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G.H. Peters, International Development Centre,
Queen Elizabeth House, University of Oxford, England
and
Douglas D. Hedley, Agriculture and Agri-Food, Canada

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DEREK BYERLEE AND PRABHU PINGALI*

Asian NARS: Frustrations and Fulfilments

INTRODUCTION

The past three decades have been a period of unprecedented change in Asian agriculture. The 'green revolution' in rice and wheat initiated in the 1960s is often cited as one of the great success stories of agricultural research. Highly focused investments in research, irrigation and extension infrastructure led to food self-sufficiency among what had until then been the chronically food-deficit countries of South and Southeast Asia. Rapid adoption of modern high-yielding varieties of rice and wheat (MVs) that ushered in the 'green revolution' led to a sharp drop in the cost per unit of food output in the irrigated lowlands of Asia and a reduction in the real price of food to consumers. Economic rates of return to investments in rice and wheat research have generally been very high, often greater than 50 per cent (Hayami and Ruttan, 1985; Pray, 1991; Evenson and Rosegrant, 1993).

Beyond genetic improvements, the contribution of agricultural research has not been very visible at the farm level. While outstanding scientific contributions have been made in the areas of crop and resource management, they have seemingly not led to widespread improvements in productivity or sustainability of agricultural systems of the region. At the same time, pressing research challenges related to the efficiency of input use and sustainability of the farm resource base are emerging in much of Asia. However, the ability of the research system to respond to the emerging problems of slowing growth in productivity, and the sustainability of Asian cereal production systems, is hampered by cuts in research funding, conflicting policy agendas and outdated institutional structures.

The purpose of this paper is to provide a brief overview of the contributions of agricultural research in Asia over the past three decades, highlighting emerging trends and challenges to research in the 'post-green revolution' period.[1] For a region as large and diverse as Asia, it is impossible to provide a comprehensive review of the subject in the time and space available. Rather, we discuss selected trends and issues that have emerged from our work over the past decade in international and national agricultural research systems in Asia. We admit at the outset a bias towards emphasis on research on the major cereal crops, especially in the intensively cropped irrigated areas of the larger and

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*World Bank, Washington, DC, and International Rice Research Institute, Los Baños, Philippines, respectively.

more populous countries of the region.[2] However, it is these systems and countries, with a population of over 2500 million people, that are critical to future agricultural growth, food security and sustainability regionally and, indeed, globally.

PHASES OF TECHNICAL CHANGE IN ASIAN AGRICULTURE

Technical change in much of Asian agriculture can be characterized by a number of phases distinguished by the development and diffusion of technologies to substitute for emerging factor scarcities (Byerlee, 1992; Pingali and Hossain, 1994).[3] Most areas of South and Southeast Asia made the transition to land-intensive production systems in the 1950s and 1960s, while East Asia made this transition earlier. By the 1980s, the land frontier had largely been exhausted and, indeed, the area sown to cereals is now declining. The first technological breakthrough in land-saving technologies came in the late 1960s, with the development and widespread diffusion of MVs of rice and wheat and their synergistic interaction with expanded use of irrigation and fertilizer. National and international research systems exploited a backlog of scientific knowledge to provide the genetic improvements that made this technical revolution possible (Evenson, 1974).

The widespread adoption of MVs was followed by a 'post-green revolution' phase of continued land-saving input intensification and, in many areas, the adoption of labour-saving technologies resulting from growing scarcity of labour. Intensification was manifested in both increasing use of inputs, especially fertilizer and water, and increased multiple cropping. In economic terms, intensification was equivalent to an improvement in allocative efficiency, resulting from improvements in input supply, capital accumulation and farmers' 'learning by doing'. Agricultural research contributed relatively little to this process, although the development and adoption of newer generations of MVs provided opportunities for steady productivity growth, through increased yield potential and stability, and earlier maturing varieties that allowed more intensive cropping.

