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INTERDISCIPLINARY CHALLENGES AND OPPORTUNITIES IN INTERNATIONAL AGRICULTURAL RESEARCH

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INTERDISCIPLINARY CHALLENGES AND OPPORTUNITIES IN INTERNATIONAL AGRICULTURAL RESEARCH[1]

ABSTRACT

The network of International Agricultural Research Centers (IARC) was established to increase levels of investment in foodcrop and livestock research in developing countries. The Consultative Group on International Agricultural Research, an informal association of countries, international agencies, and private foundations, accepts responsibility for funding existing IARCs and for taking new initiatives to strengthen international agricultural research. IARC research is problem-focused and frequently cross-disciplinary. IRRI's Cropping Systems Program is an example of a major cross-disciplinary research effort.

Conducting interdisciplinary research is not without challenges. For example, issues such as common identification of team goals, leadership, disciplinary biases, and the rewards system may constrain productivity and proliferation of multidisciplinary research teams. Many constraints might be reduced if scientists were more formally exposed to the systems approach and the philosophy of interdisciplinary agricultural research. It is argued that the IARCs have an important future role in promoting and supporting interdisciplinary research in national agricultural research programs.

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INTERDISCIPLINARY CHALLENGES AND OPPORTUNITIES
IN INTERNATIONAL AGRICULTURAL RESEARCH

Numerous international agencies, governments, foundations, and multinational companies conduct international agricultural research. Much of this investigation, however, is not international agricultural research as defined by Sir John Crawford (1977, p. 285):

> research which, although based in one country, is of wider concern regionally or globally; is independent of national interest and government control; and retains appropriate links with national and other regional or international research systems to ensure the necessary testing of results and feedback of both results and needs ....

International agricultural research centers (IARC) conduct research within this framework. This paper discusses cross-disciplinary research within the IARC network and in national research and training programs. We do not wish to imply, however, that the IARCs have a monopoly on this research approach.

Historical development of the centers and the mode of operation that created a cross-disciplinary approach to studying agricultural production problems in the developing world is first reviewed. Problems, challenges, interdisciplinary research opportunities, and methods of integrating cross-disciplinary techniques into national research programs are discussed. The economist-biologist relationship in cross-disciplinary research is emphasized rather than collaborative research within social or biological sciences. Most examples are from the International Rice Research Institute (IRRI), where the authors participate in one of its major cross-disciplinary research efforts. Similar examples could be drawn from other IARCs.

EMERGENCE OF THE INTERNATIONAL AGRICULTURAL RESEARCH SYSTEM

Generating agricultural technology for developing countries

The successful reconstruction of Europe after World War II through the Marshall Plan convinced many developed countries, foundations, and international agencies that similar plans could be used to accelerate development in poor countries. Truman's Point Four program "... to make the benefits of our scientific advances and industrial progress available for the improvement and growth of undeveloped areas" (Bingham 1953) embodied this view.

These words may explain why development planners in the 1940s and early 1950s focused on industry. Agriculture, except for estate and export crops, was often neglected and regarded as a bottleneck to effective growth in agrarian economies (Schultz 1964). However, development planners quickly recognized that methods used to reconstruct Europe, Japan, and Taiwan were not equally effective in accelerating third world development (Myrdal 1968). They learned that agriculture had to be advanced to enable predominantly rural populations to benefit from the technical development processes (Solo 1975). Agricultural development also contributes to the economic viability of the non-agricultural sectors of developing countries (Eicher and Witt 1964).

Poor agricultural performance was attributed to the fact that farmers did not have access to productive agricultural methods found in the western world. Developers assumed appropriate, highly productive agricultural technology that existed elsewhere could be transferred to the developing world with little adaptation (Johnson 1981). Extension activities and technological and institutional support (land development, mechanization, fertilizer, credit programs) were stressed as methods of taking agricultural know-how abroad. Expatriate scientists were often employed to advise national programs.

The university contract model was another variant of the science and technology transfer concept. Special relationships were developed between universities in developing and developed countries. This institution building concept, in Ruttan's (1978a) view, assumed the US land grant university model could solve agricultural technology problems in developing countries. The effectiveness of this model was limited. Expatriate professors rarely have a sufficiently long-term commitment in or to the host country or enough background experience to develop courses to meet future professional needs of the students. Further, they often study problems which they are interested in rather than those of primary importance to their host country. Western bias in academic training and professions also "tends to burden the developing country with an overexpanded bureaucracy which is unable to make effective use of the limited professional capacity available to it" (Ruttan 1978a, p. 298).

It was gradually realized that these approaches were not adequately accelerating agricultural growth. Expertise and technologies developed for temperate agriculture and western institutions did not transfer directly or easily to tropical or subtropical environments or to socioinstitutional conditions in most developing countries. Scientific knowledge necessary to increase agricultural productivity and improve institutional performance needed to be directly developed in those environments where

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agricultural innovations were urgently needed (Schultz 1980a).

National governments began to seek donors to help them develop their own agricultural research capabilities, and train their own scientists. One of the most successful associations in the 1940s and 1950s was the Mexican-Rockefeller Foundation program. Their collaborative work on rust resistance made Mexico self-sufficient in wheat by 1956 and enabled release of stiff-strawed dwarf wheat varieties to Mexican farmers in 1961 (Myren 1969). Such examples demonstrated that quality agricultural research programs could be established in developing countries. It also showed that farmers would rapidly adopt new technology if they felt it was superior to traditional methods.

However, the international community felt it would take too long to generate urgently needed agricultural technology through national agricultural research programs alone. Financial impracticality and manpower constraints of the country-by-country approach would limit the number of countries which could be assisted (Hardin and Collins 1974).

Emergence of the international agricultural research centers

The Ford and Rockefeller Foundations, influenced by the arguments of F. F. Hill and J. G. Harrar, suggested an alternative way of increasing investments in foodcrop research in developing countries and of supporting and complementing national agricultural research. They proposed that international agricultural research centers be established (Hill and Hardin 1971). Each center would focus on a limited number of crops and agroecological zones. Multidisciplinary research teams would develop superior cultivars, crop management methods, and farming systems on which improved technology for developing nations could be based.

Although the centers would be located in developing countries, they would be as well equipped and manned as research institutes in the developed world. They would be more than technology generators. They would also collaborate with national research programs to improve research quality and effectiveness. It was recognized that, as the expertise of national programs grew, the time would come when the centers as originally perceived, would no longer be needed. Then, their facilities and management would become national or intergovernmental organizations.

The first IARC, IRRI, was incorporated in the Philippines in 1960. Rice was chosen as the target crop because it was then and still is the primary or secondary food for 90% of the world's poor. Rice is also grown under a wide variety of agroclimatic and socioeconomic conditions. The International Maize and Wheat Improvement Center (CIMMYT), the second center, was established in Mexico in 1966 when the Rockefeller Foundation's Latin American maize and wheat research was restructured. Both IRRI and CIMMYT had narrowly defined commodity bases, and initially worked on narrowly defined agroenvironments. Both centers gained prominence when they released modern dwarf rice and wheat varieties in 1966 (Brown 1970).

