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EMERGING AGRICULTURAL TECHNOLOGIES, PUBLIC POLICY, AND IMPLICATIONS FOR THIRD WORLD AGRICULTURE: THE CASE OF BIOTECHNOLOGY*

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INTRODUCTION

What would eventually become known as the "Green Revolution" began in the 1960s with the release from the Centro Internacional del Mejoramiento de Maiz y Trigo (CIMMYT) of improved wheat varieties and from the International Rice Research Institute (IRRI) of improved rice varieties. The course of the Green Revolution--both its accomplishments and controversies--is now fairly well known (Dahlberg; Griffin; Hayami and Ruttan; IRRI; Johnston and Kilby; Pearse; Pineiro and Trigo; Wortman and Cummings;). While the Green Revolution controversy appears to us to have subsided in its polarization and intensity, most economists and other social scientists probably still tend to see the future of international agricultural research and low-income-country agricultural development in terms of the basic theoretical (and often ideological) parameters that were set forth over a decade ago in the Green Revolution debate.

Many of the issues raised and premises advanced in the Green Revolution debate are still relevant to the future of international agricultural research. But we would argue that several emerging agricultural technologies, most notably biotechnology, are substantially deflecting the policy issues that were associated with Green-Revolution-era agricultural research strategies. In this paper we will focus on what we feel are some of the more important policy issues for the future course of international agricultural research and agricultural development strategy. We begin by making some observations about the legacy of the Green Revolution era and the implications of that legacy for the future. Next we discuss some of the major developments, mainly in the 1970s, that have decisively changed the milieu of international agricultural research. We then describe some likely biotechnology applications in Third World agriculture and their possible socioeconomic impacts. Finally, we discuss the implications for the international agricultural research system.

THE LEGACY OF THE GREEN REVOLUTION ERA FOR THE FUTURE OF AGRICULTURAL RESEARCH AND DEVELOPMENT

On one aspect of the Green Revolution experience there is little debate: The Green Revolution was spatially uneven in its applicability and diffusion. Up to the present time the vast bulk of acreage devoted to improved varieties has been accounted for by two crops: rice and wheat. Moreover, only a fraction of the developing world's cereal grain acreage has been given over to modern varieties; this has occurred mainly in the more favorable agroecological zones and where the infrastructure, such as irrigation facilities or transportation, was suitable. Viewed at an aggregate level by continent, the Green Revolution has advanced the farthest in Asia, considerably less so in Latin America, and very little in Africa. Nevertheless, after 20 years of the Green Revolution experience, the penetration of modern varieties of food crops remains spatially uneven and limited in scope. There have emerged sizeable groups of highly-commercial wheat and rice producers,[1] but outside of these two crops (with a few localized exceptions involving millet, maize, sorghum, and potatoes) the Green Revolution has left much of developing-country agriculture and many of its agriculturalists relatively untouched.

One of the mandates of the International Agricultural Research Centers (IARCs) was to assist in the establishment and strengthening of national agricultural research programs in the less developed countries (LDCs). Like the penetration of modern varieties, the improvement of national agricultural research programs has been highly uneven. Some national programs have technical capacities virtually equivalent to those in the advanced industrial countries. But other countries--unfortunately, the majority of LDCs--have national programs that are far too undeveloped to do more than a modest level of highly-routine research. This situation obviously complicates the task of technology transfer from the IARCs to the LDCs, since a single form or medium of information will only be suitable for some countries.

U.S. institutions--in particular, its philanthropic foundations, land-grant universities and scientists, and development agencies--had an enormous influence on the IARCs at the time of their establishment. In the early years, the majority of IARC senior scientists were Americans, and American technology and ideas about the development process were strongly dominant. There is a substantial residual American influence on the IARCs, especially in terms of funding, but this influence has declined in relative terms as more countries and organizations have come to share the responsibility of funding the IARCs. Unfortunately, however, as U.S.-IARC ties are no longer as predominant as they once were, land-grant universities now lack the cohesiveness of a mission orientation in terms of the ways in which they can contribute to international agricultural research. With most land-grant universities reluctant to make long-term financial commitments to international agricultural research and to state specifically their international agricultural research priorities, land-grant research for LDC needs has become more fragmented. This, as we will argue below, may present some crucial problems in the transfer of the new biotechnologies to LDC contexts.

