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ORGANIZING AGRICULTURAL TECHNOLOGY TRANSFER

The Effects of Alternative Arrangements

PASITAM PROGRAM OF ADVANCED STUDIES IN INSTITUTION BUILDING AND TECHNICAL ASSISTANCE METHODOLOGY

Organizing Agricultural Technology Transfer

A PASITAM Design Study

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TWO PAPERS BY BURTON E. SWANSON

Organizing Agricultural Technology Transfer: The Effects of Alternative Arrangements

A Publication of PASITAM

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c International Development Research Center 1975

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Preface

"Development" involves the design and implementation of effective action systems. Novel goals, elusive and unstable settings, and a limited ability to predict outcomes are among the problems of design and implementation. Knowledge about institution building and the principles of technical assistance cannot solve these problems, but it can help meet this basic need. It can sometimes increase their manageability.

Most technical assistance involves institutional change. Sometimes it seeks to build substantially new institutions. More commonly, technical assistance attempts to adapt or reorient elements of an established institutional concern, ranging from organized arrangements to some of the beliefs, practices, and competencies of people in a society. Success in promoting institutional change, the most common goal of technical assistance ventures, frequently depends on an accurate perception of institutional problems and astuteness in resolving them.

Practical knowledge about technical assistance methodology includes practical knowledge about institution building. But the knowledge needs of technical assistance include other things as well: how to plan, organize, and determine what is actually happening; how to influence and control it; how to determine and evaluate relations between actions, aims, and outcomes; and how to use the results of evaluation to improve the quality of technical assistance.

PASITAM, the MUCIA Program of Advanced Studies in Institution Building and Technical Assistance Methodology, seeks to enlarge the capacity to meet some of these needs for practical knowledge, and to make the results available through publications, training, and consultation.

The following contribution, one of a series of PASITAM "Design Studies," examines a problem of organization, a practical problem of great importance within the field of technical assistance. In the narrowest sense, it is a case study of the different effects of alternative patterns of organization, where one pattern seems to be significantly more effective than the other in serving a given set of technical assistance aims. Cases such as this offer lessons. The lesson of this study is pertinent to

certain other arrangements for providing technical assistance. The expertise developed in producing this study is currently available within MUCIA. The study itself, along with other PASITAM materials concerning the design and implementation of effective action systems, can be used in training activities aimed at improving the quality of developmental efforts.

William J. Siffin, Director
Program of Advanced Studies
in Institution Building and
Technology Assistance
Methodology

1

Institution Building: The International Wheat Technology Development and Transfer System

This paper was written as part of a research project on international technology transfer systems being supported by the Program of Advanced Studies in Institution Building and Technical Assistance Methodology (PASITAM) of the Midwest Universities Consortium for International Activities (MUCIA) through a 211 (d) grant from the U.S. Agency for International Development. I am indebted to Drs. Norman E. Borlaug, R. Glenn Anderson, W. Ronnie Coffman, Peter R. Jennings, and J.D. Drilon, Jr. for their valuable comments on the first draft of this paper.

Burton E. Swanson was a Research Associate in the Department of Continuing and Vocational Education, University of Wisconsin, Madison, when he carried out the research reported in this paper. In August 1975, he was appointed Assistant Professor, Department of Vocational and Technical Education, College of Education, University of Illinois, Urbana-Champaign.

Spurred by the growing food shortages of the mid-seventies, the striking success of the Green Revolution technology in increasing wheat and rice production has stimulated an increased flow of resources into agricultural research for the tropics and subtropics. At the international level, ten research centers have been approved by the Consultative Group on International Agricultural Research and are operating with a commitment of resources of about 45 million dollars in 1975.[1]

There is little disagreement that the agricultural research capacity in many less-developed countries (LDCs) is weak and poorly organized, and that increased outside investment and assistance is required if improved agricultural technology is to be developed and rapid gains realized in production. However, a number of important policy questions arise regarding how these new resources should be utilized. One crucial issue concerns the role of international centers in relation to national research programs: will a proliferation of international centers actually strengthen the research capacity of LDCs, or will they tend to duplicate research work already being carried on by national programs? Or, what is an appropriate and workable division of labor between international centers and national programs? These questions, in turn, are closely related to decisions regarding the types of technological solutions that are to be pursued.

This Design Study examines a specific technological problem—the development of improved genetic technology (i.e., improved germ plasm, crop varieties, or populations)—and describes an organizational pattern being worked out by the International Maize and Wheat Improvement Center (CIMMYT) in Mexico.

The organizational pattern which is evolving in the International Maize and Wheat Improvement Center (CIMMYT) in Mexico challenges certain aspects of the conventional wisdom regarding how research systems should be organized and adds an important new dimension to the more traditional research approach. What has emerged is a spatial form of research organization operationalized by basic changes in research methodology, combined with a complex set of institutional mechanisms which systematically link national wheat research programs into an overall international wheat improvement system. CIMMYT scientists believe this emerging research system will significantly strengthen the overall process of producing improved wheat technology. In the process, this approach

has resulted in a unique and apparently successful division of labor between CIMMYT (as an international center) and national wheat improvement programs.

Since these institutional innovations relate directly to the problem of organizing international centers, I will first define what is meant by genetic technology and then examine the CIMMYT research and outreach programs that deal directly with producing improved genetic material. Finally, I will analyze this approach in terms of specific institutional and technological issues.

Genetic Technology

The cornerstone of a crop technology system is its genetic component (i.e., variety or population). A crop variety has written in its "genetic code" information that controls or determines the many different and diverse characteristics of each variety or plant population. This genetic code may be changed over time through environmental influences in a natural process known as evolution; or the process can be manipulated artificially by man through a scientific process known as varietal improvement. Following are some of the major factors agricultural scientists are most interested in modifying as they set out to create improved genetic technology:

First is the physiological capacity of a variety or plant population to transform effectively and efficiently solar energy and nutrients (including water) into usable forms of food output. This capacity is generally measured in terms of yield potential.

Second is the capacity of a variety to resist or tolerate economically important limiting factors. Certain limiting factors, such as insufficient nutrients, inadequate weed control, etc., cannot be effectively controlled genetically, but can be alleviated through improved agronomic practices. Others can be largely controlled genetically. Most important in this second group of limiting factors are disease and insects; also included are others, such as problem soils, drought, and cold temperatures. The way in which a specific crop variety or population reacts to each of these potentially limiting factors is dependent on the genetic make-up of the plant. Therefore, agricultural research workers attempt systematically to manipulate the genetic code of plants by making new genetic combinations in a crossing program. They then attempt to select those progeny (offspring) that have a high physiological capacity to produce as well as the genetic capability to resist or tolerate different limiting factors.

Third, the food output produced by a crop variety has certain qualitative characteristics that are also genetically controlled. Most obvious is the complex of factors that affect the cooking/eating qualities of food crops. Different cultural, ethnic and/or national groups frequently prefer

different quality characteristics within the same food crop. Therefore, improved varieties must be genetically tailored to meet these preferences. Perhaps more important, however, is the nutritional quality of the food output. Protein deficiency is a serious nutritional problem in many parts of the tropics and subtropics; therefore, increasing the total amount of available (or usable) protein in food crops is also a high priority research objective.[2]

The CIMMYT Wheat Research Program

The CIMMYT wheat improvement program in Mexico is a major research effort designed to increase and stabilize the genetic yield potential of the wheat plant.[3] Although the program generally follows a very traditional methodology of plant breeding (i.e., the pedigree method), the program is unique both in terms of the widely adapted characteristics of the genetic output and in terms of the way the methodology is operationalized to produce widely adapted materials.

Widely Adapted Germ Plasm

In direct contrast with the location specific genetic technology coming out of state experiment stations in the U.S., the CIMMYT wheat team is systematically engaged in producing widely adapted germ plasm.[4] The idea behind widely adapted germ plasm is to have a high yield potential or physiological capacity that is relatively stable under a variety of different environmental conditions. There are two main sets of genetic factors that influence yield stability under differing conditions.

First are the genes that control the direct impact of the environment on the physiological capacity of a plant to produce.[5] How sensitive a plant is to these environmental effects is largely dependent on how that variety was developed (i.e., the research methodology employed). The location specific approach generally results in varieties that are highly productive under specific types of conditions but which may have very low yields under other conditions. CIMMYT's widely adapted approach attempts to produce varieties with a high yield potential under optimal growing conditions, but which also produce relatively well under different conditions—particularly conditions of environmental stress (e.g., drought tolerance, adaptation to length of growing season, soil types, ability to efficiently utilize nutrients, etc.).

The second set of factors influencing the adaptability of a variety is its reaction (i.e., resistance or tolerance) to different limiting factors. Each major wheat growing region in the world has a specific set of disease and insect problems.[6] Some of these problems (such as stem, stripe, and leaf rust) are common to most wheat growing regions of the world, while others (such as Septoria, Alternaria, Hessian fly, etc.) are unique to only

a few regions. There are genes for resistance or tolerance to most of these different limiting factors; but the more different diseases and insects that any one variety is resistant to, the more areas in which it can be successfully grown without having yields reduced due to these problems.

Operationalizing the Widely Adapted Breeding Strategy

The research process used to produce a new "pure line" variety of wheat (or other self-pollinated small grains) generally requires seven generations—from the time a cross is made until the actual naming of a new variety by the plant breeder.[7] Thus, in temperate climates where only one crop (generation) can be grown per year, the varietal development process requires about seven years. Likewise in the spring wheat-growing regions of the subtropics, only one wheat crop is possible per year because summer temperatures are too high.