Several factors contributed to the dramatic success of what became known as the green revolution. First, these rice and wheat programs built on existing knowledge to develop rice and wheat technology appropriate for large regions of the developing world (Dalrymple 1978). Second, new rice and wheat technology spread rapidly in irrigated and favorable rainfed areas of the tropics. Third, national and international programs supported technology transfer to farmers. They also incorporated the scientific knowledge and germplasm generated by the centers into their own research programs. Fourth, proponents and opponents of the green revolution received considerable publicity. Social consequences or second generation problems were a major concern of the critics, a point covered later.

Initial IRRI and CIMMYT successes encouraged investment expansion in international agricultural research. There are now 13 centers in the IARC network. Responsibilities of these centers are described in Table 1. Most centers work to increase productivity of selected foodcrops and livestock in the tropics and subtropics. Three recently established centers, however, support international agricultural research in a more general way.

The International Board for Plant Genetic Resources (IBPGR) promotes conservation and documentation of germplasm of important food species to use in breeding programs in all nations. The International Food Policy Research Institute (IFPRI) assembles and analyzes information on world food production and distribution and evaluates alternative policies and strategies for increasing food production in developing countries. In 1980, the International Service for National Agricultural Research (ISNAR) was established to help developing countries strengthen local agricultural research programs.

Consultative Group on International Agricultural Research (CGIAR)

The Ford and Rockefeller Foundations funded the first four IARCs -- IRRI, CIMMYT, Centro Internacional de Agricultura Tropical (CIAT), and International Institute of Tropical Agriculture (IITA) -- but recognized it was beyond their capacity to support sustained growth in international agricultural research. Thus, the CGIAR, cosponsored by the World Bank, the Food and Agriculture Organization of the United Nations (FAO), and the United Nations Development Programme (UNDP), was established in 1971 to assume this responsibility (CGIAR 1980).

CGIAR is an informal association of countries, multilateral agencies, and private foundations which funds existing IARCs and takes new initiatives to strengthen international agricultural research

(Crawford 1977, Wortman 1973). Membership consists of donors or continuing members and fixed-term members elected by the FAO membership to represent interests of countries in the five development regions (Asia, Africa, Latin America, Southern and Eastern Europe, and the Near East and South Asia). There were 18 CGIAR donors in 1971 and 32 in 1981. Total CGIAR expenditures in 1972 were $19 M. By 1981 they were about $140 M, representing an average growth rate of 14% a year (Fig.1).

The rapid growth of financial contributions to CGIAR has probably ended. The centers now face a zero growth period, if not budget reduction. However, there are also CGIAR membership pressures to expand the range of activities sponsored by the consultative group. In coming years, decisions regarding activities, commodities (or centers) to be phased down or out will be more critically addressed -- by CGIAR and by the IARCs.

CGIAR has a chairman and secretariat, provided by the World Bank, in Washington to advise it on financial and policy matters. A Technical Advisory Committee (TAC) reviews scientific and technical aspects of all center programs and advises the CGIAR on emerging needs, priorities, and research opportunities. The TAC consists of 13 scientists nominated by the cosponsors and approved by the CGIAR. TAC is served by a secretariat staffed by FAO personnel in Rome.

Table 1. Name, location, and main programs of 13 CGIAR-sponsored Centers.

Center	Year established	Program
International Rice Research Institute (IRRI), Los Baños, Philippines	1960	Rice, multiple cropping
Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) (International Maize and Wheat Improvement Center), Mexico, D.F., Mexico	1966	Wheat, maize, barley, triticale
Centro Internacional de Agricultura Tropical (CIAT) (International Center for Tropical Agriculture), Cali, Colombia	1967	Beans, cassava, beef and forages, maize, rice, and swine
International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria	1968	Maize, rice, cowpeas, soybeans, lima beans, cassava, yams, sweet potatoes, and farming systems
Centro Internacional de la Papa (CIP) (International Potato Center), Lima, Peru	1971	Potatoes
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India	1972	Sorghum, millet, peanuts, chickpeas, pigeon peas
International Laboratory for Research on Animal Diseases (ILRAD), Nairobi, Kenya	1973	Blood diseases of cattle
International Livestock Center for Africa (ILCA), Addis Ababa, Ethiopia	1974	Cattle production
West Africa Rice Development Association (WARDA), Monrovia, Liberia	1974	Rice, West Africa
International Board for Plant Genetic Resources (IBPGR), Rome, Italy	1974	Coordinate collection and exchange of plant genetic materials
International Food Policy Research Institute (IFPRI), Washington, USA	1975	Food policy research
International Center for Agricultural Research in the Dry Areas (ICARDA), Beirut, Lebanon	1976	Wheat, barley, lentils, broad beans, oilseeds, cotton, and sheep farming
International Service for National Agricultural Research (ISNAR), The Hague, Netherlands	1980	Management of agricultural research

Although CGIAR assumes responsibility for the finances and policies of the centers, it exercises only limited control over them. Each IARC is an independent organization, reports to its own board of trustees, and is incorporated in its headquarter country. CGIAR sets reference terms for each center before it is established and through subsequent consultation. However, priorities within this mandate are developed by the board, directors, and staff of each institute. They are continually updated using advice from policy makers and scientists from countries and organizations interested in the centers' activities. TAC also reviews center programs every 5 years (Quinquennial Reviews) and also conducts commission reviews for CGIAR across centers (Stripe Reviews) on specific topics (Ruttan 1978b).

THE SHIFT IN FOCUS TO SYSTEMS RESEARCH IN THE IARCs

Rationale for a systems approach

IARCs are most concerned with biological and physical sciences. They emphasize research that will generate technology to assist developing countries increase agricultural production. Researchers seek to develop technology to increase output per land unit during the cropping year. Improved cultivars and management techniques and increased cropping intensity help increase output. Technology is usually designed to be scale neutral, or biased toward low-resource farmers (CGIAR 1981).

The best examples of the successful mission-oriented approach used by the centers are the development of high-yielding wheat and rice varieties. By 1976, 10 years after these cultivars were released, they or their descendants were planted on one-third the area growing these cereals in developing countries (Table 2). Of total area sown, proportion of new varieties varied from more than 70% for wheat in Asia to less than 5% for rice in Africa. Adoption also varied by country within geographic regions. Modern varieties were planted in 70% of Philippine rice lands, but on less than 15% of rice area in Thailand (Palacpac 1980). Percentage of area planted to modern varieties has continued to rise.

Factors influencing modern variety adoption (Feder et al 1981) and consequences of modern technology (IRRI 1978) have been thoroughly reviewed and documented. Adoption of modern varieties and associated technology was most rapid where farmers had access to irrigation and fertilizer -- environments similar to research stations and field sites where the technology was developed. Rapid spread of modern varieties and associated production increases demonstrated that if a new technology was suited to an environment, adoption was rapid. This supported Schultz's (1964) view that substantial agricultural growth is possible in developing countries if appropriate innovations are made available to farmers. Where modern seed-fertilizer technology was adopted, farmers' rice yields increased 20-40%. Wheat yields [illegible] as much as 100% (Dalrymple 1978).

