means, although their effect is generally to depress productivity rather than kill the plants; pathogen-free plants have enhanced productivity.

Interspecific crossing and embryo rescue A species is composed of individuals that are capable of sexually reproducing, so, by definition, plants of different species cannot generally be successfully crossed. Plants in the same genus may be thought of as close relatives, and plants in the same family are somewhat more distant relatives. Attempts to use the pollen of close or distant relatives to pollinate a plant in a different species ('interspecific crosses') sometimes result in the formation of an embryo, but in nature these generally abort. Embryo rescue techniques can be used to remove the embryo, place it in culture solution and coax it into living and growing. Like DNA transformation, interspecific crossing is a way to get new genes into a plant.

Limitations and costs

Each of the techniques mentioned has been implemented in plants, and some have produced new genetic compositions superior to previous ones. Many of the techniques require carefully controlled light, temperature and nutrient environments, and most can be routinely carried out only on a limited number of species. Even where they have been demonstrated, some cannot be routinely replicated. Hence a good deal more development is necessary before plant biotechnology is as predictable as car repairs (and most car owners know that process is fairly unreliable)!

Four realities about biotechnology should be recognized by those seeking to direct it to the needs of the poor: (1) biotechnology research is a risky investment; (2) the pay-off to plant biotechnology depends on adequate 'conventional' plant-breeding capacity; (3) recombinant DNA research requires a relatively large initial investment; and (4) the environmental safety of biotechnology is being questioned by a number of observers, slowing its broad-scale testing in the industrialized countries.

Risky investment Research is an investment: it requires a period of years before yielding a pay-off. It is risky: the size of the pay-off is not known with certainty when the investment is made. There is considerable private investment in biotechnology in the industrialized countries, some for agricultural but more for medical applications. Private firms or individuals invest in research only if there is a way for them to capture a return on their investment and the expected value of the return compensates for the risk. Biotechnology provides a basis for distinguishing between the genetic composition of individual plants or animals; that is, with the appropriate knowledge base, it is now possible to trace whether a particular gene is present in a particular individual. This capacity provides a practical basis for granting property rights to those who discover, construct, isolate and clone genes, and this prospect has induced

investors to provide venture capital to biotechnologists in the United States and other countries where such property rights are granted.

In countries where property rights for genetically engineered plants or animals do not exist, or where most farmers are subsistence producers so that the market for agricultural inputs is too small to attract private firms, it is unlikely that private biotechnology research and development will be undertaken. In such cases, there may be a rationale for publicly funded biotechnology research, but it must have a higher social rate of return than alternatives, if it is to be economically justified.

Complementary to other research In order to produce a 'better' crop variety, a specific desired trait or set of traits must be identified, a source of the trait must be found, that source must be combined with an existing variety and the new combination be shown to 'breed true', or be reproduced in the subsequent generations.

Genetic engineering does the work of combining and hence substitutes for the crossing step of conventional breeding. DNA markers can substitute for physical, biological or chemical markers, and hence determine the presence or absence of a gene (if it has been previously identified and cloned) but nothing in biotechnology can substitute for *determining* the important traits, *testing* crops containing new genes under farmers' conditions, *multiplying* seeds, and *distributing* them. This amounts to saying that a country must have good plant-breeding capacity for a crop in order to make biotechnology applied to that crop a useful investment. A country incapable of generating a continuous stream of genetic technological innovations that have been adopted by farmers is likely to have too weak a crop research base to make investment in plant biotechnology worthwhile.

Financial requirement Recombinant DNA research requires materials and equipment more sophisticated and costly than most crop and animal breeders use. To build the capacity for recombinant research, institutions will have to invest at a different order of magnitude than traditionally. They will have to go beyond the 'few simple sheds' and fields that, together with hard work, are the essence of an effective plant breeding programme (Jennings, Coffman and Kauffman, 1979). Tissue culture applications have more modest investment requirements.