Dr. Norman E. Borlaug (currently Director of CIMMYT's International Wheat Program) and the Mexican wheat team were not satisfied with the long gestation period required to produce new wheat varieties and experimented with the possibility of growing a second crop, during the summer, in the high mountain valley of Toluca near Mexico City. Although the ecological conditions of this valley are quite different from the regular wheat growing areas of nort'western Mexico, it was possible to successfully complete a second crop cycle per year—thus cutting in half the time required to develop a new variety.[8]

The idea of moving breeding material through different ecological environments was contrary to conventional ideas about plant breeding. Borlaug recalls one incident when his unorthodox methods came under fire:

> I was sowing the nursery when I was visited by a very eminent and dear professor of genetics and plant breeding. I described how we were moving plants back and forth in alternative generations. He said, "Young man—you didn't absorb the first principles of plant breeding. You are alternately taking one step forward and one backward." Well, not knowing better and believing in the approach, we continued and I believe the results justified our beliefs.[9]

What Borlaug was observing, as he moved the breeding materials through these two different ecological environments, was that some plants/lines did well in both environments. "In the process of moving the wheat plants back and forth up and down twice a year, wide adaptation was built into the varieties. . . ."[10]

Only those plants and lines that did well in both environments were selected and carried forward through seven successive generations of careful and rigorous selection by the Mexican wheat team. The result was that one variety could serve a wide area in the highly variable Mexican wheat ecology rather than a different variety being needed for each valley.[11]

Borlaug's increasing awareness of the advantage of developing widely adapted wheat varieties led to further changes in the breeding methodology to further exploit and refine this conceptually different type of varietal improvement process. In particular, the effect of producing widely adapted germ plasm was to manipulate a much larger number of genetic factors than is commonly done in a traditional, location specific, breeding program. To combine and select effectively and efficiently for a large number of genetic characteristics in a single experimental line required another major innovation in breeding strategy. As Borlaug puts it, "It was . . . here in the Mexican program that the idea evolved that plant breeding is a numbers game. . . . We can have the best plan, the right parental combination and the proper screening technique but without numbers, the chances of getting that plant are remote. We depend in part on making very large numbers of crosses."[12]

In addition to making thousands of crosses each season another important aspect of the numbers game is the extensive use of complex crosses—particularly double crosses.[13] Technically, this involves attempting to bring together the desirable characteristics from four parents into a single progeny or offspring in an integrated two-step procedure. It is accomplished by first making single crosses between two pairs of parents and then crossing the first generation (F_1) progeny of these two single crosses the following season.

In this procedure, two or three high yield potential varieties/lines are used with one variety/line having one or two desirable genes to be transferred. In the resulting segregating population, there is a high yield of plants with superior agronomic characteristics. By contrast, *because of the recessive nature of many of the genes for good agronomic type,* the single cross of a tall, weak strawed, agronomically undesirable type with a high yielding parent gives few agronomically superior plants. The probability that these few plants also possess all of the other desirable characteristics being sought is infinitesimal. Therefore, by utilizing two growing seasons per year and by making several thousand complex crosses each year, the CIMMYT program is greatly accelerating the development of widely adapted varieties which have genetic resistance/tolerance to many different limiting factors.

Organizational Features

There are other organizational features unique to the CIMMYT wheat program. First, the CIMMYT wheat research program represents a total integrated interdisciplinary team approach to varietal improvement. In traditional forms of research organization, scientists from different disciplines work with the plant breeder in the varietal improvement process, but do so by operating parallel screening programs. To select

experimental lines that are resistant/tolerant to different limiting factors (e.g., stem rust), the plant breeder will generally give his advanced lines to the appropriate disciplinary specialist (e.g., the pathologist). He will in turn grow the nursery material, screen it (e.g., for resistance to stem rust), and report to the plant breeder which lines are resistant/tolerant. In this case, the task of integrating the various desirable genetic characteristics is left to the plant breeder.

The CIMMYT program is very large, and to have several identical screening nurseries for different limiting factors would result in considerable duplication of effort. Furthermore, the CIMMYT system of having all scientists (from each discipline) working in the same nursery on the same material results in the material being screened for many different limiting factors simultaneously. Thus, the thousands of experimental lines that result from the thousands of genetic combinations made each year are *quickly* narrowed down to a couple of hundred advanced lines that have many of the different genetic characteristics the wheat team is trying to combine.

Another organizational characteristic originated by the CIMMYT program is the complete standardization and routinization of the research methodology. Because of the large amount of material being handled in the program and the integrated interdisciplinary structure of the program, there is potential for error and under-utilization of the diverse germ plasm coming through the program. To avoid this problem and to insure maximum efficiency, the entire program is systematically organized around a series of highly efficient research procedures. A pictorial diagram of the CIMMYT Bread Wheat Breeding Program summarizes this process (see Fig. 1). As the program progresses through the growing season (and through the seven generation varietal development process), each scientist knows exactly what his responsibilities are and when each research task is to be performed. The result is that at final selection time (at the end of each season), there is a full complement of objective data available on each line that has been systematically contributed by each scientist on the CIMMYT team. Furthermore, final decisions are generally made by the full team, representing each scientist's specialization, rather than leaving these decisions to the plant breeder.

In conclusion, it should be noted that while CIMMYT operates what must be the largest and most productive varietal improvement program for wheat in the world, it has never named or released a single variety. Mexican varieties are known around the world; and although these varieties are the product of a joint effort between the national wheat improvement program in Mexico and CIMMYT, it is the Mexican program, not CIMMYT, that makes the final decision whether a variety is named and released in Mexico. This policy decision has very important

BREAD WHEAT PROGRAM

CROSSING BLOCK

INTERNATIONAL SCREENING NURSERIES
300 OR MORE PROMISING VARIETIES AND LINES FROM MEXICO. THIS MATERIAL CHANGES EVERY YEAR.

PROGENITORS
ARRANGED BY GROUPS ACCORDING TO YIELD, DISEASE REACTION, QUALITY, ETC.
PLANTED IN 3 TO 8 DATES, SPACED 60 TO 18 DAYS.
FIRST DATE: APPROXIMATELY 250-300 VARIETIES AND LINES.
SECOND DATE: SAME VARIETIES AND LINES PLUS NEW BULLS.

MISCELLANEOUS
MATERIALS FROM AROUND THE WORLD FOR WHICH THERE IS NOT ENOUGH INFORMATION. ONCE STUDIED MAY BECOME PROGENITORS.

EVERY SEASON, ABOUT 3 TO 5 THOUSAND NEW CROSSES MADE ACCORDING TO SPECIFIC NEEDS.

SINGLE CROSSES (good length for production of double and three way crosses)
DOUBLE CROSSES
THREE WAY CROSSES
BACK CROSSES

ON BASIS OF PROGENITORS' PERFORMANCE
(diseases, adaptation, agronomic and industrial characteristics, etc.)
ABOUT ½ OF CROSSES DISCARDED BEFORE PLANTING.

F_1
APPROX. 1500 CROSSES
1/3 IS KEPT ON BASIS OF VIGOR AND DISEASE REACTION.

SELECTED SINGLE CROSSES HARVESTED IN BULK

INDIVIDUAL PLANTS SELECTED FROM DOUBLE, BACK, AND THREE WAY CROSSES

THESE MATE[illegible] THE SEAT TO VARIO[illegible] TRIES

F_2
1.5 TO 2 MILLION PLANTS

PLANTS INDIVIDUALLY INOCULATED WITH SPORE SUSPENSION OF THE PREVALENT RUST RACES IN MEXICO TO ELIMINATE SUSCEPTIBLE WHEAT GENOTYPES

SOME F_2 POPULATION OR F_3 TO F_6 LINES GROUPED FOR SPECIFIC NEEDS SUCH AS

ARID LANDS - IRRIGATED AREAS - SPECIFIC DISEASE PROBLEMS.

[redacted] BULLS

INDIVIDUAL PLANTS SELECTED → AGRONOMIC TYPE → DISEASE REACTION

AGRONOMIC TYPE:
- PLANT HEIGHT
- STRAW STRENGTH
- TILLERING
- SIZE AND DENSITY OF SPIKE
- FERTILITY
- MATURITY

DISEASE REACTION:
- STEM RUST
- LEAF RUST
- STRIPE RUST
- SEPTORIA
- LEAF FIRING

[redacted]

SEED OF SELECTED F_2 PLANTS SOWED IN ONE DOUBLE, 5-METER ROW.

F_3
INDIVIDUAL PLANTS SELECTED OUT OF BEST LINES.
LINES SELDOM HARVESTED IN BULK.