Table 2. Estimated area of high-yielding wheat and rice varieties as a proportion of total area planted to these crops, less developed nations, 1976-77.[a]

Region	% of total area		
	Wheat	Rice	Total
Asia	72.4	30.4	41.1
Near East[b]	17.0	3.6	16.5
Africa[b]	22.5	2.7	6.5
Latin America	41.0[c]	13.0	30.8
Total	44.2	27.5	34.5

[a]Excluding Communist nations, Taiwan, Israel, and South Africa. [b]Very rough estimate of area planted to high-yielding varieties. [c]Includes large and very rough estimate for Argentina, and short varieties in Brazil (1974-75). Source: Dalrymple (1978, p. 123).

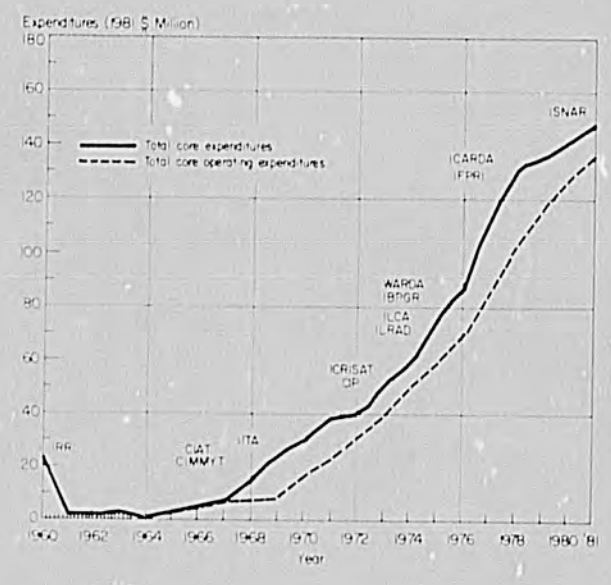

Fig. 1. International Agricultural Research Centers annual core expenditures and core operating expenditures, 1960-80 (in terms of constant 1981 dollars) (Source: CGIAR 1981).

When modern varieties were released, a major controversy arose as to their impact on socioeconomic structure within countries growing them on large areas (Griffin 1974; Wade 1974a,b). It has been argued that because the new technology was better adapted to favorable environments, it bypassed most farmers in disadvantaged areas and aggravated regional income disparity. There was also concern that technology emphasized high levels of purchased inputs, and increased returns to capital at the expense of labor. Distributional consequences

of new technology have been widely researched. While recognizing these problems, the welfare of disadvantaged, particularly rural and low-income groups, might be far worse now if modern foodcrop technologies had not been developed (Hayami and Herdt 1977, Hayami and Kikuchi 1981).

Because of varied needs of national programs and increasing sensitivity to production and welfare implications of the technology emanating from their research, IRRI and CIMMYT diversified their target environments and began to direct research toward more resource-efficient technology (CGIAR 1977). IITA, the International Crops Research Institute for Semi-Arid Tropics (ICRISAT), and the International Center for Agricultural Research in Dry Areas (ICARDA), were founded to emphasize crop development and land management for less advantaged environments.

Problems originally studied by IRRI and CIMMYT were relatively straightforward compared to challenges set for newer centers. Therefore, output and productivity gains by new centers will probably be less dramatic than those achieved by IRRI or CIMMYT in the mid-sixties. New advances will also probably be less rapid and cost more (Ruttan 1978a).

As research focused on poorer environments, scientists realized that the wide adaptation philosophy, appropriate for large irrigated areas, was probably not applicable for most rainfed environments (Farmer 1979). Comparative lack of crop and soil management knowledge and improved genotypes for these environments also would not allow research strategy to be as narrow as it had been for irrigated areas. Land development, management, and utilization, in addition to varietal improvement, are now major research areas for most centers.

The technology adoption debate and the sensitivity of centers to socioeconomic ramifications of modern technology emphasized that research results, per se, might not provide productivity gains or social justice for low-resource farmers or landless laborers (Barker 1980). Scientists are more aware that technology must be designed which is, to use Winkelmann's phrase, consistent with the means, needs, and circumstances of low-resource farmers.

Researchers' knowledge of the farmer and his environment have often been so inadequate they could not design relevant technology for him. There is now increased emphasis on understanding farming systems in specific environments to identify research that will provide profitable results for the farmer. Scientists are also testing varieties and component technology in these situations to determine their suitability for farmers. Including man in the research process has challenged biological and social scientists to jointly build improved, acceptable crop technology.

This new philosophy has changed some of IARC breeding and crop management program objectives. Strict production orientation has shifted toward developing plant types and crop management systems adapted for target environments. Increased emphasis on research designed for the farmer and his farm caused cropping (farming) systems studies to be part of CIAT, IITA, ICRISAT, and ICARDA programs from the beginning. A recent TAC review of farming systems research at the centers supported this trend and encouraged more crop productivity research to be done within a systems context (Dillon et al 1978).

Cross-disciplinary research programs

Growing emphasis on studying crops within farming systems and using systems concepts in agricultural research has increased demand for cross-disciplinary teams in several centers. Cross-disciplinary research is not new to the IARCs, however. Team problem solving has always been part of their research structure (Hill and Hardin 1971). Now, however, there is a more formal attempt to organize scientists from different disciplines to collaborate in research beyond individual crop technology. This trend has encouraged the holistic examination of constraints and opportunities for increasing crop or farm system productivity. Social scientists, usually agricultural economists, have been included in this integrative research process.

While IARCs generally are organized to conduct cross-disciplinary research, membership, structure, and cohesion of research teams vary within and among centers. Discipline composition and structure variations of IITA and IRRI can be compared by studying Figures 2 and 3.

IITA has four multidisciplinary programs. Each reports to a program leader, who is responsible to institute management for administrative and scientific program leadership. IRRI uses discipline-oriented departments and department heads. Staff time and resources are allocated across nine institute-designated research program areas. Most IRRI scientists work in several program areas. Each area has a coordinator with limited administrative or scientific control over the assigned program. The Cropping Systems Program is an exception, because it is coordinated by the head of the Multiple Cropping Department. Zandstra (IDRC, pers. comm.) considered this unambiguous scientific and administrative control important to that program's organization.

IRRI research programs are coordinated by joint scientific planning and review sessions. Institute administration strongly supports integrative problem solving. CIAT no longer has a farming systems research team, but biological and social scientists are included in commodity programs and conduct research within a systems context (CIAT 1981).