The movement from single-crop cultivation systems to a double- and triple-crop system also increased the demand for labour and accentuated peak-season labour demands,[4] leading to a rise in real wages even in densely populated labour-surplus countries such as India (Bardhan, 1976; Lal, 1976) and Indonesia (Naylor, 1992). Widespread adoption of labour-saving mechanical and chemical technologies has alleviated these constraints, and contributed substantially to overall productivity growth (Sidhu and Byerlee, 1991). Even the intensification of chemical fertilizer use can be viewed as a labour-saving change, given the high labour intensity of organic sources of fertilizers.[5] However, the research and development for these labour-saving technologies has largely been done in the private sector, much of it through direct technology transfer from higher wage economies.

By the late 1980s, the most advanced 'post-green revolution' areas of Asia, such as the Punjab of India and Central Luzon of the Philippines, had reached a point of sharply diminishing returns to further intensification and had entered a second 'post-green revolution' phase characterized by the use of better knowledge and management skills to substitute for higher levels of input use. Productivity gains accrue to farmers from differences in the way these inputs are used; that is, the timing and method of using inputs rather than their levels (Byerlee, 1987; Pingali *et al.*, 1990). In the most advanced 'post-green revolution' areas, farmers' technical knowledge and management skills have become the primary determinants of differences in productivity between farmers, which are expressed in differences in farm-specific technical efficiencies (Ali and Byerlee, 1991; Hussain and Byerlee, this volume). This phase, which is still relatively recent in most of Asia, challenges agricultural research systems to provide the site-specific crop and resource management information that is required to utilize inputs more efficiently and to conserve the resource base. While the adoption of varieties and fertilizer use took place rapidly, the intensification of production systems was a more gradual and evolutionary process that responded to trends in factor and product markets.

The second phase of 'post-green revolution' agriculture emphasizing input efficiency promises to be even more evolutionary, since typically productivity increases will result from a series of incremental changes in several factors, such as crop stand and spacing, improved week control, correction of micronutrient deficiencies, reduced tillage, crop residue management and more efficient on-farm water management. Many of these practices are quite site-specific and require well-developed local research and extension systems and skilled farmers.

OVERALL TRENDS IN AGRICULTURAL RESEARCH IN ASIA

Agricultural research in most large Asian countries was initiated in the early part of this century although, until the post-colonial period, there was more emphasis on export crops than on food crops.[6] Research efforts in food crops were generally smaller and more fragmented. Beginning around 1960, emphasis switched to organized research on major food commodities, leading to the establishment of national coordinated commodity research programmes in many countries. These national coordinated programmes, together with the international agricultural research institutes (IARCs) that were established shortly after, spearheaded the breakthrough in food crop technology in the late 1960s.

The success of the 'green revolution' gave further impetus to investment in agricultural research, especially plant-breeding research. Resources invested in agricultural research increased rapidly, at a rate of over 6 per cent annually, from the 1960s to the 1980s (Anderson *et al.*, 1994). At the same time, the number of coordinated commodity programmes multiplied and the concept was applied to non-commodity or factor-oriented research. Many Asian countries also established umbrella national research councils to coordinate the direction and financing of agricultural research at the country level.

By the 1980s, there were over 50 000 agricultural researchers working in the NARS of Asia, or two-thirds of the total number of agricultural researchers in the developing world. Altogether, almost US$ 3000 million (1980 purchasing power parity dollars) was being invested annually in the region (Anderson *et al.*, 1994). China and India have the largest research systems in the developing world as measured by the number of scientists, and accounted for over three-quarters of these totals. From Pardey *et al.* (1991) and others, a number of broad quantitative generalizations can be made about Asian agricultural research systems:

- NARS of Asia tend to be large, with ten having over 1000 scientists.
- Relative to other developing regions, scientists in Asian research systems tend to be well qualified, with over one-half holding a postgraduate degree.
- The intensity of research investment expressed as a percentage of agricultural value-added at 0.3–0.4 per cent is relatively low by world standards.

The lower intensity of research in part reflects the low salaries of scientists in Asia, which in turn implies a relatively favourable supply of scientists. The intensity of research is generally lower for major food crops, such as rice and wheat (Pray and Ruttan, 1985), reflecting economies of size and scope in conducting many types of research. Agricultural research in aggregate has generally been successful, as measured by the high rate of return on the investment found in over 60 *ex post* studies conducted in the region (Evenson and Rosegrant, 1993). By the late 1980s, however, the period of rapid expansion of NARS was ending. This slowdown in spending on research has been a worldwide phenomenon and the effects in Asia have generally been later and less serious than those experienced in other developing regions. Nonetheless, by the early 1990s, a shortage of funds led to a reduction in research activities in several countries.