TO THE SCREENING NURSERY

[redacted]

[redacted]

F_4

INDIVIDUAL PLANT SELECTION SCREENED FOR SEED TYPE

BEST FAMILIES HARVESTED IN BULK FOLLOWING PEDIGREE SYSTEM

F_5

[illegible] ARE [illegible] AS LIN[illegible]

F_6

7[illegible] LINES OF CO[illegible]ORATORS [illegible] THE WORLD

BEST LIN[illegible] LEASED AS COM[illegible] VARIETIES

CIANO YIELD TEST
AFTER TWO YEARS OUTSTANDING CIMMYT LINES ARE INCLUDED IN AN INTERNATIONAL ELITE SCREENING YIELD TRIAL WHICH IS DISTRIBUTED IN 20 PLACES AROUND THE WORLD

PI [illegible]MINARY [illegible]ASE PLOTS
AGRONOMIC AND PHYSIOLOGICAL TEST
DATES AND RATES OF SOWING, FERTILIZER LEVELS, IRRIGATION PRACTICES, TRAINEE TEST IN FARMS, PHYSIOLOGY TESTS IN CIANO, TESTS WITH COLLABORATORS IN THE WORLD

[illegible]NCIPAL COMMERCIAL [illegible] WHEAT VARIETIES [illegible]R COUNTRIES

SMALL INCREASE PLOTS TO MULTIPLY AND PURIFY POTENTIAL VARIETIES

SI

IMP
INTERNATIONAL MULTIPLICATION PLOTS
TO INCREASE SEED OF COMMERCIAL AND NEWLY RELEASED VARIETIES AND LINES FROM OTHER COUNTRIES

ISWYN
INTERNATIONAL SPRING WHEAT YIELD NURSERY
100 LOCATIONS IN 81 COUNTRIES

consequences in terms of the relationship between CIMMYT, as an international center, and national programs; this will be discussed in more detail in the final section of this paper.

Summary

The CIMMYT wheat program in Mexico is essentially a large genetic assembly line. The widely adapted breeding strategy being followed by the CIMMYT program results in a more complex set of breeding objectives being pursued. To incorporate and combine a large number of desirable genetic characteristics in an individual experimental line, CIMMYT makes thousands of genetic crosses each year. To accelerate this process, CIMMYT grows two generations per year and makes extensive use of complex crosses. To read the genetic code of each plant for the many genetic characteristics CIMMYT hopes to combine, the wheat team systematically moves the genetic material through a variety of different ecological environments, as well as through many different testing and screening procedures. This process allows each plant/line to express its genetic makeup.

An expression frequently used in CIMMYT's training program captures this process very well: "The plants are talking to you [about their genetic code], but you have to use your eyes to hear what they are saying." By systematically exposing the early generation material (that is, segregating for both the desirable and undesirable characteristics of its parents) to a variety of different conditions, the wheat team is able to read the genetic code of plants and select those plants/lines that have both a high yield potential and the particular combination of different characteristics they are looking for. As will be shown in the next section, CIMMYT makes extensive use of this same principle, through its different international nursery programs, to obtain more information on each advanced line and, thereby, is able to read accurately the genetic code of these lines in even more detail.

International Genetic Transfer Systems

The international wheat improvement strategy being pursued by CIMMYT is built around the concept of strong, independently functioning national wheat improvement programs that are interdependent or linked together in a worldwide wheat improvement network. Building strong varietal improvement programs at the national level is primarily carried out through CIMMYT's training programs. These training and other outreach activities are summarized elsewhere;[14] therefore, in this section attention will be given to the international network that links all these wheat improvement programs together.

In the decade since the first International Spring Wheat Yield Nursery

(ISWYN) was sent out, the regular, systematic international exchange of wheat germ plasm has grown dramatically. In 1974, CIMMYT assembled and distributed 24 different international nurseries which were grown in up to 83 different countries at as many as 137 different locations.[15] The total number of individual nurseries (experiments) sent out in 1974 totaled 1,346. The Appendix contains several tables that indicate (1) the distribution of nurseries by regions in 1974, (2) the total number of nurseries sent to different countries during the four-year period 1971-74, and (3) quantitative information on the size of each nursery sent since 1964. The following description deals with the major types of nursery programs in terms of primary function(s).

Progenitors (Crossing Block)

CIMMYT makes available to returning trainees and newly developing wheat improvement programs a nursery representing the varieties and lines contained in CIMMYT's crossing block. This nursery generally includes more than 250 individual varieties/lines that CIMMYT uses as primary parent lines or progenitors in its crossing program. These lines generally have a high yield capacity; but more important, they represent a wide range of genetic diversity, both in terms of sources and types of resistance/tolerance to different limiting factors and for different quality characteristics.

In addition, most lines are well documented so a program or returning trainee can immediately start crosses with several hundred elite parents on which there is good information regarding the genetic history and characteristics of each line. Furthermore, CIMMYT's crossing block is quite dynamic with many lines changing each year; so even a well-organized, ongoing national program can find valuable new germ plasm in this nursery.

Segregating Nurseries (F_2's)

In the second generation after a cross is made (the F_2 generation), individual plants within a population are segregating for the various desirable and undesirable characteristics of their parents. To identify individual plants that have the right combination of desirable characteristics (from the parent lines), the varietal improvement team must expose the segregating populations to different limiting factors and environmental conditions so that, ideally, each plant will express its genetic make-up. Although the CIMMYT wheat team can do this work very well in Mexico, the plants actually selected in Mexico are those genotypes that do best under Mexican environmental conditions. These lines are bred and selected to be widely adapted, but some valuable genotypes may be discarded because they are not outstanding under Mexican growing conditions. The same populations grown elsewhere, under different

environmental conditions, might well result in different plants being selected—the reason for the segregating nurseries.

Any F_1 population (first generation after crossing) that looks particularly promising and that the CIMMYT team believes may produce a superior line(s) is included in an F_2 nursery sent out to about thirty different locations.[16] Individual plants selected at any one of these different locations may represent a unique genetic combination that could not have been identified in Mexico but which may be particularly well suited to the wheat growing conditions in other parts of the tropics or subtropics. Since most of these segregating populations are from complex crosses, they represent a great deal of genetic diversity that national programs can tap immediately for outstanding new experimental lines (F_3's).

Segregating nurseries are particularly valuable to national programs that lack the trained technicians and field assistants needed to carry out the mechanics of making a large number of complex crosses—such as the material represented in these segregating nurseries. Furthermore, CIMMYT has already invested two seasons of work in these populations when they are sent out, so they represent a considerable savings in time for national program scientists.

Screening Nurseries

Screening nurseries consist of advanced lines from CIMMYT and other active national wheat improvement programs.[17] The objectives of these nurseries are: (1) to assess the performance of new advanced lines under a wide range of climatic and disease conditions, and (2) to release additional new sources of diverse germ plasm to national programs. Cooperators may reselect individual lines from these nurseries or move an outstanding line immediately into nationwide testing prior to releasing it as a named variety. In addition, these materials are frequently looked to as new sources or progenitors in national crossing programs.

In connection with the actual conduct of the nursery itself, each cooperator is expected to take appropriate field notes on each line, including such things as disease reactions and yield data. These data are sent back to CIMMYT to be summarized, published, and distributed to all cooperators. This feedback information is valuable to both the CIMMYT and national wheat teams in reading the genetic code of these different advanced lines in order to make critical decisions regarding the possible release of advanced lines as new varieties. At the same time, other outstanding lines are identified that can be exploited as new progenitors in the crossing program.

Yield Nurseries

CIMMYT conducts essentially two types of yield nurseries. The oldest is the International Spring Wheat Yield Nursery (ISWYN), designed to

> test the adaptation of groups of spring wheat varieties under a wide range of latitudes, climates, day lengths, fertility conditions, water management and disease complexes. . . . These experiments are designed to study the performance of some of the most important varieties and experimental material from the major wheat growing areas of the world under the environmental conditions of many countries.[18]

ISWYN is open to promising new lines and outstanding varieties from any wheat improvement program in the world. Also, as national programs identify outstanding lines and varieties, these materials are sent to Mexico for testing and are frequently used as progenitors in the CIMMYT breeding program. The long-term effect is to increase and pyramid the occurrence of genes for adaptation and, thereby, continuously increase and broaden the productive base of the germ plasm (particularly the crossing block) in the CIMMYT program.

CIMMYT has a second type of yield nursery that is used to assess the performance of its most outstanding advanced lines. Experimental lines identified in the screening nursery may then be included in the Elite Selection Yield Nursery (ESYN) for more precise yield testing in replicated experiments. Again, field notes are taken by each cooperating scientist on disease reaction and other agronomic characteristics to further document various aspects of the genetic complex represented in each experimental line. This information is useful both to CIMMYT and national programs in further assessing the performance of these outstanding lines--of great importance in making future program decisions.

Surveillance Systems to Detect Genetic Vulnerability

One extremely important problem in growing the same variety (or varieties with the same source of disease resistance) over a wide geographical area is the danger of disease epidemics or genetic vulnerability. In particular, genetic resistance or tolerance to certain diseases tends to be fairly short-lived because disease pathogens (particularly the three types of rust, in the case of wheat) have a great capacity to find ways (through natural mutation or sexual/asexual recombination) around the genetic roadblocks (genes for resistance) that agricultural scientists attempt to incorporate in improved varieties.

To detect changes in the different disease pathogens, a potential threat to stable wheat production throughout the world, two regional disease and insect surveillance systems are maintained. The first "early warning" surveillance system (RDISN—Regional Disease & Insect Screening Nursery) was established in 1970 by the Arid Lands Agricultural Development Program (ALAD) of the Ford Foundation in Beirut (in close cooperation with CIMMYT and FAO's Near East Cereal Improvement Program) and serves North and East Africa, the Middle East, Southern Europe, and South Asia.