The CGIAR farming systems research review did not consider that one cross-disciplinary research structure was superior to another (Dillon et al 1978). Operational structures within the institutes show how center management chose to design

Disciplines included in research programs	IITA research programs			
	Farming systems	Root and tuber improvement	Grain legume improvement	Cereal improvement
	Agronomist	Agronomist	Breeder	Agronomist
	Ag. chemist	Breeder	Entomologist	Breeder
	Ecologist	Entomologist	Microbiologist	Entomologist
	Economist	Pathologist	Pathologist	Pathologist
	Engineer		Physiologist	Physiologist
	Entomologist			
	Microbiologist			
	Nematologist			
	Crop nutritionist			
	Soil physicist			
	Weed scientist			

Fig. 2. Research organization structure of the International Institute of Tropical Agriculture (IITA). Source: IITA 1980.

Scientific department	IRRI research program areas								
	Genetic evaluation and utilization of rice	Control and Management of rice pests	Irrigation water management	Soil and crop management for rice	Climatic environment and its influence	Constraints on rice yields	Consequences of the new technology	Cropping systems	Machinery development and testing
Agronomy									
Chemistry									
Economics									
Engineering									
Entomology									
Farm									
Information Services									
International Rice Testing Program	The time and resources of scientists working in disciplinary departments are allocated across nine IRRI research program areas.								
Irrigation Water Management									
Library									
Multiple Cropping									
Plant Breeding									
Plant Pathology									
Plant Physiology									
Rice Production Training/Research									
Soil Chemistry									
Soil Microbiology									
Statistics									

Fig. 3. The matrix of disciplinary departments and research program areas of the International Rice Research Institute (IRRI).

programs to meet the diversity of research problems, financial and technical resources (including staff personalities), and flexibility needs of their organization.

The CGIAR (1981, p. 40) identified four research levels within the IARCs:

- basic research, to generate new understanding;
- strategic research, to solve specific research problems;
- applied research, to create new technology; and
- adaptive research, to adapt technology to specific environmental conditions.

Within these, four levels of cross-disciplinary research are identified:

- Disciplinary research. This applies to basic, strategic, and certain kinds of applied research at the centers. For example, most research in plant physiology, tissue culture, genetics, pathology, and soil chemistry is disciplinary. Although there is no a priori reason why all research should be cross-disciplinary (Cock 1979), communication between center directors and scientists, and between scientists (formally and informally) should cause most research to reflect some influence of other disciplines (Cowell and Wigand 1980).

- Multidisciplinary research (Rossini et al 1978). After a common research goal is identified or an administrative decision made for scientists to work in a common research area, scientists pursue individual research interests they perceive to contribute to program objectives. Research results are usually reported by discipline, often with an introduction and summary to integrate ideas. Annual IARC reports suggest a large proportion of research at the centers is multidisplinary.

- Interdisciplinary research. This systematically integrates studies to imply that "there is a common view . . . which permeates and dominates the research effort" (Rossini et al 1978). The IRRI Cropping Systems Program (Zandstra et al 1981), CIMMYT on-farm research program (Byerlee et al 1980), and ICRISAT Farming Systems Program (Binswanger et al 1980), best meet this definition. Program scientists cooperatively define problems, design research, conduct site-specific studies, and evaluate and interpret results. The centers develop methodology and train scientists in cross-disciplinary research by this process. National programs use interdisciplinary research to formulate crop recommendations for farmers where the research was conducted.

- Transdisciplinary research. To Rossini, transdisciplinary research is the highest level of integration. Rossini writes "we transcend our individual skills and disciplines and work with other disciplines to create a new common cognitive map of the problem." Truly transdisciplinary research projects are rare (Swanson 1979). The IRRI integrated pest management project comes close to meeting this definition. In the project entomologists, an anthropologist, and community organizers design and transfer rice pest management practices to farmers (Goodell et al 1982). Transdisciplinary research is more practical for adaptive research.

Although interdisciplinary or transdisciplinary methods are valuable, researchers and policy makers should not forget that disciplinary skills are the cutting edge of scientific innovations leading to technological advancement. The challenge for research administrators is to promote a desirable mix of disciplinary and cross-disciplinary research. Proponents of cross-disciplinary research should realize that high returning CIMMYT and IRRI research (Arndt et al 1977) was basically disciplinary. Nonetheless, given the anticipated problems of developing food-crop technology in the future, there are strong arguments for a cross-disciplinary systems approach to agricultural research (Barker 1980, Dillon 1976, Dillon et al 1978, Harrington 1980).

In summary, most IARC cross-disciplinary research is multidisciplinary rather than interdisciplinary. Research projects with well-defined objectives are flexible, and enable team members to operate independently within limits set by program management. This structure works for scientists who are trained, who think, and who are assessed by professional peers within a disciplinary context. Truly interdisciplinary research is difficult to conduct, in our experience.

OPPORTUNITIES FOR INTERDISCIPLINARY RESEARCH IN TECHNOLOGY GENERATION AND EVALUATION

IRRI economists allocate substantial time to cross-disciplinary research in irrigation management, rice productivity constraints, agricultural mechanization, and cropping systems. The constraints project in particular combines talents of agronomists, economists, irrigation engineers and statisticians to evaluate limitations to higher rice yields in farm environments (De Datta et al 1978, IRRI 1979). However, the Cropping Systems Program is the largest cross-disciplinary enterprise -- in breadth of disciplines, in scientists, and in budget -- involving IRRI economists.

The IRRI Cropping Systems Program is interdisciplinary in structure and research implementation. Cropping (farming) systems research is also conducted by most other crop-based IARCs (ICRISAT, ICARDA, CIMMYT, and IITA). Their adaptive research programs are similar, but they each have different capacities and biases toward on-station strategic and applied research, versus farm-focused adaptive research.

Cropping systems research seeks to develop technology, within a farming systems context, that increases food production and is acceptable to target groups of farmers. New crops and improved management for existing cropping systems may be introduced. Researches must go beyond demonstrating the productivity and biological feasibility of cropping patterns on research stations. Technology must be tested by farmers.

Farm conditions with respect to climate, land, resource availability, market structure, and social and political institutions create many environments for which new knowledge must be adapted. It is neither appropriate nor feasible for the IARCs to study each environmental complex in the regions where they work. Fine-tuning technology for individual environments is the responsibility of national agricultural research organizations. Recognizing this, the tasks of the centers are twofold. The centers must provide national organizations with methodologies that allow them to develop improved farming systems for predominant environments in their areas, and they

must identify management techniques that overcome common limitations to cropping pattern intensification in regions where their mandate crops are grown (Zandstra 1979).

A conceptual model of IRRI cropping systems-applied research programs is shown in Figure 4 (Zandstra et al 1981). The following review of procedures and opportunities for interdisciplinary activity is based on methods used by the IRRI Cropping Systems Program. Program disciplines are in Table 3.

Selection of Target Areas

Target areas for cropping systems research in national programs are selected by planners and researchers. Final decisions about research location are frequently made by government planners and administrators who choose development areas using national priorities, feasibility studies, etc. Scientists perform a critical role in the decision making process. They have the technical knowledge to identify areas where greatest progress (in current technology application, and from site-based research) can be made in the least time, and areas that best represent broad regions within a country.