Agricultural research has made important contributions to overall productivity growth in the region. The few available studies suggest that total factor productivity (TFP) growth has ranged from 1 to 3 per cent annually, with research accounting for one-third to one-half of that (Rosegrant and Evenson, 1992; Lin, 1994; Pardey *et al.*, 1992). However, there is some evidence that TFP growth was slower in the 'post-green revolution period' (Evenson and Rosegrant, 1993; Pardey *et al.*, 1992) and, in at least one case, Pakistan, was negative (Ali and Velasco, 1993). Moreover, the rate of cereal yield growth in Asia has slowed sharply, from 3.2 per cent annually in the 'green revolution' decade, 1963–72, to less than 2.0 per cent annually in the past decade, 1983–92.[7] These trends are worrying indicators of diminishing returns to 'green revolution' strategies of technical change, as well as emerging problems of sustaining the quality of the resource base (discussed below).

THE 'GREEN REVOLUTION' AND THE DEVELOPMENT OF CROP-BREEDING RESEARCH: AN INSTITUTIONALIZED SUCCESS STORY

The evolution of crop-breeding research

The impact of modern rice and wheat varieties has been analysed extensively in the literature (Herdt and Capule, 1983; Dalrymple, 1986a, 1986b; Evenson and Gollin, 1991; Byerlee and Moya, 1993; Byerlee and Traxler, 1994). These impacts of plant-breeding research can be divided into two types. The first corresponds to the 'green revolution' period of replacement of old, tall varieties by semi-dwarf MVs. This phase is now well advanced in Asia, with recent estimates that perhaps 70 per cent of the total cereal area is covered by MVs.[8] Initially, the main impact was with rice and wheat in irrigated areas but, since the mid-1970s, MVs have been widely adopted in rainfed areas (Byerlee and Moya, 1993; David and Otsuka, 1994; Jansen, 1988). For example, almost one-half of the area of maize, sorghum and millet in India, and most of the sorghum area in China, is now sown to MVs (Fertilizer Association of India, 1992; Fan and Pardey, 1992). The remaining area covered by traditional varieties is located in areas with severe drought or problems of water control. Some estimates attribute one-third or more of growth in total factor productivity to adoption of MVs during this period (Evenson and McKinsey, 1991).

The second type of impact of plant breeding corresponds to the gains in productivity in the 'post-green revolution' period through the adoption of newer generations of MVs. The number of varieties released by national programmes of the region increased steadily for all major cereal crops. For example, the number of rice varieties increased from an annual average of 12 in the 1966–70 period to an annual average of 82 in the 1986–90 period. In most areas of Asia, at least two generations of MVs have been adopted since the original introduction of MVs.[9] These newer types have embodied steady improvements in yield potential (at least in yield per hectare per day) (Byerlee, 1993; Pardey *et al.*, 1992; Jatileksono and Otsuka, 1993; Otsuka *et al.*, 1994). In addition, newer generations of MVs have made important contributions to maintaining and improving resistance to disease and insect pests. The economic value of these contributions to yield stability is estimated to be as important as gains in yield potential (Byerlee and Moya, 1993; Pardey *et al.*, 1992).

The success of research on genetic improvement can be attributed to international linkages between national research systems and with IARCs, local innovations, and long-term political and institutional commitment to food crop research. The IARCs have provided strategic support to national breeding programmes through the supply of advanced genetic materials, often with specific traits such as pest resistance, that require intensive breeding efforts. The transactions costs involved in the search for appropriate germ-plasm by national programmes have been significantly reduced by participation in international germ-plasm exchange and evaluation networks (Evenson and Gollin, 1991). For example, half of all rice varietal releases outside China since 1966 have been based on IRRI-bred cultivars or crosses derived from IRRI germ-plasm. (Evenson and Gollin, 1991). However, this share has fallen steadily, indicating increased maturity of NARS crop-breeding efforts. By contrast, for wheat, 80 per cent of varieties released in Asia (outside China) in the 1986–90 period had CIMMYT parents or were selected from CIMMYT crosses, and this percentage has tended to increase over time. These figures, of course, mask considerable variability across countries, with India and China having the largest and most mature programmes, while other programmes depend relatively more on 'spill-ins' from national and international sources of germplasm.[10]