> The objectives of the RDISN are to: (1) evaluate the resistance of wheat varieties at "hot spot" locations in the region from India to Morocco and throughout East Africa;[19] (2) standardize the disease (and insect) scoring so meaningful comparisons can be made; (3) summarize the data at an early date so the information can be used in selection work, in arranging future yield trials, or in developing the crossing program; (4) operate the nursery in such a fashion that the burden of cooperation is minimized; and (5) analyze the data in detail and make evaluations on sources of resistance.[20]

The Latin American Disease and Insect Screening Nursery (LADISN) was subsequently established in 1972 to serve the same function in the Americas. This nursery is directly coordinated by CIMMYT. In both cases, however, these regional nurseries not only give the earliest possible warning to cooperators of new virulent races of rust, but also provide all national programs with the mechanism to screen their advanced lines in regional disease "hot spots"—before they are released as varieties—to get an accurate reading of the genetic code of each line. In this way, cooperators can have greater confidence that the variety they are releasing is, for the time being at least, disease-resistant. Furthermore, when there is a new threat of a rust epidemic, the national program will know which varieties are still resistant; only those will be recommended to farmers before the disease can have an economic impact in the country.[21]

Special Purpose Nurseries

Multiline varieties. The rapid spread of the Mexican wheat varieties during the late sixties increased the threat of genetic vulnerability. CIMMYT scientists knew that these new high-yielding varieties would soon become susceptible to disease and would have to be replaced. Although the research capacity in national programs was increasing and was being strengthened by the emerging international network, CIMMYT scientists were still worried. In response to this concern, an innovative approach involving the development of multilineal varieties was started.[22]

To explain the concept of a multilineal variety and how it will lessen the threat of a disease epidemic, Borlaug uses the analogy of an explosive prairie fire. Such a fire can quickly spread across a vast expanse of dry prairie grass, just as a virulent stem rust epidemic can quickly spread across a large area where one uniformly susceptible group of wheat varieties is grown. He points out, however, that if

> . . . only half the grass plants are dry and the rest green, the fire will spread much more slowly; if the proportion of dry plants is dropped to 6 to 12 percent of the population, the fire will spread very slowly or not at all. We predict that where multilineal wheat varieties are planted in large areas, the seasonal rate of spread of stem rust will be reduced in a similar manner.[23]

A multiline variety is produced by making a mechanical mixture of a sizable number of phenotypically similar lines (i.e., plants that look and produce alike) that differ genotypically for disease resistance (i.e., have different genes for disease resistance). CIMMYT is now developing the components for a multiline based on the most outstanding Mexican variety released during the sixties (Siete Cerros) which was a line selected from the cross "8156."[24] By making thousands of simple and complex crosses between 8156 and other varieties/lines that carry different sources of disease resistance—particularly to the three rusts but to other diseases as well—CIMMYT is able to select a large number of lines that look and produce more or less like 8156, but which have many different sources and combinations of disease resistance.

In 1974, CIMMYT completed the initial work required to develop a multiline variety based on cross 8156. The international nursery system is again being utilized to screen the many experimental lines that will eventually be used as components in making up national multiline varieties. Some 285 CIMMYT derived lines and 65 additional lines from the Coordinated All-India Wheat Improvement Program are now undergoing trials at 31 locations in 19 countries.[25] Once feedback information is received on these and subsequent nurseries (both disease readings and production data), CIMMYT will then work directly with individual national programs on a continuing basis to select fifteen or twenty different component lines that can be used in creating and maintaining a national multiline variety.

In each country, component lines must have disease resistance that holds up in "disease hot spots" around the world which are also well adapted to local growing conditions. Each national program will then multiply the selected lines, mechanically mix the seed, and release the new multiline variety to farmers. Later, as one or more component lines of the mixture become susceptible to a new race of rust, those elements can be replaced with new resistant lines and the variety re-released to farmers. Thus, each national 8156 multiline variety could be substantially different genetically from other national multiline 8156 varieties; at the same time, each national 8156 multiline variety would be dynamic, changing in genetic composition over time as the need arises.

The result of this extensive research effort is to regain the genetic diversity or disease escape mechanism of traditional wheat production systems while maintaining most of the production potential of an outstanding, widely adapted, high yielding, pure line variety. In the future, when another truly outstanding variety emerges from the international wheat system that significantly surpasses the yield potential of 8156, the process of developing a second (spring bread wheat) multiline will begin.

Spring wheat-winter wheat crossing program. Another special-purpose program using the international network is the spring wheat-winter wheat crossing program. CIMMYT initiated this program to combine certain desirable characteristics of winter wheats (such as drought and cold resistance, septoria resistance, increased yield potential, and a wider range of maturity) into spring wheats. At the same time, spring wheats can provide winter wheats with greater disease resistance, dwarfing, better grain quality, and increased yield potential.[26]

Again, the Toluca valley in Mexico represents an environment uniquely suited to this program. Nighttime temperatures during January are below freezing; therefore, the winter wheats, which require freezing temperatures for vernalization, will flower (from October sowing) in early May. Spring wheats are planted in February, and they flower in May as well; so the crosses can be made. The F_1 generation is planted in November at the CIANO station in Northwest Mexico during the winter growing season. Then the F_2 seed is split; one-fourth is sent to Oregon State University, one-fourth to the Turkish National Program, one-fourth to Argentina, and the rest remains in Mexico to be planted in the summer nursery (May-June) in Toluca.

In Mexico, only the spring-habit wheats survive since the winter-habit wheats fail to flower (because they are not vernalized). Outstanding plants are selected from these segregating populations and move through the regular CIMMYT program. Advanced lines are now moving out through the international system for testing throughout the world.

On the Anatolian Plateau of Turkey, in Oregon, and in Argentina, the rest of the F_2 seed is planted (November in Oregon and Turkey, May in Argentina) and grown out under winter wheat growing conditions. In these nurseries, only the winter-habit wheats survive the cold winters, and these plants are selected for desirable genotypes—particularly those with good sources of disease resistance. These materials, in turn, are sent out in an annual international winter wheat screening nursery to (1) make these improved genetic materials available to other national programs, and (2) test this germ plasm under a variety of different environmental conditions to further read the genetic code of these lines.

CIMMYT scientists guard their optimism about the potential impact of the spring wheat-winter wheat crossing program on worldwide wheat production, but clearly the potential is far-reaching. While it appears that the spring wheat-winter wheat crossing program is accomplishing most of its original objectives, two major developments bear mentioning here. First, preliminary observations indicate that the drought resistant genes of the winter wheats have been captured in some of the new spring wheat lines. This breakthrough is a necessary first step in significantly moving the Wheat Revolution into the natural rainfed areas of the subtropics

that have not been greatly affected by the dwarf wheats to date.

Another important byproduct of the spring wheat-winter wheat crossing program is that this approach appears to be capturing considerable heterosis (hybrid vigor) in both the spring and winter wheat offspring. This development could mark another major and simultaneous yield breakthrough for both the spring and winter wheats. As these new advanced lines are tested around the world in their respective international nursery systems, this yield potential will be more accurately measured.

Summary and Conclusions

The international wheat research and technology transfer system that has been operationalized by CIMMYT, in close cooperation with national research programs in the tropics and subtropics, utilizes several innovative tive concepts and procedures. First, the systematic movement of germ plasm through different ecological environments in Mexico led to a recognition of the concept of widely adapted genetic technology.

Second, to produce widely adapted genetic technology requires the manipulation of a much larger number of genetic factors than is commonly necessary in a more traditional, location-specific type of breeding program. To do this, CIMMYT employs a large number of complex crosses to combine or pyramid an increasing number of desirable genes in a single progeny or experimental line.

Third, the manipulation of a large number of genetic characteristics is meaningless unless there is an accurate, yet efficient method of reading the genetic code of each plant/line. CIMMYT does this in Mexico through the use of an interdisciplinary team that makes regular observations for specific genetic characteristics in the field, combined with the extensive use of early generation screening procedures and micro-tests in the laboratory. In this way, the CIMMYT wheat team can quickly and systematically sift and winnow the thousands of new genetic combinations made each season to select a few dozen lines that show promise.

Finally, these lines then move out through the international technology transfer system where they are grown under a vast array of environmental conditions. Information on these nurseries is then compiled and distributed to cooperating programs around the world to enable both CIMMYT and national program scientists to read accurately the genetic code of each line under field conditions.[27] This international wheat improvement network or system is now producing results such as the following:

> The top-yielding variety in 1971-72 (in Lebanon), recently named Arz, may be used to exemplify how international and regional wheat work fits together. Our earliest records indicated that this line was grown in Tunisia during 1968-69 from seed received from India. The cross number shows that the cross was made in

Mexico, probably in the early sixties. It showed good rust and Septoria resistance in Tunisia and was therefore sent to Lebanon where its yellow rust resistance was confirmed in 1969-70. It entered the Lebanese National Yield Trials in 1970-71 and yielded above Mexipak, the standard for selection. In 1971-72 it showed up among the top varieties at 20 of 30 locations (in regional trials).[28]

Policy Implications and Analysis

The international wheat improvement strategy being developed by CIMMYT is based on clearcut policy decisions regarding the types of technological solutions to be pursued through the international system and what problems should be of direct concern to national programs. In this section, a brief statement is given summarizing the major components of a crop technology system; then an examination is made of (1) the different types of research alternatives that are possible to pursue in solving specific limiting factors of production, (2) the advantages and disadvantages of relying on genetic solutions to solve certain types of production problems, and (3) other policy implications of an international genetic technology development and transfer system.

The Components of Crop Technology Systems

A nation's soil and water resources, as well as its climatic conditions (solar energy, natural rainfall, etc.), determine in large part the types of technically and economically feasible crop technology systems. Given these general parameters, however, the production potential and performance of individual crop technology systems are quite varied. Many different factors (independent variables) affect or influence crop production (as a dependent variable). Among these factors are the physiological capacity or capability of a cultivar (variety or population) to transform solar energy and nutrients into food, feed, or fiber; some contributing factors to increased production, such as optimal levels of nutrients (including water) and appropriate cultural practices; various limiting factors, particularly the presence of different pests (e.g., insects, disease, and weeds); as well as various economic, institutional, and human factors.