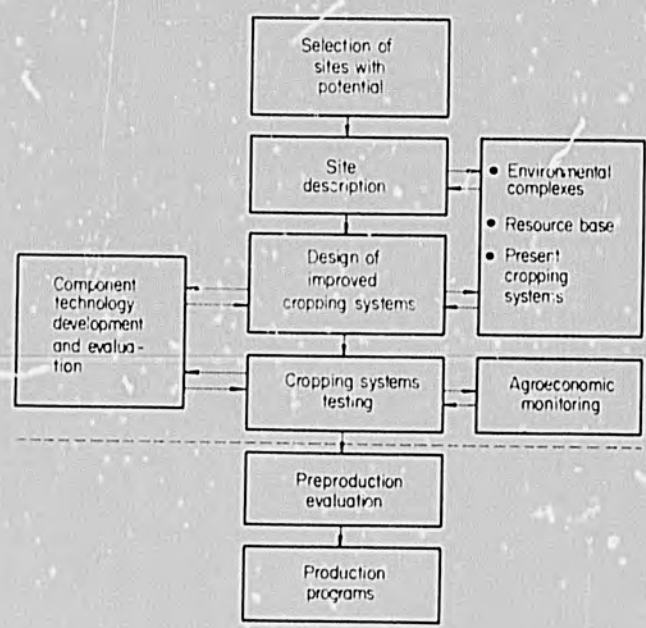

Fig. 4. Components of IRRI site-related cropping systems research methodology. Source: Zandstra et al (1981, p. 6).

Table 3. Disciplines and research areas of scientists participating in the IRRI Cropping Systems Program.[a]

Discipline	Department	Research area
Agronomist (Program leader)	Multiple Cropping	Basic cropping systems agronomy (soil fertility, crop management, etc.)
Agronomist	Multiple Cropping	Cropping systems agronomy, environmental description
Agronomist (ACSN[b] coordinator)	Multiple Cropping	Varietal testing, collaborative projects within ACSN
Crop production specialist	Rice Production Training and Research	Applied research, multilocation testing of cropping systems, production programs
Entomologist	Entomology	Insect pest control in rice-based cropping systems
Plant pathologist	Plant Pathology	Disease control in rice-based cropping systems
Weed scientist	Agronomy	Weed control in rice-based cropping systems
Economist	Agricultural Economics	Economics of rice-based cropping systems
Economist (ACSN)	Agricultural Economics	Economics of rice-based cropping systems and coordination of economics work - ACSN

[a]The responsibilities of staff listed in the table allocate all, or almost all, their time to the Cropping Systems Program. Several other scientists have part-time commitments. These include other economists and agronomists, an agricultural engineer, a statistician, and a communications specialist. [b]Asian Cropping Systems Network.

Mosher (1981) supports this view and stresses that development priorities should first concentrate where tangible results can be made in reasonable time, and where institutional factors -- markets, logistics, and social infrastructure -- will not be major bottlenecks. However, development sites are frequently chosen for political reasons (e.g. insecure areas), rather than for technical feasibility or production potential. When this happens, the cropping systems team may have to be concerned with issues of both technological and infrastructural development within a region.

IARCs may also choose field sites not of priority to host countries. Some locations may be chosen to develop methodologies, research particular problems of broad scope, or use as training areas. Otherwise, from an operational viewpoint site selection must be consistent with national priorities.

Site description

A research team must first study past research carried out in the region and review development plans of other agencies working there. Then they must understand existing cropping systems and farm environments, focusing on features of the area which may condition technology performance and farmer acceptance. Ideally, all scientists on the team should be involved in surveys, site description, and analysis. This helps them develop first-hand knowledge and sensitivity to feasible research opportunities and to the problems faced by farmers.

At least an agronomist and an economist should participate in the site analysis. CIMMYT's survey procedure (Byerlee et al 1980, Collinson 1981), the sondeo model of the Institute of Agricultural Sciences and Technology (ICTA) in Guatemala (Hilderbrand 1981b), and IRRI's survey for design (Zandstra et al 1981) are well-documented site description methods. CIMMYT's East African program (Collinson 1979) and the Integrated Cereals Project in Nepal (ICP 1980) are excellent examples of published interdisciplinary site descriptions.

Design of cropping patterns and component technology

Research site analysis provides the background for designing improved cropping patterns and crop management methods. In the design process, scientists who understand the physical and socioeconomic realities of the location, existing cropping pattern productivity, and available farm and market resources propose alternative patterns and practices for study. Suggested alternative farming patterns must be considered biologically, technically, economically, and socially feasible before they are included in field testing (Fig. 5). Many possible improved management practices are specified, based on existing technological knowledge and local methods. Other proposed practices may also be studied at the site, or in regional, national, or international experiment stations.

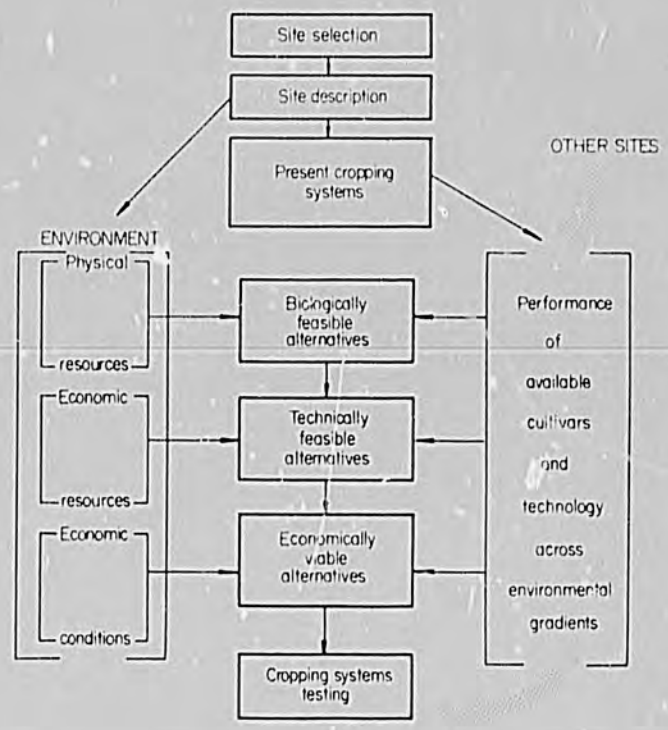

Fig. 5. Schematic model of the design phase of IRRI cropping systems research methodology. Source: Zandstra et al (1981, p. 31).

Economists should seek ways to increase their contribution to the design stage. Most economic studies of technology adoption have been ex post facto. Methodological issues in predesign research appraisal which will increase the efficiency of technical innovations have been inadequately explored. The challenge, argued Valdez et al (1979), is for economists to use generalized paradigms to estimate the relative merit of alternative choices for low-resource farmers. Anderson and Hardaker (1979) examined analytical procedures which may be used for ex ante evaluation. They concluded that skilled intuition complemented by careful analysis using simple budgeting models are the most useful technology design techniques. Alternatively, Price (1977) argues that the most important design stage role of an economist is to ensure realism in input levels, including farm-family resources. He also demonstrates how cropping patterns can be designed to minimize competition for resources, particularly labor, given current farming systems (Price and Barker 1978).