Table 2 shows my rough estimate of the cost and time necessary to demonstrate certain relatively well defined plant biotechnology goals on crops which have not heretofore been subject to each technique. Additional time and money would be required to make each process routine and to make it possible with varieties different from the one on which it was developed. The guesses derive from the Rockefeller Foundation's experience with rice. Additional time and resources will be needed to get the genetically engineered crops into the hands of farmers. There is considerable imprecision associated with the estimates.

The Rockefeller Foundation has expended roughly US$35 million to develop the techniques of biotechnology that have enabled scientists to demonstrate genetic engineering of rice, *Oryza sativa*. We hope that in two to five

years, and with an additional expenditure of US$15 to 25 million, a genetically engineered rice will be available that incorporates a new kind of resistance to rice tungro virus, one of the major diseases of rice. Assuming it will be possible to put that genetically engineered rice into farmers' hands in developing Asia by the year 2000, the additional rice produced in the decade between 2000 and 2010 would have a present value of about US$4.0 billion. Success with other traits will add to the benefits. That economic benefit will be distributed among poor and non-poor, consumers and producers, urban and rural, as discussed in the first section of this paper.

TABLE 2 *Rough estimate of resource requirements for biotechnology research*

Technique	Cost ($ mill)	Time (yrs)
Disease-free propagation of perennials	0.5–1.0	3–6
RFLP map to assist breeding	1.0–5.0	3–8
Protoplast fusion, regeneration	0.5–15	2–15
Genetic engineering for virus resistance	40–60	8–15
Genetic engineering for nitrogen fixation	100–500	20–40

Genetically engineered resistance to tungro virus, and all other traits for which the Foundation is supporting research, will not require farmers to use additional inputs other than seeds (which in rice are self-reproducing, except for 'true hybrids'). For tungro, genetic resistance is the only available control strategy, other than pesticides that are sometimes used to kill the insect which transmits the virus. To date, resistance incorporated by conventional plant breeding has not been durable; the incorporation of DNA that encodes for the protein coat of the virus particle itself is expected to be extremely durable on theoretical grounds. I believe that this and other strategies usable through biotechnology have the potential to provide the poor with more benefits than input using agricultural technologies.

Environmental Bio-safety There is considerable apprehension in some quarters about the potential environmental problems that may be associated with the introduction of genetically engineered organisms into the environment, especially genetically engineered micro-organisms. Less danger is perceived from genetically engineered plants, but potential dangers analogous to the ecological nightmares caused by the introduction of plants or animals from one continent to another are possible: rabbits to Australia, kudzu to the United States, kariba weed in Africa, and many others. On the other hand, many see biotechnology as holding the promise of replacing chemical pesticides with genetic means, thereby eliminating the need for farmers to handle dangerous chemicals and contributing positively to the environment.

The issues of environmental bio-safety are among the most complex accompanying biotechnology (Walgate, 1990). Some organizations are calling for 'a general slowdown in the rate at which organisms are engineered, tougher regulations, control on an international scale, and prohibitions against release of genetically engineered organisms in certain locations' (Mellon, 1988). Ecologists are cautious. While they agree that the capability of genetic engineering to make precise changes increases confidence that unintended changes in the genetic make-up of organisms will not occur, 'precise genetic characterization does not ensure that all ecologically important aspects of the phenotype can be predicted for the environments into which an organism will be introduced' (Tiede, *et al*, 1989).

A panel commissioned by the National Academy of Sciences to advise the Agency for International Development of the United States put its bio-safety recommendations at the top of the list of what USAID should do to assist developing countries to benefit from biotechnology (NRC, 1990). The potential environmental dangers of possible bio-engineered crops will have to be weighed against the potential benefits, along with the other costs associated with their use. If biotechnology can be directed specifically towards problems of the poor, then increased equity may be added to its other benefits.

DIRECTING RICE BIOTECHNOLOGY RESEARCH

Some vocal critics of biological research imply that biologists are unaware of the potential value to farmers of plants that are drought-tolerant, resistant to soil problems, or that give high yield with low inputs, and are too reluctant to turn their energies to such problems. But that over-simplifies the challenges of bio-engineering. It is extremely difficult to determine what genes are involved in producing traits like drought resistance, high yield and resistance to toxic soils conditions, to say nothing of identifying the genes that give such traits.