Each of these different factors can contribute to or reduce overall crop production. In designing a research system to develop improved crop technology, it is necessary to have a logical structure through which each technical factor or problem can be addressed and alternative solutions considered—in the context of the economic, social, and institutional milieu of a particular country.[29] In the research process, some of these technological factors offer little flexibility in terms of the types of solutions that are possible to develop. For example, cultural practices such as the date and density of planting, fertilizer recommendations, and weed control must be worked out for every crop technology system. Other production problems offer considerable flexibility (research alternatives)

regarding the types of technological solutions that can be pursued. This latter group of production problems is given primary attention here.

Research Alternatives

In solving certain types of limiting factors, such as insect and disease problems, there can exist several different types of technological solutions (i.e., chemical, mechanical, biological, and/or genetic). Given the human, institutional, and economic constraints faced by many less-developed countries, it appears likely that certain types of solutions are more appropriate than others. For example, certain insect and disease problems can be controlled to a greater or lesser degree by chemical, biological, and/or genetic means. Each type of solution has certain costs and benefits, and the decision to pursue a particular research alternative not only has major implications vis-a-vis the research investment that will be required (i.e., each strategy requires different types of scientific equipment, facilities, and personnel); but this decision also has direct implications regarding the type of delivery system that will be required for agricultural producers to have access to the technology developed.

The decision to pursue a *chemical solution* to a particular limiting factor implies a number of different costs and infrastructure requirements. Most obvious is the direct cost of the chemical to the farmer. However, in addition there are the costs of the delivery system to make available the input to large numbers of small producers at the proper time; the cost of operating a credit system so that farmers who lack capital can have access to the inputs; and at the national level, the capital cost of building the necessary industrial capacity to produce the chemicals (probably requiring a substantial foreign exchange outlay). To be effective in solving a specific pest problem, chemical solutions must be properly applied (i.e., proper timing, rate, and method of application), which implies an educational cost for extension services. In addition, there are potential, long-term ecological costs that may be incurred through the extensive and continuous use of certain pesticides; and some agricultural chemicals represent a serious health hazard to millions of untrained peasants and farmers who ultimately have to handle these materials in the production process. Finally, for some nations, chemical solutions can represent certain political costs since these inputs (or the industrial capacpacity to produce these inputs) can only be obtained by dealing with foreign petro-chemical companies.

On the positive side, however, chemical solutions are generally a very effective means of controlling specific types of pest problems. Direct research and development costs to LDCs may be quite low since chemical technology is frequently quite transferable (i.e., certain pesticides and herbicides work equally well in the tropics as they do in temperate

regions). In addition, chemical solutions that are transferable may be available immediately without having to wait for an extended research and development gestation period until alternative solutions can be developed. Therefore, in solving specific types of technical problems, particularly in the short run, agricultural chemicals may represent the best and possibly the only solution to certain production problems.[30]

Biological solutions are frequently quite inexpensive in terms of both direct economic and ecological costs, but these alternatives may offer more limited and less predictable levels of pest control. Solutions of this type are frequently quite location-specific and, in addition, may require a high managerial input to be effective. Examples of different types of biological controls would be the use of predatory insects or changing crop rotation patterns to control or prevent the build-up of certain economically important weeds and/or insects. These methods of pest control should be developed and utilized by national programs whenever possible; but this approach has obvious limitations, particularly at the international level, both in terms of transferability and surety of control.

Genetic Solutions to Limiting Factors

Genetic solutions to disease and insect problems have been used to a greater or lesser extent in the past, depending on the crop in question. However, due to the location-specific nature of many pest problems, as well as the location-specific nature of many varieties produced by research institutions in the United States, this approach has been primarily utilized when other forms of control are not technically or economically feasible. CIMMYT's development of widely adapted genetic materials, combined with the methodology and international system to develop and identify experimental lines/varieties with reliable sources of resistance, makes genetic solutions a more viable alternative for crops grown in the tropics and subtropics. There are several important reasons why this type of technological solution is particularly appropriate for the tropics and subtropics wherever it is technically feasible to develop it.

First, genetic solutions involve little economic cost to the farmer beyond the purchase of his initial seed; therefore, the cost of adoption is minimal and is not a regular, annual production cost. This advantage is of considerable importance when dealing with small farmers who have very limited availability of or access to capital.

Second, genetic solutions to limiting factors are simple to adopt from the farmer's standpoint. Although the dwarf wheat varieties required a different set of cultural practices (particularly depth of planting and proper irrigation) to be grown successfully (in addition to increased levels of fertilization), these differences were associated with the different physiological characteristics of the crop (dwarf stature, fertilizer respon-

sive, etc.), not with being disease resistant. Therefore, genetic solutions to problems such as insect pests and disease do not require an extensive educational input (as would be the case with pesticides) to be successfully utilized.

Third, genetic solutions do not require substantial investments in industrial capacity and the necessary supply or delivery system to make inputs (such as pesticides) available to farmers when needed. In addition to these direct capital costs, the task of organizing an efficient and reliable delivery system for capital inputs that can reach millions of small producers is very difficult (given the poor basic infrastructure in most poor nations) and can be a serious institutional obstacle to the adoption of improved crop technology systems by farmers.

Fourth, genetic solutions avoid the potential ecological costs associated with chemical solutions to limiting factors; they also eliminate the serious health hazards associated with handling pesticides.

Finally, genetic solutions can give widespread control of specific limiting factors across large geographical areas and, if properly maintained by an effective research and monitoring system, can do so with little risk of genetic vulnerability. However, since genetic vulnerability represents a continuing and serious danger to the utilization of genetic solutions to limiting factors (particularly certain diseases), this problem will be examined in more detail.

Genetic Vulnerability

As modern, science-based crop technology systems are adopted by agricultural producers in the tropics and subtropics, the problem of genetic vulnerability to disease and insect pests becomes an increasing threat to food production. There are two main aspects of this problem, along with two other closely related factors.

First is the impact of intensive crop production systems on the micro environment in which the plant grows. To increase yields substantially, cropping systems must be intensified generally involving high plant populations along with heavy levels of fertilization. Lush vegetative growth results which is ideal for the development of certain types of diseases and insect pests. This lush growth also tends to produce heavy dews that can persist much of the day, producing moist conditions, ideal for certain foliar diseases and insects to develop, reproduce, and spread rapidly. Under intensive production systems, therefore, adequate control measures are essential if the crop is to survive and produce.

Second is the problem of genetic uniformity. Within about seven years after the first introduction of the high yielding wheat and rice varieties into Asia, over 15 million hectares (approximately 39 million acres) of each crop were being planted to these varieties.[31]

Some observers are concerned that these varieties have too narrow a genetic base for disease and insect resistance.[32] The result of large acreages being grown to the same variety, or to varieties with the same source of disease resistance, is to put maximum selection pressure on the disease to survive. Under such conditions, it is predictable that sooner or later a mutant form (a new race) of the disease will occur that can attack the previously resistant variety. Furthermore, with millions of acres of varieties with the same sources of genetic resistance being planted, if environmental conditions are right, a new virulent race of a disease could produce an economically serious epidemic capable of spreading quickly across an entire continent.

Third, with the rapid introduction and spread of high yielding varieties, traditional varieties that represent a rich source of genetic diversity (i.e., new sources of disease and insect resistance that can be drawn on in future breeding efforts) are quickly being replaced. Although some international efforts have been made to save these genetically diverse cultivars, more remains to be done—and soon.[33]

Fourth is the lack of a natural disease escape mechanism in the tropics, common to most crops grown in temperate regions. Cold winters, while preventing year-round cropping, serve as a natural means of controlling or reducing the severity of disease epidemics and/or insect outbreaks. In the tropics, diseases and insects are not killed by cold temperatures, but traditional farming systems generally keep pest problems in check.[34] Now with the increased use of highly intensive and year-round cropping systems, the potential for serious and continuing pest problems is greatly increased. Therefore, if intensive cropping systems are to be maintained, effective control measures are imperative.

Although there are very serious risks involved in the extensive use of genetic solutions to different disease and insect problems, if those risks can be minimized through a carefully organized research infrastructure, then the advantages of this type of technological solution (wherever possible) would generally appear to outweigh other types of solutions. The key question is: How should the research system be organized to minimize these risks?

Organizational Issues Concerning Crop Improvement Research in the Tropics and Subtropics

Theodore Schultz has expressed his concern about the increased integration of the research process and the increasing centralization in the allocation of resources to agricultural research. He indicates that his bias is in favor of increased competition between research organizations.[35] The success of both public (state experiment stations) and private research organizations in the U.S. to produce improved agricultural tech-

nology would certainly support this proposition. Furthermore, although independent or parallel research activity implies a certain amount of duplication of effort, this independence generally results in a much wider diversity of research inquiry; and, particularly in the U.S., this competition between research organizations and theoretical paradigms has resulted in a rapid and efficient expansion of the frontiers of knowledge, especially in the biological and physical sciences.

In my opinion, the case that Schultz makes for a more decentralized, competitive research structure is valid, given the resource base of wealthy industrialized nations and the nature of the technological problems of crop improvement in temperate regions. At the same time, however, I would argue that a strong case can be made for increased cooperation and integration of certain segments of the research structure in the tropics and subtropics—particularly those activities that relate directly to crop improvement research.