Emerging concerns

The success in genetic contributions to productivity growth reflects the high priority that NARS have placed on developing strong crop-breeding programmes. The number of scientists engaged in crop breeding has increased rapidly, so that, by 1990, the intensity of investment in Asia was as high as in industrialized countries. For maize and wheat, respectively, it is estimated that there were a total of 720 and 770 full-time equivalent scientists engaged in crop improvement research aimed at generating new varieties, or about four to six scientists per million tonnes of production (Bohn and Byerlee, 1993). In addition, institutional innovations in the form of national coordinated commodity research programmes have provided an integrated approach to highly focused crop improvement work. While these coordinated commodity programmes were initially intended to promote broad-based research on all aspects of a commodity, in practice, crop breeding has dominated.

While productivity gains due to plant breeding tend to be linear, the growth in resources invested in plant breeding has been exponential, suggesting some decline from the high rate of return to investment in plant-breeding research experienced during the 'green revolution' period (Byerlee, 1993; Byerlee and Traxler, 1994; Lipton, 1994). This trend is not limited to Asia, and indeed reflects experience in the United States as well (Duvick, 1991). However, it does raise a number of issues with respect to future research priorities and the efficiency of research. One of these is the relative priority that should be given to breeding for more marginal environments, where MVs have not been very successful to date. Given the high pay-offs of MVs in the more favourable environments, some have argued for more effort to develop MVs for marginal areas as a way of extending the gains and also concentrating on regions (often poorer) that have been left behind by the 'green revolution'. Byerlee (1993) reviews evidence on this question and concludes that such a strategy is not necessarily well founded, for a number of reasons.

(1) Investment on crop-breeding research for marginal areas has been substantial, and in some cases considerably greater than the share of marginal areas in total agricultural value-added (see also Lipton with Longhurst, 1989).

(2) While considerable progress has been made in developing varieties for rainfed areas, progress for the most difficult areas with severe drought or

water control problems has been very slow. In addition, improved varieties with only a modest yield advantage require other characteristics that are important to farmers in marginal areas, such as grain quality and fodder value, thus compounding the difficulty of developing varieties acceptable to farmers.

(3) In the most marginal areas, it is questionable whether a 'plant breeding first' strategy is the most appropriate. Investments in research on crop and resource management (for example, on moisture conservation) are likely to provide higher pay-offs in many marginal areas.

Given the relatively high intensity of investment in crop improvement research, another opportunity for maintaining high returns in the future will be to increase the efficiency of these investments through consolidation of plant-breeding programmes. Recent work suggests that technological spillovers from one country to another, or from one programme to another within a country, are much greater than previously estimated, at least for plant breeding (Maredia *et al.*, 1994). This, combined with mounting evidence of considerable size economies in crop improvement research (Bohn and Byerlee, 1993), suggests that this type of research might best be organized with a relatively few centralized research institutes, each with a critical mass in terms of disciplines and resources. For example, India has 50 programmes conducting wheat improvement research for some 25 defined environments. However, just three of those environments account for 66 per cent of national wheat production but receive only 27 per cent of the research resources invested in wheat improvement (Jain and Byerlee, 1994).

A further opportunity for increasing efficiency of resources invested in plant breeding is through greater efforts by the private sector. For crops for which production of hybrid seed is feasible, such as maize and sorghum, where intellectual property can be protected through trade secrets, there has been a rapid increase in investment by the private sector in plant breeding in Asia since the late 1970s (Pray, 1991; Pray *et al.*, 1991). For example, by 1992, fully one-third of maize breeders in Asia outside China worked in the private sector (Byerlee and Lopez-Pereira, 1994). Although the research and development (R&D) that established the market for hybrid seed has largely been done in the public sector in most countries, the participation of the private sector increases as the market matures. Since many markets in Asia are reaching this phase of development, and with hybrid rice now approaching reality outside China (see below), the role of the private sector in crop improvement R&D in Asia is likely to increase rapidly in the future (and especially if China encourages private-sector R&D). However, for many farmers in the more marginal areas, and for staple food crops such as wheat for which hybrid seed is not feasible, the public sector will continue to be the dominant provider of improved varieties. This will be so even in the likely event that intellectual property rights (IPR) for plant varieties are strengthened in Asian countries (for example, through plant varietal rights legislation). Because of the small size of most Asian farms, it will not be cost-effective for private companies to attempt to enforce IPRs, other than trade secrets, at the farm level (Byerlee, 1993).