A more productive approach for those interested in equity would be to assist biological scientists to identify the major problems on crops produced or consumed by the poor. The Rockefeller Foundation decided to focus its biotechnology programme on rice in part because rice is the most important food crop for the poor in many poor countries. Having decided to focus attention on rice, the Foundation drew up a list of the possible rice production challenges at an early stage of the programme. A quantitative analysis was undertaken to help in directing the Foundation's programme among the challenges listed, and a modified cost–benefit approach was used to set priorities for the Foundation's support of applied rice biotechnology research (Herdt, 1991). It essentially consisted of:

(1) quantitatively estimating, for all possible challenges, the expected benefits to society from solving each;
(2) weighing the benefits by their contributions to environmental and equity goals; and
(3) evaluating, for each challenge, the likely effectiveness of biotechnological as compared to conventional approaches.

The result was an ordered list of priority traits for attention. The list was publicized among participants and potential participants in the programme and outside (Herdt, 1987). The analysis gave added weight to strategies or traits that were especially beneficial to the poor and to the environment. The Foundation has used the priorities list to help guide programme development and funding decisions, and has been pleased with the response of the research community in developing projects on challenges of high priority. I believe that such clearly stated priorities need to be developed for individual rice-growing countries and for issues beyond rice biotechnology.

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DISCUSSION OPENING – ANTONIO L. LEDESMA*

Coming as I do from the non-governmental organization (NGO) community to this IAAE Conference is akin to a quasar's light threading its way across a vast distance and finally arriving as a minuscule presence in an enormous gathering. I was quite reluctant to come to Tokyo, since I felt some degree of bias against what I felt might be a meeting of scientists linked, in some way, to the interests of the powerful rather than to those of the poor. However, Professor Dams assured me that the IAAE is 'NGO-friendly'. It has certainly proved to be so. I have heard so much about sustainability, equity, ethics, poverty alleviation and participation, from so many speakers, that I feel there is congruence between the values of the typical NGO worker and those who make up your membership.

I do have bias since there is considerable debate relating to the question of whether positive benefits of biotechnology can ever be directed towards aiding the poor. In that debate, fear is often expressed that biotechnology has the capacity to displace traditional agricultural commodities on a massive scale, that it is likely to accentuate inequality, and perhaps increase the vulnerability and dependence of farmers through concentration in the power of transnational agribusiness. Prior experience adds to those concerns. The green revolution, in my view, brought dependence on the use of chemical inputs at the farm level, while the use of powerful materials provided hazards to public health and to the environment. The Bhopal pesticides tragedy, and other examples of chemical spillage, are stark reminders of what can occur.

Against that background of old apprehensions, I listened to Dr Herdt with considerable interest. I also remembered some of his earlier work, references to which he quotes, in which there was obvious concern with the central issue of the distribution of the benefits of technical change. I can best summarize his paper by saying that it attempts both to de-mystify the scientific techniques utilized in crop technology, and to set out the research agenda, priorities and basic aims of the Rockefeller Foundation. He did, however, begin with a short but very striking description of the conditions facing the poor, and he ended with an outline of an evaluation system which stresses both equity considerations and environmental safety. Thus his sensitivity to the needs of the poor is very much in evidence. It is a significant paper, very much in the tradition of the founders of the IAAE, who put the first objective of the Association as being 'to foster the application of the science of agricultural

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economics in the improvement of the economic and social conditions of rural people and their associated communities'.

Despite all of that, however, I still retain my own worries. I cannot criticize Dr Herdt for having neglected them, since he has much to cover in a short paper. Those of us who work in NGOs are still concerned about the potentially damaging effects of the aggressive marketing of biotechnology-based products in monopoly or near-monopoly conditions, and about the privatization of biotechnology through patent protection, thereby restricting access by the potential Third World user. We are also concerned about the extent to which it is possible for Third World organizations, working among the poor, to secure relevant information and to ensure that it can be used to promote greater participation by potential, and needy, beneficiaries. This Conference, through the efforts of Dr Herdt and others, has provided me with a great deal of useful information on the latter count, though it has not really addressed the issues of control of use.