The IARCs were established with a mandate to do research on food crops (rather than agroindustrial-export crops or livestock [with the exception of ILCA and ILRAD in Africa and the pasture improvement program at CIAT in Colombia]). The logic behind this strategy was an attractive one; concentrating limited research resources on improvement of food crops would enable peasants to not only produce more food for their own consumption, but also enable them to produce a marketable surplus for growing urban populations. What ultimately led to much controversy about the Green Revolution was that the simultaneous accomplishment of both goals--improved

nutrition from self-provisioning and production of marketable surpluses--often did not occur. Although there were significant variations by crop and by country, the typical adoption pattern was that larger, more commercially-oriented farmers were the first to adopt the improved varieties (even in areas where adoption was rapid and became essentially universal). In some LDCs (e.g., rice production in Colombia) the use of modern varieties would remain largely confined to large farmers. As noted earlier, criticism of the IARCs erupted shortly after the nature of these early adoption patterns had been discovered. The IARCs over time responded to this criticism, mainly by increasing their commitment to concentrate their research efforts on the needs of peasant smallholders. This reorientation is laudable, but it is also a challenging mission to live up to in the agricultural development milieu of the mid-1980s. Many of the agricultural systems of the world, especially in Latin America, have become more sharply polarized into large landowner/smallholder systems, with large landowners becoming more attentive to technological innovations and with smallholders decreasingly able to make the necessary investments to be able to utilize many new technologies.[2] The research strategies necessary to meet the needs of peasant smallholders--in particular, production systems involving the fewest possible purchased inputs--are more time-consuming than those of the early "high-payoff" period in the IARCs and are less likely to result in the spectacular improvements that historically stimulated continuin interest on the part of CGIAR donors.

INSTITUTIONAL ASPECTS OF THE EMERGENCE OF BIOTECHNOLOGY IN INTERNATIONAL AGRICULTURAL RESEARCH

At the very time when the debates over the Green Revolution experience were heating up there were being set in motion a number of institutional changes that are now substantially deflecting this debate. Several major aspects of the new institutional environment for international agricultural research can be identified. First and foremost, a number of factors have combined to stimulate a tremendous amount of private investment in agricultural biotechnology in general, and in plant-related biotechnologies in particular. In addition to crucial scientific breakthroughs such as the discovery of recombinant DNA, these factors have included legal changes (the Plant Variety Protection Act and the 1980 U.S. Supreme Court decision in the Diamond v. Chakrabarty case), the acquisition during the 1970s of seed company subsidiaries by large chemical and pharmaceutical companies, and increased direct and indirect subsidies by developed-country governments to high-technology industries such as biotechnology. One concomitant of increased private investment in the plant sciences has been increased competition, which has led to increased interest in penetrating LDC seed markets.

The institutional implications of private sector interest in developing LDC cereal grain seed markets can be illustrated by beginning with an elementary observation about agricultural biology. For the cereal grains, a crucial input and the most important output are identical; both are seeds. Thus there tends to be a natural barrier to commercialization of seeds as a purchased input: In the production process the farmer multiplies the basic input. Therefore, the first and most formidable competitor of private seed firms is the farmer. Another unique aspect of agriculture is the prevalence of public research institutions that historically have placed major emphasis on developing new crop varieties. Thus, public institutions may be another competitor for private seed companies. Finally, as is the case for companies in most other industries, individual seed companies face competition from other firms.

It was not until the early 1980s that the solutions to the barriers to private sector penetration of LDC seed markets began to emerge. First,

technical advances in hybridizing rice and wheat have created the possibility of replicating the hybrid corn success story in the developed countries, since with hybrids farmers must repeatedly enter the market to purchase the higher-yielding hybrids. Second, the new legal milieu of plant variety protection and the ability to patent genetic information and genetically-modified organisms increased the likelihood that seed companies would be able to protect plant breeding inventions from competitors. Third, however, the IARCs and the LDC's national agricultural research programs represent a significant barrier to private market expansion.

Each of these aspects of developing Third World seed markets has vast potential implications for the IARCs and the national programs. Hybridization represents a conundrum that the IARCs had largely sidestepped until recently. The modern varieties that propelled the Green Revolution were reproductively stable nonhybrids. Now, however, wheat and rice hybrids hold out the promise of repeating the high-payoff experience of the early modern varieties. But if the next Green Revolution is based on these more expensive hybrid seeds, it would be more socially and spatially uneven than its predecessor. Whether and how much to pursue rice and wheat improvement through hybridization thus will represent a pivotal policy decision for the IARCs and national programs.[3]