First, I believe the economic argument for pursuing genetic solutions to many limiting factors of crop production is strong. Based on recent discussions with program leaders of crop improvement programs at six international centers, I believe there is already widespread acceptance of this approach. Therefore, in terms of resource allocation in international agricultural research, many of the major strategy decisions have already been made and are in the process of being implemented.

Second, because of the accelerated biological dynamics of the tropics, where there is not a natural disease and insect escape mechanism and where scientists are attempting to increase crop production in the center of origin of different food crops, there is little question that the technological limitations to crop improvement in these areas are of a greater magnitude and complexity than in temperate regions.[36] Therefore, when the technological nature of the problem is considered in the context of the technological solutions being pursued, I believe that a key factor—and perhaps the most critical organizational factor—is one of *scale*.

The wheat technology development and transfer system described in this paper cannot function effectively without considerable cooperation between national programs. This international cooperation has the effect of integrating national crop improvement programs into an interdependent international research system. Or, to use Schultz's language, there results a general indivisibility of the research function.[37]

It must be pointed out, however, that a crucial aspect of the question of scale in organizing crop improvement research is the added "spatial dimension" of the international system. It is this dimension that allows individual national programs access to specific ecological resources in other countries—particularly the disease and insect hot spots mentioned earlier. Only through this type of cooperative effort can national program

scientists make available to farmers relatively low-cost and low-risk technology, with a high degree of confidence that their nation's food supply will not be unexpectedly reduced by a virilent disease epidemic or insect outbreak.

The inherent problem of pursuing genetic solutions to limiting factors (such as disease and insects) with an independent, competitive research structure, is that elite germ plasm tends to be highly pervasive and will generally become an important progenitor in any aggressive breeding program. Therefore, if there is a minimum movement of germ plasm between independent programs, there is a very good chance that these programs may end up with the same source(s) of disease/insect resistance in their independently produced varieties.

Rather than having independent programs that are not fully aware of the type and level of their genetic duplication (thus uniformity), it appears that the *spatial organization* of crop improvement research is an *essential factor* in developing disease and insect resistant varieties. Including a well-organized worldwide testing and surveillance sub-system—along with other safeguards, such as multiline varieties, discussed earlier—as an integral part of this overall research system would enable cooperating programs to know exactly where their genetic "soft spots" are and where they are most vulnerable to genetic dysfunction.[38]

Finally, having the international center responsible for bringing new and diverse sources of disease and insect resistance into elite germ plasm, which in turn can be exploited by national programs, seems to be an efficient and safe means of organizing the *limited scientific resources* of less-developed countries into a strong, interdependent research system capable of providing high-yielding genetic technology to farmers in each country of the tropics and subtropics.

While I believe a strong case can be made for an integrated approach to research and development within specific crop improvement programs, this does not preclude a competitive relationship between the different international crop research systems. As the existing international centers expand their research and outreach programs and as new centers become established, the demands of these centers for financial resources will quickly overtake the supply of resources that is forthcoming from donor countries and organizations through the Consultative Group on International Agricultural Research (CGIAR). As these demands increase, there will be increasing competition between centers for these limited resources. While this competition should help to encourage the effective and efficient use of resources, the effect could seriously damage the cooperative relationship between centers and national programs that appears so essential to the effective working of an integrated research system.

At issue is each center's need to establish and maintain its credibility to the CGIAR and to donor nations so that it can maintain its flow of resources, but to do so without jeopardizing its relationship to national program scientists. Center directors (as well as center scientists) must be continually aware of and sensitive to the need to fully share the credit for research and production successes with national program scientists—to both the CGIAR and to government policymakers within individual countries. If centers fully understand, accept, and are committed to developing an integrated international technology development and transfer system, then national programs must be recognized as full and equal partners of that system. There are specific things international centers can do to structure their research activities, so that a fully cooperative relationship with national programs can be maintained. The following observations about the international wheat technology development and transfer system suggests some of these structural considerations.

Concluding Observations on the International Wheat Technology Development and Transfer System

The international wheat technology development and transfer system appears to have developed a very complementary relationship between CIMMYT, as an international center, and national wheat improvement programs with the nature of this relationship being largely defined by the research capacity of each national program. There are several reasons that help explain why such a high level of international cooperation between wheat scientists has occurred.

First, CIMMYT makes available a wide assortment of genetic materials to national programs on a regular basis—materials that can be released directly as national varieties or that can be ploughed back into the crossing program as new progenitors. Through the international network, each cooperating program has almost immediate access to the most outstanding experimental lines coming out of other wheat improvement programs around the world. Therefore, each national program has much to gain by participating in the international system.

Second, the international nursery system allows national programs to test their advanced lines around the world to get an accurate reading of the genetic code of each line. In pursuing genetic solutions to many diseases and insect problems, these ecological resources become invaluable to national programs.

Third, CIMMYT does not name or release varieties, or even register experimental lines; therefore, CIMMYT is not in *competition* with national programs in terms of developing new varieties.[39] National program scientists take full responsibility and get full credit for any variety released in their country. This is an extremely important point as national

research scientists compete with other governmental agencies for scarce resources at the national level. Therefore, CIMMYT, by maintaining a low profile at the national level, does not threaten the credibility of national programs.

Moreover, because the international wheat improvement system is so highly interdependent, no one program or center can legitimately take more than partial credit for the improved varieties eventually released in any country. Therefore, national programs view CIMMYT as performing specific functions that they cannot do themselves—functions that are extremely helpful in increasing their effectiveness and efficiency (i.e., there is a clear division of labor between CIMMYT and national programs).

Finally CIMMYT's role in developing genetic resources for use by national programs avoids a great deal of duplication of effort. As varietal improvement programs attempt to manipulate and combine more and more of these genetic factors, the research task increases in complexity —more or less at geometric proportions. An important reason for this is that many plants, while having certain desirable genes, will also have many undesirable characteristics that come along as excess genetic baggage. Therefore, while incorporating a particular gene for resistance into a new line is generally quite easy, doing so in combination with a good plant type with a dozen or so other desirable characteristics is a process that may take many successive recombinations. This is particularly true when attempting to use more exotic germ plasm (i.e., wild types, land races, etc.). While these unimproved cultivars have new sources (i.e., genes) of resistance that are needed to diversify the germ plasm base of wheat improvement programs, they generally have a preponderance of undesirable genes that can severely reduce the productive capacity of the progeny produced. Thus, one step forward in terms of genetic diversity frequently means ten steps backward in terms of yield potential. This is the primary reason why most varietal improvement programs end up with a relatively narrow genetic base—the introduction of exotic materials can severely erode the productive capacity of the elite material. While these genes can be incorporated with this elite capacity, doing so can be a long process that can consume considerable time and resources—time and resources that may not be available to a small program. However, CIMMYT, as an international center, can perform this function and make these genetic resources available to several dozen national programs quickly and efficiently.

NOTES

1– International Rice Research Institute (IRRI)–Philippines, 1960; International Maize and Wheat Improvement Center (CIMMYT)–Mexico, 1966; International Center for Tropical Agriculture (CIAT)–Colombia, 1968; International Institute for Tropical Agriculture (IITA)–Nigeria, 1968; International Potato Center (CIP)–Peru, 1972; International Crops Research Institute for Semi-Arid Tropics (ICRISAT)–India, 1972; International Laboratory for Research of Animal Diseases (ILRAD)–Kenya, 1973; International Livestock Center for Africa (ILCA)–Ethiopia, 1973; International Board for Plant Genetic Resources (IBPGR)–Rome, 1974; International Center for Agricultural Research in Dry Areas (ICARDA)–Lebanon, 1975. For activities see Nicholas Wade, "International Agricultural Research," *Science* 9(May 1975): 585-9. See also J.G. Crawford, "International agricultural research: an encouraging venture in international collaboration" (Paper delivered at the Conference on Resource Allocation and Productivity in International Agricultural Research, Airlie House, VA., 26-29 January 1975, hereafter cited as Conference on Resource Allocation and Productivity. Papers from this conference will be published by the University of Minnesota Press in 1976 under the title *Resource Allocation and Productivity in National and International Agricultural Research*).

2– For a summary statement on protein quality as a breeding objective at CIMMYT, see Haldore Hanson, "Role of Maize in World Food Needs to 1980" in *Symposium Proceedings*, World-Wide Maize Improvement in the 70's and the Role of CIMMYT (El Batan, Mexico: CIMMYT, April 1974), pp.7-12.

3– The CIMMYT wheat program actually deals directly with four specific cereals: spring bread wheat, durum wheat, triticale, and barley. In addition, CIMMYT works with winter wheats through its spring/winter wheat crossing program. Since this paper is concerned with organizational issues that relate to agricultural research and not with describing each of CIMMYT's programs, primary reference (and examples) will be to the spring wheat program. The other four programs, organized in essentially the same way with necessary modifications, represent organizational replications of the spring wheat program.