Existing and planned infrastructure will influence the range of realistic options included in the researcher's designs. It is important for researchers to consider how critically their technology depends on the perfomance of the technology delivery system. They should consult other agencies whose input may help the development process -- e.g. extension, public administrators. Changes needed in infrastructural support must be considered by the group. Where technology feasibility

depends on group action (synchronous planting, watershed-based soil and water management, cooperative marketing) participation of social scientists such as sociologists and anthropologists may be important.

Testing cropping patterns

This part of the research sequence evaluates new cropping patterns and component technologies in farmers' fields. Operations involved, and results and outputs sought from this phase of the process are shown in Figure 6.

Four types of on-farm trials are frequently conducted: cultivar screening, patterr testing (crop sequences and combinations), agronomic components evaluation (fertility and pest management), and trials that integrate knowledge gained to formulate productive management practices. Agronomic feasibility and economic viability assumptions from the design stage are updated based on results from component technology experiments. Next, potential patterns and practices are evaluated by farmers (under researcher supervision) to test their reaction to the pattern, its productivity, and profitability. A cost and returns analysis is usually used to evaluate these large-scale tests (Perrin et al 1976, Price 1978). Procedures that reflect farm-level opportunities and constraints as explored by Banta (1982) and Price (1980), need to be further developed for econometric use in cropping systems studies. Dillon and Hardaker (1980) discuss farm management procedures that could be more usefully applied in the testing phase of the research process.

Applied research and preproduction testing

The most profitable cropping patterns should be tested on a variety of farm sites in the target environment. A zone over which the pattern may be confidently extrapolated can then be delineated. Technology is evaluated by agronomic and economic results and by farmer acceptability. This analysis helps identify how the technology may be more precisely adapted to the physical and economic environment beyond the study location (Denning 1981). Scientists work with other institutions at this stage -- particularly with extension agents who formulate and implement production programs.

Crop production programs

Economists must also help evaluate technologies that have been adapted to target area conditions. This judgment is normally made by agronomists, economists, and extension personnel. It seeks to measure technology performance under farmer management and the important component technologies in farm environments, and tries to [illegible]ss any adoption constraints caused by limita[illegible]s in technology support services. These data [illegible]sed to adjust technology before widespread imp[illegible]ation, and to provide feedback to researchers and others responsible for the production program.

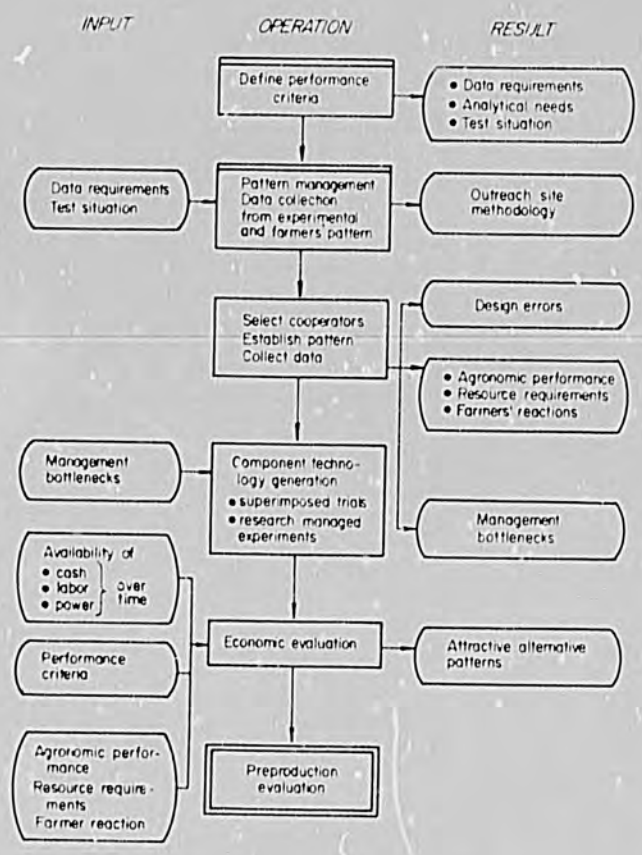

Fig. 6. Schematic model of operations used to test cropping patterns in IRRI cropping systems research methodology. Source: Zandstra et al (1981, p. 48).

Cropping systems research procedures at IRRI were developed cooperatively with the Asian Cropping Systems Network (ACSN). ACSN is a consortium of 10 countries in South and Southeast Asia -- Bangladesh, Burma, China, India, Indonesia, Nepal, Philippines, South Korea, Sri Lanka, and Thailand -- and the IRRI Cropping Systems Program. Procedures are continuously updated, tested, and modified based on experience at ACSN and national program sites. Technologies generated at cropping systems locations form the basis of major production programs and extension efforts in Sri Lanka, Nepal, Philippines, Indonesia, and Bangladesh.

International centers and their collaborators represent only a portion of cross-disciplinary research in developing countries. The Caqueza Project in Colombia (Zandstra et al 1979) is a well-documented example of an interdisciplinary agricultural project. The Australian Development Assistance Bureau (ADAB)-assisted Zamboanga del Sur Development Project (ZDSDP) in Mindanao, Philippines (ZDSDP 1980), is another. ZDSDP demonstrates the value of close interaction between agricultural research and technology transfer, and shows the complementary roles various disciplines can play in agricultural development.

Private foundations that played innovative roles in the establishment and growth of the IARCs continue to play a catalytic role in promoting multidisciplinary research in developing nations. For example, the International Development Research Centre (IDRC) was a partner in the Caqueza Project and has financially supported and encouraged the Asian Cropping Systems Network. Similarly, the Rockefeller Foundation has facilitated cross-disciplinary research in Latin America (Hilderbrand 1981b, Waugh 1981), as has the Ford Foundation in South Asia and the Middle East (Biggs et al 1981).

CHALLENGING ISSUES IN INTERDISCIPLINARY RESEARCH

Two interrelated sets of factors limit the effective structuring of multidisciplinary research teams. There are problems of group dynamics (social elements of people working together) and the difficulties of integrating research from different disciplines (Swanson 1979). There is extensive literature on group dynamics (Sills 1968, Rossini et al 1978) but less information on disciplinary research integration. The latter literature tends to discuss personal experiences rather than report structured research (Barker 1980, Harrington 1980, Hilderbrand 1981b, Waugh 1981).