Proprietary protection of plant breeding innovations represents another conundrum for research. Proprietary considerations were relatively unimportant in the Green Revolution experience. Now, however, the IARCs and national programs will need to operate in a milieu in which much of the research relevant to LDC agriculture is done in private companies in the advanced industrial societies and in which intellectual property restrictions on new research techniques and genetic material will be employed. Whether the IARCs and national programs will experience problems in obtaining the information and genetic material they need (or whether they will need to pay substantial royalties to obtain this information) remains to be seen (Barton). Also, the IARCs and national programs may well find themselves in an unprecedented and uncomfortable situation of being viewed by large multinational agricultural input firms as competitors. It is generally recognized that over the long term, the most attractive potential seed markets in the LDCs are in rice and wheat--precisely the crops to which the IARCs have devoted the greatest efforts over time (Barton, Buttel, 1984; Buttel et al., 1985a, 1985b; Kenney and Buttel; Kloppenburg). The experience in the developed countries has been for the private sector to use political influence on public agricultural research institutions to urge them to withdraw from varietal release in crops that are privately profitable to breed (Kloppenburg; Busch et al.). The extension of this strategy to the CGIAR network would be a formidable challenge to an institution that heretofore has jealously guarded its autonomy.

Several other factors associated with the new biotechnologies are creating new possibilities and challenges for LDC agriculture. First, biotechnologies are a diverse collection of techniques which have applications far beyond the plant sciences. Biotechnologies may be applied to agricultural improvement, but they may also be applied to displacement of agricultural sources of secondary metabolites (e.g., pyrethrum) or of food itself (e.g., industrially-produced single-cell protein, which may substitute for soybeans for animal feed; Buttel et al., 1985b). Also, biotechnologies are generally most readily applicable to vegetatively-propagated cultivars such as potatoes or cassava and are, somewhat paradoxically, more difficult to apply to the cereal grains. Further, biotechnology is more advanced in livestock applications (in the form of new vaccines, growth hormones, and reproductive technologies) than

in crop applications. Second, the emergence of biotechnology promises to exacerbate the already-large disparities in LDC research capacity. The more technically-advanced LDCs have begun to establish national biotechnology programs at the same time that other LDCs lack the capacity to do the most routine plant breeding (Kenny and Buttel). In sum, biotechnology represents both opportunity and challenge for international agricultural research and development. It vastly expands the range of choices in research and broadens the policy issues to be addressed, and the question of research priorities and strategies thus becomes increasingly pivotal and complex.

THE SOCIOECONOMIC IMPACTS OF BIOTECHNOLOGY: SOME SCENARIOS

In discussing various forms of agricultural improvements through biotechnology, we will consider four broad commodity groups separately: livestock, industrial or plantation crops, cereal grains and legumes, and roots and tubers. For each we will provide some examples of the kinds of problems that the IARCs and LDCs will have to contend with in establishing policy guidelines and research priorities.

First, as noted earlier, biotechnology is considerably more advanced in livestock than in crop applications. Livestock applications are being made in the form of reproductive technologies, growth hormones, and new vaccines (Kalter et al., 1984). The initial impact of livestock applications on the LDCs is likely to be felt through new vaccines. For example, vaccines developed at ILRAD in Kenya and at other research centers could lead to major improvement in animal and human health in Africa. We must, however, ask: Will this simply lead to more pressure on existing food and feed supplies, or will it be posible to bring new lands into cultivation with the eradication of major diseases? As yet no one is studying this perplexing question, although the Rockefeller Foundation plans to cooperate with ILRAD to support social science research on this issue.

The second category of commodities includes industrial and plantation crops which in many LDCs represent important exports. This is an area where the private sector will have a major impact and where the payoffs for research by private sector multinationals are likely to be very large. For many of these crops significant yield increases can be achieved with tissue culture techniques which are already perfected. Consider the case of palm oil in Malaysia. Palm oil captured 13.6 percent of the world market for edible oils and fats last year. Malaysian exports accounted for four-fifths of the international market. Unilever has cooperated with the Malaysian palm oil industry to produce a high-yielding palm oil using tissue culture. In a few years the impact of this new technology will be widely felt in the world market. Meanwhile, the Technical Advisory Committee of CGIAR has identified coconuts as one of the high priority crops not currently receiving research support from the system. Coconut and palm oil, however, are direct substitutes. It would seem that the CGIAR, if it were to support research on coconuts, may already be too late.

Cereal grains and grain legumes present more challenging technical problems to researchers. Easily applied wide-crossing with related species and tissue culture techniques offer limited opportunity for increasing yields. It will be at least another decade before enough is known about gene linkages, restoration of plants from a single cell, and gene transfer and regulation to allow recombinant DNA techniques to be applied. Among the three major cereal grains we are most advanced in corn and least advanced in rice.