IMPROVED CROP AND RESOURCE MANAGEMENT IN THE 'POST-GREEN REVOLUTION' PERIOD: THE RESEARCH SYSTEM'S ELUSIVE GRAIL

Crop management research in the 'post-green revolution' period has focused on input intensification, especially the use of external inputs to exploit the yield potential of the MVs. In fact, much of the growth of Asian agriculture in this period has resulted from steady intensification of input use and cropping systems. However, this intensification process has been brought about largely through increasing land scarcity, investment in irrigation and more effective input markets, rather than as the direct result of crop and resource management research (Byerlee, 1994).[11]

Crop management research has been slow to make the transition to the second phase of 'post-green revolution' agricultural development, where increased productivity largely results from improvements in input efficiency. Improved farmer knowledge and skills help farmers improve the technical and allocative efficiency of input use as a substitute for higher levels of inputs. A large number of studies in Asia over the past decade have identified a 'technical efficiency gap' averaging about 30 per cent (Ali and Byerlee, 1991), indicating considerable potential to raise yields for the same level of inputs (or reduce input use without affecting yields). Fertilizer timing and placement, water use and pesticide application are some of the areas in which efficiency gains can reduce the unit costs of production. Farmers' incentives for adopting these techniques depend upon the price of inputs relative to the cost of acquiring and processing improved technical information.

A well developed system of decentralized adaptive research linked to a dynamic extension system and skilled farmers is needed to reduce the cost of producing and transferring improved technical information and to enter this phase of technical change successfully. In addition, price policies that subsidize the price of many inputs have provided a disincentive for farmers to improve input efficiency. The recent and highly acclaimed success of integrated pest management (IPM) for rice in Indonesia was only possible because of the government's decision to ban a large number of chemicals and to remove subsidies on the remainder (Rola and Pingali, 1993). However, similar success in improving fertilizer efficiency through better timing and placement of inorganic fertilizers and wider use of organic sources of nutrients is unlikely, given the long-term secular decline of fertilizer prices relative to labour (Pingali and Hossain, 1994) and the high cost of providing site-specific information on nutrient management to a large number of small-scale farmers.

The importance of emphasizing more efficient use of inputs has been reinforced by recent evidence of significant problems in sustaining the quality of the resource base for intensive rice and wheat production systems in Asia (Byerlee, 1992; Pingali and Rosegrant, 1993; Cassman and Pingali, forthcoming; Pingali and Hossain, 1994; Fujisaka *et al.*, 1994). These sustainability problems are most evident in the rapid decline in partial factor productivities, especially for nitrogen fertilizer, and the levelling off and/or decline in the growth of total factor productivity. In other words, the yield gains achieved in the 'post-green revolution' period are being maintained by increasingly higher levels of inputs to compensate for degradation of the lowland resource base (Byerlee and Siddiq, 1994). Declining productivity trends can be directly associated with the ecological consequences of intensive monocultural systems, such as build-up of salinity and waterlogging, declining soil nutrient status, increased soil toxicities and increased pest build up, especially of soil pests (Pingali and Rosegrant, 1993; Ali and Velasco, 1993).

Given this evidence of serious problems of resource degradation in the bread-baskets of Asia, crop and resource management research must focus not only on short-term efforts to increase the efficiency of input use, but also on improvements in long-term nutrient management and the development of more diversified crop rotations to reverse the process of degradation of the resource base. To meet this demand, crop and resource management research must be undertaken at two levels: (1) long-term strategic research to understand processes affecting the productivity and sustainability of major systems and to evaluate technological interventions over the long term; and (2) site-specific research to provide recommendations that are conditional on the specific field, season and farmer circumstances. These strategies imply a sharp departure from the generalized 'package-of-practices approach', emphasizing increased yields, higher input use and standardized technologies, that has been the driving philosophy underlying crop management research in Asia over the past four decades.