Team goals

Identifying a goal for a multidisciplinary research team is not difficult. An example is: "to develop more productive cropping systems for region x." This goal may be conditioned by policy objectives related to target crops and impact on particular social groups. Few would find fault with such a goal. However, such a general statement provides little direction to guide the research priorities of participating scientists. As a result, team members tend to translate the goal and conceptualize research problems in terms of personal disciplinary bias (Johnson and Raussen 1977). Disagreement among participants about research issues, therefore, often occur. After the program has been established (problems specified and tasks assigned) research generally proceeds with a disciplinary focus. For problem solving efficiency this may be advantageous, providing research problems are jointly identified, and providing there is subsequent research integration and evaluation within a holistic framework during regular intervals throughout the project.

However, when research is conducted within a disciplinary framework without conscious integration, all participant viewpoints may not be acknowledged. There may be disinterest in the implications or interactions of one individual's technologies on the constraint placed on the feasible alternatives of other scientists. Scientists of different disciplines often use different criteria to choose sites, treatments, and factor levels for experiments. Therefore, team members working on the same crop may report different findings. A similar challenge emerges when components of one discipline's technology must merge with those of another. Best practices of one discipline or disciplines may be difficult to integrate with other best practices. Therefore, scientists may regard other's research as irrelevant to present problems. There must be time for team members to agree on experimental strategy, on criteria used to evaluate results, and on project implications.

Peer evaluation of results is often a sensitive point in multidisciplinary research. Scientists use different criteria to evaluate research quality, progress, and relevance. Team members may find it difficult to agree on a common yardstick to evaluate each other's work. Unless a special effort is made, individual scientists will evaluate their research by standard practice for their discipline. A biological scientist might evaluate work from a technical viewpoint, regarding farm trial results to be the end-product of his participation. An economist probably will evaluate results from an economic viewpoint. If this fragmentation occurs, evaluation may become sequential, not cooperative.

If farmers do not adopt technology judged "good" by this process, natural scientists tend to label the problem socioeconomic (extension, infrastructure, marketing bottlenecks), and beyond his responsibility (Hilderbrand 1981a). Economists also consider their analysis defensible and imply that there were technological flaws or inadequacies in the extension services. Indeed, as Biggs (1981) observes, the propensity of agricultural researchers to imply inadequate extension may divert them from examining practical relevance and viability of the technology they propose to the extension services.

Team structure and leadership

Team leadership and a willingness and ability for team members to work together are key elements in effective interdisciplinary research. Small teams with members who are well trained in their own disciplines who also have knowledge to contribute in one or more other fields are most productive. Barker (1980) limits team membership to six. He writes that as team size increases, participants' time necessary to communicate and coordinate research also increases. Desirable team balance depends on participant experience, problem type, and depth and breadth of research. A team should include broad subject matter specialists, particularly in agronomy and economics, who can integrate work of narrowly discipline-oriented team members.

There is frequently a tendency to expand research boundaries beyond objectives initially identified. Benefits of breadth or scope gained by adding new team members must be weighed against diseconomies of coordinating a large group. The most successful multidisciplinary crop-research teams have a sharp focus. When team and problem size increase beyond a certain limit, cohesion and productivity diminish.

Leadership is often identified as the critical factor in determining research team effectiveness

and cohesion. Hill (1979) identifies three kinds of leadership. The first is laissez-faire, involving a nondirective leader who allows scientists to set their own objectives, procedures, and evaluation methods. It is an ineffective leadership form (Swanson 1979). However, if a group of equally strong-minded, unbending scientists must form a research team, or if management is unwilling to appoint formal leadership, it may be the only workable method of group coordination.

Authoritarian leadership permits the group little or no influence in setting priorities and procedures, and as such does not foster an effective research environment.

Democratic leadership is probably most effective for interdisciplinary research. It is participatory and group centered, and the team leader encourages mutual discussion among team members (Hill 1979). Zandstra's conduct of the IRRI Cropping Systems Program, and Collinson's work with CIMMYT in East Africa are examples of democratic leadership. Leadership training and experience, and an appreciation of how various disciplinary skills can be integrated to solve problems, increase leader effectiveness. However, leadership of cross-disciplinary teams also depends on the art of interpersonal relationship -- something which may be difficult, and often is not taught to students in agriculture or economics.

Social scientists in multidisciplinary research teams

This paper discusses interdisciplinary research by social scientists and biologists, rather than among biological scientists or social scientists alone. Rossini et al (1978) report that, in a number of cross-disciplinary studies, economists were regarded as the most difficult scientists with whom to communicate. They use jargon; are preoccupied with models and methodology which are not seen, in a practical sense, to contribute directly or obviously to problem solving; often make insatiable demands for data without output within project time targets; and are unable, or unwilling, to consider non-economic goals in the arguments.

Rossini's study related to the industrial sector but economists in agricultural research institutes may suffer professional isolation because they have difficulty in communicating with biological scientists. Because most IARCs are production-oriented, many biologists see agricultural economists in a limited or secondary research role. This is reinforced if economists who are inadequately trained or disinterested in the approach are assigned to multidisciplinary teams.

Agricultural economists tend to have the most tenuous footing in the IARCs, Schultz (1980b) observes. Therefore, they must effectively demonstrate the contributions they can make to multidisciplinary research. If they do not, agricultural economics will be regarded as the most expendable discipline and may be first to go, should resources become more limited.

Disciplines and rewards

Because individual researchers were trained as disciplinarians, they often feel cross-disciplinary research threatens their traditional research activities (Harrington 1980). Even researchers who see a need for interdisciplinary research may have little incentive to argue for its introduction because the current incentive structure (salary increases, promotion, peer approval, opportunities to publish research in prestigious journals) favors those who excel as disciplinarians. It may even be detrimental to be closely associated with interdisciplinary projects, with the present reward system (Johnson 1981). Biggs (1978) argues that the training and reward system should be restructured to increase career advantages of interdisciplinary research. However, Dillon (1976) suggests academics and institutions may resist such a new research approach because they are the most conservative participants in agriculture. Institutional resistance to change seems to be stronger in developed than in developing countries.

Interdisciplinary research in national research programs

To have widespread impact, interdisciplinary research in agricultural development must be part of national research programs. Cropping systems methodology developed by the Asian Cropping Systems Working Group and IRRI has been effectively transferred to several countries in South and Southeast Asia. These countries may have rapidly adopted the methodology because it was developed with and for national programs in Asia.

In some countries, however, adoption of a multidisciplinary agricultural development methodology approach has been slow. Government agencies have historically structured research and administration along disciplinary or commodity lines. It is often administratively difficult to assign scientists from different departments or institutes to work on a cross-disciplinary project. Bureaucrats resist the loss of jurisdiction over subordinates and may resent that a portion of their budget is being allocated to activities they may not control. This problem is compounded if disciplines are divided into different governmental departments, perhaps a Department of Agriculture and a Department of Economic Development. However, institutions are changing. Indonesia, Philippines, and Thailand have recently reorganized research arms of their departments of agriculture to enable interdisciplinary farming systems research.

In many countries research and extension are in different administrative agencies and have operated independently. Widespread implementation of the Training and Visit System of agricultural extension (Benor and Harrison 1977) has encouraged

many national programs to strengthen ties between research and extension. More interdisciplinary problem solving in agricultural development is beginning.