As noted earlier, hybridization offers the potential for the private sector to capture a share of the profits from varietal improvement. This could lead to competition between the public and private sector for scarce

resources which would limit the beneficiaries to the more well-to-do farmers who can afford the seed. The current situation with respect to the hybrid seed corn industry in the Philippines illustrates the kind of problems that could develop. Four private firms (two from the U.S. and one each from Australia and the Philippines) are currently selling hybrid corn. These companies have hired Filipino scientists to adapt the new hybrids to local conditions. The best talent has left the university and public sector to join the private companies. However, the potential market for hybrid seed in the Philippines is very limited. The private sector would, at best, serve only a small fraction of Filipino corn producers. For the average farmer the U.S.$45 per hectare cost for hybrids established by the seed firms is prohibitive. At the same time, the public sector with fewer trained scientists now faces the problem of attempting, on the one hand, to develop hybrids that can be sold to farmers at lower cost and, on the other, to improve open-pollinated varieties. But the real constraint that the public sector faces is the inability to multiply and distribute improved seeds to smallholders throughout the country. Thus, there is a clear need for the public and private sectors to work together to create a viable system which would give smallholders access to seeds.

The future of hybrid seed companies in the developing world is as yet very uncertain. It is too early to tell whether hybrid rice or wheat will make a significant impact in the developed let alone the developing world. There are many technical problems to be solved in both rice and wheat before hybrids become a viable alternative. But in the long run the degree to which hybrids succeed or fail may depend on the relative balance of research between the public and the private sector. A continued strong program of varietal improvement in nonhybrids in the IARCs will make it difficult for the private sector to penetrate LDC seed markets.

The final commodity group that we have listed above is root crops. As in the case of commerical export crops, it is already possible to make considerable progress in varietal improvement in root crops using tissue culture. Since the bulk of root crops is produced and consumed by smallholders, private sector interests are not likely to be important in the future development of most of these crops. There could be important exceptions, however. For example, under specific market conditions cassava has the potential for being an important commercial crop in livestock feed, manufacture of flour, and manufacture of alcohol.

IMPLICATIONS FOR THE INTERNATIONAL AGRICULTURAL RESEARCH SYSTEM

Biotechnology represents both opportunity and challenge for international agricultural research and development. It vastly expands the range of choices in research and broadens the policy issues to be addressed. At the same time such research can be costly and demanding in terms of trained manpower. The question of research priorities and strategies thus becomes increasingly pivotal and complex.

At the national level, countries will have to analyze carefully their comparative advantage in agriculture and determine in which specific areas biotechnology applications will have a significant impact. Their main challenge will be to obtain the necessary information about biotechnology developments and potentials as the basis for establishing national research priorities and identifying needs for trained manpower.

The role of the IARCs is likely to be pivotal in creating biotechnology applications and training scientists from national programs. The IARCs must ask much the same questions as the national programs. McCalla has posed these issues as follows: First, given that the CGIAR is dedicated to improving the food income capacity of lower-income LDCs, critical needs of these countries as seen by them--not developed country

scientists--should be articulated. Second, where does international research as fostered by the CGIAR have a comparative advantage? In short, what research activities should be given priority by the IARCs because they are important to do? Which activities should be pursued because they are unlikely to be done by the national programs? Which should be given priority because they are unlikely to be done by either the public or private sector research in the developed world?

Assuming a decision by CGIAR to pursue expanded involvement in agricultural biotechnology, the IARCs will have to decide how much of their limited funds should be used to strengthen their capacity to do more strategic and perhaps basic research. Strengthening the linkages between the IARCs and public research institutions in the developed world in focused research undertakings is essential. A recent Rockefeller Foundation decision to support biotechnology research on rice and the decision of USAID to provide support for joint university-IARC research are important steps in the right direction.

In summary, the tremendous promise of biotechnology for LDC agriculture is that new technologies can be developed which may be especially well suited to enhancing the productivity of marginal agroecosystems and of their smallholder peasant cultivators. This, in turn, should make it possible to broaden the base of agricultural and economic development. Whether such a promise materializes will depend on the capacity of both the national programs and IARCs to develop appropriate research priorities and strategies. Also, close links will have to be forged between the IARCs and research institutions in the developed world in order to promote basic research which will address the needs and priorities of the developing countries.

FOOTNOTES

1. This change can be attributed only in part to the diffusion of modern varieties, since commercial agriculture in the developing world preceded the Green Revolution and commercialization has proceeded in non-Green Revolution commodities.

2. This increased polarization in Latin American agriculture and elsewhere in the developing world, however, is generally not directly attributable to the diffusion of modern varieties.

3. Over the past five years IRRI has developed a hybrid suited to tropical conditions which gives 15 to 20 percent higher yield. But the process of developing hybrids is still laborious and time consuming, requiring five backcrosses to develop a suitable male-sterile parent. Research on hybrid rice, however, currently represents a very small part of IRRI's total breeding effort.

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