4– The location specific genetic materials coming out of state experiment stations in the U.S. are largely a function of the research objectives and resource parameters of these stations, as well as the overall structural characteristics of the land-grant college system. As the land grant system developed, research workers in state experiment stations were expected to produce knowledge and technology directly relevant to local state problems. At the technological level, therefore, lines of communication (and movement of germ plasm) among state programs were not well developed. Second, the fact that individual state breeding programs had limited resources for each crop improvement program (experimental land, scientists, technicians, etc.), program objectives were necessarily limited. Breeders selected problems (limiting factors) economically important in their state which admitted a reasonable chance of finding genetic solution. These factors resulted in relatively small breeding programs being replicated in each state where a particular crop was economically important. Because of the limited number of technological problems addressed in such a program, the trend was to make a limited number of simple crosses (primarily single and back crosses) rather than attempt to manipulate several different factors through more complex crosses. This strategy, becoming part of the conventional wisdom in the U.S., then dictated how research capacity for varietal improvement among most cereals (except maize) should be organized.

5– E.g., plants can be highly sensitive or quite tolerant to differences in nutrient, including moisture, availability (both excess and inadequate); temperature differences (both excess heat and cold temperatures); the amount of light (both length of photoperiod and amount of solar energy); and other factors.

6– For examples of the specific wheat insect and disease problems facing different countries in the tropics and subtropics, see Sanjaya Rajaram, "Protection: Disease and Insect Resistance" in *Proceedings: Wheat, Triticale and Barley Seminar*, ed. R.G. Anderson (El Batan, Mexico: CIMMYT, January 1973), pp.109-13.

7– It takes about seven generations to produce a line that the breeder knows merits varietal status. In addition, at least another two, possibly three, years (generations) are required for regional evaluation trials and seed multiplication. Therefore, it generally requires about nine or ten generations from the time the cross is originally made until farmers first receive commercial feed of a new variety. In small grain breeding programs in the U.S., the process often takes twelve years. Peter R. Jennings to Swanson, 9 June 1975.

8– Some important environmental differences between the winter nursery at the CIANO Experiment Station in the state of Sonora in Northwestern Mexico and the summer nursery in Toluca are: latitude (28°N vs. 18°N)–which affects day length, an important factor in selecting lines/varieties that are photoperiod insensitive; amount of precipitation (Sonora is a very dry, irrigated area; Toluca is wet and damp with daily afternoon rains); easonal temperature patterns (Sonora is hot and dry during the latter half of the growing season when foliar diseases become a serious problem; Toluca is cool and damp–conditions highly conducive to disease epidemics); differences in elevation (the CIANO and Toluca stations are 100 feet and 8500 feet above sea level, respectively); amount of solar energy during the growing season, soil types, etc.

9– Norman E. Borlaug, "CIMMYT's Past Role, Present Position and Future Challenges," *Wheat, Triticale and Barley Seminar*, p.93. An absorbing account of Borlaug's struggle to implement his unorthodox approach is told in Lennard Bickel's biography, *Facing Starvation: Norman Borlaug and the Fight Against Hunger* (New York: Readers Digest Press, 1974), pp.136-7,145-84.

10– Borlaug, "CIMMYT's Role," p.93.

11– Ibid.

12– Ibid., p.92.

13– In the Bread Wheat Program, approximately 3,000-5,000 crosses are made each season (two seasons/year), with about 50 percent of these genetic combinations being double crosses. Just the mechanics of making such a large number of crosses is a major undertaking: to make one double cross requires the emasculation and pollination of eight to ten heads (spikes). In addition, all of the crossing work must be accomplished during the flowering period, which lasts only four to six weeks per season (the flowering period is actually extended to four to six weeks through the use of staggered plantings of the crossing block). In addition to the Bread Wheat Program, each of the other CIMMYT programs (Durums, Triticale, Barley, and the Spring Wheat-Winter Wheat Crossing Program) make 1,500-2,000 crosses per season.

14– See Burton E. Swanson, "Impact of the international system on national research capacity: the IRRI and CIMMYT training programs" (Conference on Resource Allocation and Productivity); idem, "Training Agricultural Research and Extension Workers from Less Developed Countries," (PhD diss., University of Wisconsin, 1974);

and CIMMYT's annual reports and the *Wheat, Triticale and Barley Seminar.*

15– An international nursery, such as the International Spring Wheat Yield Nursery (ISWYN), consists of a group of identical experiments grown in many different locations. In the case of ISWYN, each experiment or individual nursery, composed of fifty different varieties (or experimental lines in the case of other nurseries), is replicated three times. After harvesting the winter nursery material in April of each year, CIMMYT prepares individual seed packets that are sent to each international nursery during July and August. To facilitate the planting of these experiments by cooperators and to minimize error, seed packets are prepared for each row, of each variety, for each replication, of each experiment. To give some idea of the mechanics of preparing these nurseries, ISWYN requires the labeling, filling and sealing of 120,934 individual seed packets, which in turn must be sorted and organized into the 137 individual nurseries or experiments, boxed and air freighted to nearly 137 different experiment stations around the world. In addition, all of this work must be done in a six- to eight-week period so the nurseries are received by September or in time for fall planting. ISWYN, although the largest, is only one of CIMMYT's twenty-four annual international nursery programs.

16– Actually there are two F_2 Nurseries sent out each year for the bread wheat and triticale programs–one nursery that contains materials well suited for irrigated conditions and another with materials appropriate for natural rainfed conditions. Each of these nurseries is sent to thirty different locations within the major spring wheat growing regions of the tropics and subtropics, as well as to certain unique environments that are particularly useful for screening germ plasm for specific sources of disease/insect resistance.

17– In the case of the bread wheat program, there are two main screening nurseries: (1) the International Bread Wheat Screening Nursery (IBWSN), a general purpose screening nursery designed to evaluate advanced lines for level of adaptation, disease resistance, etc.; (2) the International Septoria Nursery (ISEPTON), a special purpose screening nursery designed to screen material for specific types of disease resistance, particularly septoria resistance.

18– "Instructions for the Management of International Yield Nurseries," (El Batan, Mexico: CIMMYT, March 1971), p.1.

19–"Hot spots" are specific sites in a region where disease epidemics regularly occur in a severe form. Often in these locations new races of a disease are first detected and present a threat to existing varieties; from E.E. Saari, "Wheat Rusts in West Asia and North Africa and Possibilities for Development of Resistant Varieties Through International Cooperation" in *Proceedings of the European and Mediterranean Cereal Rusts Conference* (Prague, Czechoslovakia, 1972), pp.213-6.

20– Ibid., p.216.

21– Saari points out that "normally, when a new race makes its appearance there is an expected time lag of two or more years before the race becomes a major problem. There are cases, however, when the crop can be threatened in the first year." (Ibid., p.214).

22– The concept of multilineal varieties is not new; Borlaug had developed and reported on the methodology of developing multilineal varieties in 1958. See Norman E. Borlaug, "The use of multilineal or composite varieties to control airborne epidemic diseases of self-pollinated crop plants" in *Proceedings: The First International Wheat Symposium* (Winnipeg, 1958), pp.12-27. In 1962 when the first semi-dwarf

variety was released in Mexico, Borlaug had just completed producing a multiline for Mexico; it was never released, however, due to the greatly increased production potential of the dwarf varieties. A multiline was developed by J.W. Gibler and colleagues for stripe rust resistance in Colombia, and it is still being grown successfully there. See Norman E. Borlaug, "Basic Concepts Which Influence the Choice of Methods for Use in Breeding for Disease Resistance in Cross-Pollinated and Self-Pollinated Crop Plant from *Breeding Pest-Resistant Trees*, Proceedings of a NATO and NSF Symposium held at the Pennsylvania State University, 1964, p.332.

23– Borlaug, "The use of multilineal or composite varieties," p.15.

24– Siete Cerros and other sister lines selected from cross number 8156 have been released as national varieties in several dozen countries and are presently being grown on millions of hectares. In India and Pakistan, where this variety is grown extensively, it is known as Kalyansona and Mexipak, respectively. To avoid the confusion of using varietal names, whenever further reference is made to varieties derived from this cross, the cross number "8156" will be used.

25– *CIMMYT Review 1974* (El Batan, Mexico: CIMMYT, 1974), p.3.

26– Ibid.

27– "Scientists estimate it would take any one collaborator fifty years of repeated trials in his own station to obtain data as comprehensive as that from one year's trial on a world wide basis", see Haldore Hanson, "Articulation of the international and national systems: the CIMMYT outreach program" (Paper presented at the Conference on Resource Allocation and Productivity, 26-29 January 1975).

28– Gebrand Kingma, "Regional Evaluation of Germplasm" in *Wheat, Triticale and Barley Seminar*, p.290.

29– No attempt is made in this paper to develop such a logical structure. Although many have attempted to develop decision models to facilitate this process, the objective here is to raise the issue of research alternatives from the perspective of the innovative approach to research organization that has been institutionalized through the international wheat network.

30– Herbicides would generally fall into this group. Although weeds can sometimes be effectively controlled through proper cultural practices (mechanical or hand weeding, or crop rotations), in other cases herbicides may be the most effective method particularly if used in combination with appropriate cultural practices.

31– Dana G. Dalrymple, "Impact of the international institutes on crop production" (Conference on Resource Allocation and Productivity, January 1974), p.22.

32– *Genetic Vulnerability of Major Crops* (Washington, D.C.: National Academy of Sciences, 1972), pp.136-7.

33– The International Board for Plant Genetic Resources (IBPGR) was formally approved in 1974 by the Consultative Group on International Agricultural Research as the international center responsible for coordinating and facilitating the collection and storage of germ plasm for all major food crops.

34– Although large wheat-growing areas were infrequently destroyed by disease and insects, traditional cultivars were never free of disease and insect problems. These cultivars, while having certain genes for disease resistance, were at the same time quite susceptible to other diseases and insects. Thus, the combination of a large assortment of genetically diverse cultivars being grown in any one area and the low planting density and fertility of traditional farming systems generally resulted in avoiding or slowing widespread disease epidemics.