Other constraints are related to finance, mobility, and the location of field-based research teams. Study sites normally are located away from government administrative centers. Salaries often are late and expenditure approval and supplies delivery are slow. Auditing departments sometimes are unwilling to provide research teams with budget flexibility. Field-based research frequently has higher recurrent cost per scientist than research station work. Logistical support is necessary to provide field mobility, and budget allocation per researcher may be higher for remote teams than for conventional on-station agricultural researchers.

Team members working at remote field sites are at a disadvantage compared to main office or regional station staffs. Frequently they are financially disadvantaged, have fewer available social amenities, and are neglected when promotions are considered. Government administration must provide incentives for staff to remain at field sites and provide them the flexibility to make administrative and scientific decisions with minimal referral to the head office.

Dillon (1976) argues that justification of the systems approach depends on its "inherent logic as an approach to understanding" and on inadequacies of disciplinary agricultural research. While this may be so, greater documentation of rural development speeded by interdisciplinary field research is needed to convince national planners that the system benefits exceed costs and inconveniences of administrative restructuring and staff retraining.

Training for cross-disciplinary research

Basic tertiary-level training in agriculture normally results in specialization during the last 2 years of the bachelor's degree program. Advanced degree training results in further specialization. Increased specialization causes the agricultural scientist to have less contact with the total agricultural system.

Scientists from developing countries who have specialized often cannot practice their specialization for a substantial part of their career. Because of their advanced training, they tend to become administrators -- research station superintendent, agricultural cooperative manager, or development project manager. In these roles they have little opportunity to use their technical expertise. They may have to coordinate, provide leadership, and allocate budgets to scientists with disciplines foreign to their own, and consequently may require holistic rather than specific knowledge. The capacity of a narrowly specialized scientist to accomplish these roles effectively is questionable.

Dillon (1976) suggests the structure of professional training should be changed. He recommends training which involves a 1-year introduction to the systems approach, followed by 2 years of disciplinary specialization. A 1- or 2-year program to bring together various disciplines in the context of a relevant agricultural system would complete the curriculum.

Barker (1980) supports this training reorientation. Cornell University and Florida State University in the United States are experimenting with multidisciplinary research and training programs in agricultural sciences. According to Barker (1980), the Cornell program has had mixed success because professors tend to maintain a strong disciplinary style in teaching, supervising students, and research. Further efforts are needed to strengthen the contribution of systems and interdisciplinary thinking in academic institutions training students for international work.

Within existing tertiary education systems such changes are in the future. We must recognize, however, that today's development problems are being tackled by scientists who have already completed their degrees or will do so soon. Alternative teaching methods exist within nontraditional research and training institutes, and more need to be developed.

To meet the demand for multidisciplinary training, several IARCs conduct nondegree training courses for national scientists working in applied agricultural research. IRRI teaches a 5-month Cropping Systems Training Program (CSTP) each year. CIMMYT offers similar courses. The IRRI course is designed to train scientists and technologists in cropping systems research methodology used by ACSN (Hagerman and Khan 1981). The CSTP provides participants an overall view of low-resource farmers and their farming systems, and how to conduct research within these systems. Participants are exposed to biological, economic, and social disciplines. The ways these disciplines may act and interact in multidisciplinary agricultural research are emphasized. In this way, the CSTP seeks to help researchers develop improved cropping systems acceptable to small farmers.

National program response to the CSTP has been encouraging. Not only do the programs finance students who undertake this course, but demand exceeds IRRI's capacity of 40-45 students per year. Many graduates are now manning or supervising important cropping systems sites in their home countries.

The shortage of trained economists working in national research programs has also constrained the emergence of interdisciplinary agricultural research. IRRI understands this problem and has initiated an annual training course for economists working in national research programs. To strengthen Asian agricultural economics research, IDRC also funds an economics coordinator at IRRI to support national ACSN programs. One of his major tasks is to train and encourage young economists to participate in farming or cropping systems interdisciplinary research.

Western European donors of CGIAR have initiated a different educational program with a similar purpose. The International Course for Development Oriented Research in Agriculture (ICRA) is a postgraduate course to train agriculturists to cooperate more effectively in interdisciplinary development teams (ICRA 1981). The program requires course work at Wageningen and 3 months field work in developing countries, where participants are members of interdisciplinary groups. The course is intended to bring scientists from various biological and socioeconomic disciplines into contact with environmental and human problems of farmers and to provide methods and experience so graduates can structure more relevant research objectives and solutions.

The ICRA and IRRI programs are helping train scientists who will increase interdisciplinary research capabilities of national programs. Because these courses are in such demand, serious effort must be made to develop similar courses at national universities and training institutions.

The future of IARC interdisciplinary research

Agricultural economists have probably been most effective and accepted in adaptive, system-focused interdisciplinary research. Much of this research, after methodologies are developed and tested, works to solve site-specific problems. Solutions must be conditioned by biophysical and socio-political realities in those environments. Such site-specific work is the responsibility of national research programs, not the IARCs. Binswanger et al (1976), Mosher (1977), and Ruttan (1978b) have cautioned that the international institutes will lose their advantages and become competitive with national programs if they undertake site-related research purely to address site-specific problems.

Primary objectives of IARC site-related research should remain the development and transfer of methodologies to national programs. New technologies should be developed and tested in consultation with them. It is recognized, however, that site-related research by the centers is justified for training and demonstration purposes and necessary to research specific problems common to several national programs.

Economics must accept the challenge and contribute to further methodological developments in adaptive research. Better ways are needed to identify farmers' goals and objectives and better methods are needed to incorporate them in an analytical framework to improve ex ante evaluation of technological options. Virtually all the economic analysis has been at crop or plot level. Little research has been done at the farm household level. Whole-farm analysis which can be readily applied in field sites must be increased. Methodology necessary to analyze group action situations (integrated pest or soil and water management) must be improved. Ways of studying the impact of technological change on villages or regions must be refined. Therefore, rural sociologists and anthropologists will probably play an increasingly important role in interdisciplinary research at the centers. Achievements of noneconomic social science at ILCA and CIP have demonstrated the substantial contributions these disciplines can make to agricultural research (Okali and Milligan 1981, Rhodes et al 1981).

As national programs progress toward using multidisciplinary research for agricultural development, and as methodologies are refined, the IARCs will need to increase staff time allocated to these activities. IARC cropping systems scientists may spend more time with national programs. They may also spend more time in disciplinary oriented research -- examining problems identified during participation in national multidisciplinary teams. More effort will be devoted to training and collaborative work to adapt methodologies for national programs. The centers' roles as clearinghouses for information, and as coordinators and analysts of collaborative experiments between countries may increase. IARCs should continue to train scientists in multidisciplinary research, and to serve as sources of trained personnel until national programs can assume this responsibility. Short-run productivity gains in IARC multidisciplinary activities may be shifting from technology and methodology development to teaching how multidisciplinary principles can be used by national agricultural research organizations.

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