While there is evidence of a slow change in the focus of crop and resource management research, it is still insufficient to meet the urgency of the task at hand. There was a significant shift towards farming systems research in the 1980s, but the impacts to date have been only modest (Byerlee, 1994). The type of problem-focused multidisciplinary research needed to address long-term crop and natural resource management issues is still a rarity in most systems.[12] Institutional structures that compartmentalize research by discipline and commodity, and incentive systems that fail to develop accountability in terms of problem focus and farm-level impacts, are increasingly inadequate in the face of the evolving demands on the research systems of the region. Furthermore, the success of long-term management strategies depends on a set of factors similar to those needed to enhance input use efficiency over the short term: namely, a conducive policy environment (to remove disincentives on input efficiency and crop diversification) combined with considerable improvements in the technical knowledge and skill base of farmers (since most resource management strategies are knowledge-intensive).

Again reflecting the strength of plant-breeding programmes, one of the few successes in strategies to enhance input use efficiency and sustain the resource base has been the development of varieties with multiple resistance to a wide spectrum of insects and diseases in order to stabilize yields and contain the growth in pesticide use. This form of embodied knowledge is easier to transfer to a large number of small-scale farmers than the disembodied knowledge inherent in most integrated management practices. However, the long-term benefits of using host-plant resistance to pests are substantially higher when farmers practise other components of IPM.

ASIAN RESEARCH SYSTEMS FOR THE NEXT CENTURY: FUTURE CHALLENGES

Given diminishing returns to further intensification as a major source of growth, agricultural research will play an even more important role in increasing productivity in the future than it has in the recent past (Evenson and Rosegrant, 1993; Fan and Pardey, 1992). However, it is clear that the focus of research in 'post-green revolution' areas must rapidly shift from input intensification to considerations of cost and environmental concerns. This raises formidable institutional challenges to Asian research systems as they move into the next century.

Plant-breeding research

While we have argued that this emphasis must shift from plant breeding towards crop and resource management research, investment in varietal development and the new biotechnologies will continue to play an important role in the future in moving out the yield frontier and stabilizing yields.

Two innovations promise to increase the cost-effectiveness of conventional plant-breeding research in the coming decades. The first of these is the exploitation of heterosis to increase yield potential. Hybrid seed is now widely used in maize, sorghum, millet, cotton and some oilseed crops in the region. However, the largest opportunity lies in extending the technology for hybrid seed production in rice, the dominant food crop in Asia. This technology was developed in China in the early 1970s and by the early 1990s over half of the rice area in China was planted to hybrid seed, with an estimated average yield advantage of 15–20 per cent over conventional varieties (Lin, 1994). More recently, hybrid rices suited to tropical environments have been developed by IRRI and are now in the early stage of commercial release in India. Thus hybrid rice is poised to make significant contributions to productivity gains over the next decade, although the relatively high cost of seed means that its initial adoption will mainly occur in high-potential and more commercially oriented rice-growing areas. Even in China, the area sown to hybrid rice is reported to have declined in recent years, in part because of the lifting of seed subsidies (C. Pray, personal communication).

The second area of opportunity is in biotechnology, which offers the potential to reduce the cost of varietal development through the use of molecular markers to more precisely select plants that carry genes for desirable characteristics, and to transfer genes from unrelated species, which would not be possible through conventional breeding. Both applications are being applied largely to the development of varieties with better and more durable pest resistance. The most advanced work, and the one with greatest application in Asia, is the research being conducted as part of the rice biotechnology network, which has been successful in inserting several new resistance genes for various rice pests.[13] It is likely that varieties carrying some of these genes will be released in Asia by the end of the century. Although these new biotechnologies will not lead to a new 'green revolution', they will make important contributions towards a more sustainable agriculture, for example through reinforcement of recent trends away from the use of pesticides as the main weapon in pest control. Institutionally, they raise important issues for research systems of the region owing to the relatively high cost and considerable scale economies of much of the research, and the fact that much of the R&D on new techniques of molecular biology is being conducted in the private sector in industrialized countries. Several Asian countries have moved aggressively to establish centres of excellence in biotechnology (for example, India, described in Pray and Parthasarthy, 1994) and the IARCs are also shifting resources towards biotechnology, although their level of investment may not be adequate (Evenson and Rosegrant, 1993). In addition, the divorce of specialized biotechnology research institutes from conventional plant breeding poses challenges both in defining priority problems to be addressed and, more importantly, in incorporating the new knowledge into varieties to be released to farmers.

Sustaining agricultural systems

Perhaps the most critical challenge to researchers is to arrest the tendency towards a long-term decline in productivity of intensive irrigated systems that are the livelihood and bread-basket of literally billions of people. The problem of sustaining productivity growth comes about because of inadequate attention to understanding and responding to the physical, biological and ecological consequences of agricultural intensification. The focus of research ought to shift from a fixation on yield improvements to a holistic approach to the long-term management of the agricultural resource base that considers the 'true' costs of production (including environmental costs). It is unlikely that there will be quick answers for reversing the current negative trends in productivity growth, and sustained research investments with a multidisciplinary and multi-commodity approach to diagnosing and tackling specific resource management problems will be needed.[14]

Nonetheless, we caution against a sharp reallocation of resources to focus exclusively on environmental concerns that might best be addressed through other types of interventions, for example the removal of price distortions that encourage socially sub-optimal use of certain inputs (Binswanger, 1994). While it is clear that short-term production gains should not be derived at the expense of long-term degradation of the resource base, diverting resources away from research aimed at enhancing productivity growth can have significant negative welfare effects, both through higher real prices for the basic food staples of poor people and in increased risk of environmental degradation through the further encroachment of agriculture onto marginal lands (Pingali, 1992; Harrington, 1993).

Institutional challenges

The increasing demands being placed on the research systems of the region contrast with the lack of institutional innovation in research system management and organization, combined with stagnation or decline in funding for agricultural research. In part, the very success of the 'green revolution' which led to a sharp increase in food supplies and a long-term downward trend in food prices may have induced the slowdown in research funding (Rosegrant and Pingali, 1994). This cyclical nature of research funding makes it difficult for national and international research programmes to commit human and financial resources to addressing long-term strategic issues crucial for sustaining productivity growth.

In addition, with a few notable exceptions, such as the Punjab of India, public research systems that will continue to be the key source of technical change for basic food staples have generally failed to muster political support for funding agricultural research. More efforts to show the impacts of research, combined with closer interaction between policy makers, researchers and farmers, is required to build political support. Ways of increasing the contribution of farmer financing and farmer influence over research should be explored. For example, in South Asia a very small cess on grain procured would add considerably to operating research funds and would be relatively easy to implement as well as being progressive (since large-scale farmers in the most advanced areas contribute most of the procured grain). Some research stations in China are now charging royalties for the use of their germ-plasm, although it is too early to assess the efficiency and equity implications of this policy. Finally, there is much potential for involving farmer organizations in fund raising and research priority setting.

Reform of the organization and management of research systems is also long overdue. The 1970s and early 1980s were golden years for agricultural research in Asia. Agricultural research was a prestige investment and, with rapidly rising budgets, research programmes and institutes proliferated. In the climate of austere budgets of the 1990s, it is clear that there are considerable potential efficiency gains from streamlining research priorities and reforming management and incentive systems. This implies the consolidation of overlapping programmes at the state, university and national level, especially in plant-breeding research. The number, role and function of national coordinated programmes also need to be re-examined. The issue now is whether highly centralized research management fostered by coordinated programmes is the appropriate organizational mode for research on all crops, and especially for research on crop and resource management. Finally, there are questions about the future role of national research councils. These councils were established to coordinate the financing of research and to give agricultural researchers some independence from rigid civil service regulations on hiring and remuneration. In practice, many of these councils have become large research organizations in themselves, but none has been able or willing to break away from the rigidities of government civil service rules. Consequently, many research systems are suffering a crisis of management, with top-heavy bureaucracy, centralization of decision making and lack of incentives for the innovation process so essential for research (Antholt, 1994). One result of this is that the quality of scientists is declining, since it has become difficult to attract and retain the best scientists into public-sector agricultural research.

CONCLUSIONS

There is little doubt that Asian agricultural research systems have had major impacts over the past three decades. From a relatively small beginning they have grown rapidly and now include some of the largest and most developed research systems in the world. However, in one sense the success of these systems has been rather narrowly based on the development of strong plant-breeding programmes for the major food staples that have continued to contribute to steady growth in productivity in the 'post-green revolution' period, as well as to increased stability and sustainability of food production systems. But these same systems have failed to evolve sufficiently rapidly to provide the knowledge base on crop and resource management to exploit the potential of modern varieties and maintain the quality of the resource base.

In the 1990s, new challenges are emerging, both on the scientific front, especially the new biotechnologies, and on institutional support and management for research. Institutional structures that were evolved during a period of rapidly rising public-sector support for agricultural research are no longer adequate to ensure efficiency and relevance of research in the climate of austere budgets of the 1990s. Nor are they appropriate for addressing the complex problems that characterize crop and resource management in 'post-green revolution' agriculture. Thus, in moving to the next century, the success of agricultural research will depend on active exploration of institutional and management innovations to revitalize research systems so that they can deliver the new sources of technical change required for sustainable productivity growth. In doing this, policy makers will have to consider research systems as composed, not just of a monolithic public sector, but of a variety of institutional structures, including the private sector, and with various sources of funding.

NOTES

[1] The 'post-green revolution' period is defined as the years following the almost complete adoption of modern varieties. In advanced areas such as the Punjab in India and Central Luzon in the Philippines, this occurred around 1975.

[2] That is, India, Pakistan, Bangladesh, Indonesia, Vietnam, the Philippines, Thailand and China.

[3] There are of course, many variants on this sequence of change. It best describes the areas of South and Southeast Asia that underwent the 'green revolution' in rice and wheat in the 1960s. The situation in China is more complex, but by the late 1980s, agriculture had essentially reached the 'post-green revolution' phase, as in advanced areas of South and Southeast Asia.

[4] See Barker and Herdt with Rose (1985) and David and Otsuka (1994) for farm-level evidence on the upward shift in labour demand accompanying the adoption of MVs of rice.

[5] Thus, even in China, which has traditionally depended heavily on organic sources of nutrients, the use of chemical fertilizers has increased dramatically over the past two decades and they are now the major source of nutrients.

[6] See Pardey *et al.* (1991) and Pray (1991) for descriptions of the early evolution of Asian research systems.

[7] Rates of yield growth for rice for each decade were 2.1 per cent, 2.6 per cent and 1.4 per cent and for wheat 6.0 per cent, 4.1 per cent and 1.9 per cent.

[8] The percentage of area sown to MVs in 1991 in Asia, excluding China, was 67 per cent for

rice, 88 per cent for wheat and 45 per cent for maize. In China, practically all of the cereal area is sown to MVs, although some area of wheat is still sown to relatively tall, improved varieties (Byerlee, 1993).

[9] Adoption of these newer generations of MVs has continued to provide steady genetic gains in yield, estimated at about 1 per cent annually for wheat, or perhaps half of total factor productivity growth in the 'post-green revolution' period. In rice the major gains have been made in yield per day.

[10] For example, Nepal relies heavily on varieties developed in neighbouring states of India or at CIMMYT. However, there are high returns to local testing programmes which screen for local release (Morris et al., 1994).

[11] It is sometimes useful to distinguish between crop management research where the emphasis is on increasing productivity, and resource management research which focuses on conserving the resource base. In practice, the two types of research blend, since the objective is to increase productivity while conserving the resource base.

[12] It should be noted that agricultural economics is one of the disciplines that is most commonly absent from most crop and resource management research.

[13] The rice biotechnology network was initiated by the Rockefeller Foundation to stimulate research relevant to rice production in Asia, by public institutions in both the industrialized and developing countries, and in IRRI. By the mid-1990s, over US$ 100 million will have been invested (R. Herdt, personal communication).

[14] A good example of this type of research is the rice-wheat initiative involving several NARS and IARCs to conduct research on long-term sustainability of the very extensive rice-wheat systems of South Asia.

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