35– Theodore W. Schultz, "The uneven prospects for gains from agricultural research related to economic policy" (Paper presented for discussion at the Conference on Resource Allocation and Productivity, 26-29 January 1975), pp.5-6.

36– Peter Jennings has pointed out some of the difficulties associated with the improvement of crops within their centers of origin and has offered possible explanations for this biological phenomenon. See Peter R. Jennings, "Rice Breeding and World Food Production," *Science* 186(1974):1087.

37– This is my conclusion, not Schultz's; in theory, he would argue the opposite. See Schultz, "Uneven prospects," p.5.

38– If such a system had been in place for maize, the Southern Corn Blight epidemic of 1970 could have been predicted as early as 1962. See *Genetic Vulnerability of Major Crops*, pp.12-13.

39– This is not to say that CIMMYT does not develop advanced lines that could be directly named and released as varieties by the national program. Some national programs do not have the resource capacity at the present time to operate a fully functioning wheat improvement program; therefore, until wheat technicians and scientists can be trained, the program may be limited to testing advanced lines from CIMMYT and varieties from other national programs. While weak national programs can exploit the international system to meet their short run technology needs, the overall strength of the international system is dependent on strong contributing national programs. It is in the interest of CIMMYT and other national programs, then, to encourage and assist all wheat growing countries to build a national research capacity for wheat improvement.

2

Institution Building: Impact of the International System on National Research Capacity– The IRRI and CIMMYT Training Programs

This paper was written as part of a research project on international technology transfer systems being supported by the Program of Advanced Studies in Institution Building and Technical Assistance Methodology (PASITAM) of the Midwest Universities Consortium for International Activities (MUCIA) through a 211 (d) grant from the U.S. Agency for International Development. The original research, on which this paper is based, was supported by grants from the International Rice Research Institute, the International Maize and Wheat Improvement Center and the Land Tenure Center, University of Wisconsin.

The development and international transfer of improved agricultural technology (particularly the high yielding varieties of rice and wheat) made a dramatic impact on agricultural production in many parts of the tropics and subtropics during the late sixties and early seventies. These production successes were largely spearheaded by the research work carried out at two international research and training centers: the International Rice Research Institute (IRRI) in the Philippines and the International Maize and Wheat Improvement Center (CIMMYT) in Mexico. Donor nations are now looking increasingly to international research centers as an effective means of helping less-developed nations solve many of their critical technological problems in agriculture. However, as these poor nations shift to agricultural production systems based on modern science and technology, it is imperative that they build their own effective research institutions to meet long-term technological needs. This Design Study examines the impact of the different training strategies being employed by IRRI and CIMMYT in helping to build this national research capacity.

Transferring Research Capacity

It is necessary first to clarify how research capacity is being viewed in this paper. Ruttan and Hayami considered the problem of international technology transfer and differentiated the process into three phases: (1) material transfer, (2) design transfer, and (3) capacity transfer.[1]

The international transfer of wheat and rice technology during the late sixties was largely in the "material transfer" stage, as represented by the substantial international seed importations carried out by many less-developed countries (LDCs) during that period.[2] At the same time, "design transfer" was occurring as national research institutions began to receive new, high yielding experimental lines and varieties of wheat and rice that were, in turn, tested and in some cases multiplied and released to agricultural producers.[3] In addition, the third phase of the technology transfer process, or "capacity transfer," was receiving attention by these international research centers through their training and outreach programs. However, building a national research infrastructure (i.e., capacity transfer) that can produce scientific knowledge and improved agricultural technology—and adapt it to local ecological, resource, and institutional

conditions—has been found to be a slow, difficult, and complex task.[4]

To better understand the institution-building task associated with capacity transfer, it is useful to differentiate research capacity into its two primary functional components: science and technology. During a parallel discussion on technology transfer in space science, Price developed some generalized definitions that are useful to this discussion: science is taken to be those research activities that result in scientific papers being written and published, and technology is ". . . that research where the main product is not a paper, but instead a machine, a drug, a product, or a process of some sort."[5]

The point in making these rather sharp distinctions between science and technology is not to artificially separate one part of this functional process from the other or to suggest that research workers should work in only one area or the other. Many agricultural research workers function in both knowledge generating (science) and technology developing roles and move easily and effectively between them. But in organizing national research institutions, there has been a tendency to overlook the technology development function.[6] Therefore, it is important to know which hat a research worker has on at any one time so we can better understand the thrust of his overall research program and how it contributes to national research capacity.

Both scientists and biological architects who develop improved agricultural technology use many common research tools, but differences in research objectives and output demand substantially different types of cognitive behavior.[7] In his pursuit of new knowledge, the scientist largely engages in analytical research. Analysis, as a cognitive skill, ". . . emphasizes the breakdown of the material into its constituent parts and detection of the relationships of the parts and of the way they are organized."[8] The scientist, in turn, uses different research tools as a means of verifying specific hypotheses that result from his analytical inquiry.

The biological architect largely engages in creative thinking, and by trying new materials and methods in different combinations and amounts, attempts to develop new technology or technological components that will better achieve a production objective (such as increased output, reduced risk, or reduced costs). In terms of cognitive behavior, this creative thinking is characterized as synthesis.[9] In synthesis, the research worker ". . . must draw upon elements from many sources and put these together into a structure or pattern not clearly there before. His efforts should yield a product."[10] The biological architect, in turn, uses research tools to test or evaluate these new technological combinations or components that he has created to determine their production potential.[11] Perhaps it is because the biological architect must spend so much of his time evaluating his new technological combinations and components—through the

use of relatively simple and routine research trials and tests—that the importance of his intellectual or cognitive contribution has been overlooked or minimized.

This framework has been applied to research capacity as it relates to crop technology. In the past it was the plant breeder who generally developed improved genetic technology by manipulating different genetic factors to produce improved varieties, and the production agronomist who developed and refined improved production recommendations for farmers' use by manipulating new and/or existing factors of production (such as improved varieties, fertilizers, pesticides, cultural practices, etc.) in new or different ways. In more recent years, as agricultural technology has become increasingly sophisticated and complex, the trend has been to form interdisciplinary research teams who work together in manipulating and integrating different chemical, biological, or mechanical factors of production in building superior agricultural technology.[12]

Before moving into a discussion of the training strategies being used by IRRI and CIMMYT, and the impact these strategies have on research worker behavior and research capacity, one other institutional factor should be noted that appears important to the question of science and technology and the process of building national research capacity. This factor is the predominant reward system within agricultural research that appears to be having an important and continuing influence on research worker behavior and national research capacity.

Reward Systems In Agricultural Research

One explanation as to why research institutions in many LDCs have been ineffective in producing improved agricultural technology is that research workers have tended to concentrate on more theoretical research problems rather than working to solve farmer production problems.[13] An hypothesis that is logically consistent with and will explain this behavior is that agriculture research workers in LDCs have adopted or internalized the normative structure of the public research establishment (the university and the corresponding academic/scientific professions) of industrially developed countries.[14] The following factors serve to support and elaborate on this hypothesis.

First, most research workers in the LDCs with advanced degrees received their academic training in foreign universities, primarily in the United States and Europe. Many of these research workers may have been influenced (socialized) by the "publish or perish" reward system that is common to large, research-oriented colleges of agriculture in the United States. Furthermore, advanced research degrees generally require an "original" research inquiry that contributes to the body of knowledge in the respective discipline; therefore, these research projects are frequently

highly specialized and theoretical in nature. Both of these factors could tend to orient young research workers toward more theoretical, scientific inquiries.

Second, in the United States the knowledge generating research function (science) is primarily carried on within the public sector (universities), whereas the majority of technology developing research is carried out in the private sector (industry).[15] Although research workers who conduct technology development types of research have much less opportunity to publish in scientific journals and to gain professional recognition from their colleagues, salary schedules in private industry have traditionally been higher than in public research institutions. Thus, in the overall agricultural research system of the United States, there is, to some extent, a trade-off between professional and economic rewards. Research workers, depending on their interests, abilities, and what they consider to be important, have alternative career patterns they can pursue.

On the other hand, in LDCs, most (if not all) of the national agricultural research capability is located within the public sector, generally within a ministry of agriculture or a university. Therefore, the opportunity for research workers to select between economic and professional rewards is quite limited. Agricultural research workers receive salaries according to the bureaucratic procedures and criteria being followed by the research institution, not according to the type of research carried on. Therefore, there is no potential within the research institution itself for inducing research workers (through economic rewards) to pursue career patterns oriented toward technology development research objectives.

Thus, in the absence of an alternative reward system, it appears inevitable that professional rewards will take on increasing importance in influencing the types of research activities being undertaken by research workers in LDCs—particularly given the professional recognition associated with publishing in a prestigious scientific journal with an international clientele.

Third, in most cultures agricultural work is considered a low-status occupation; therefore, there are no positive social rewards (essentially only negative ones) that would encourage a highly trained research worker to work on practical problems—the results of which would only be of direct importance to a peasant or cultivator and which would not result in any significant professional recognition. Even if individual scientists were motivated to do this type of research, the research organization has no effective way to formally reward these successes.

Finally, the spirit of cooperation is frequently missing from national research institutions, and scientists may tend to think in terms of achieving *personal* rather than *institutional* credit. To develop improved

agricultural technology requires considerable interdisciplinary cooperation, but in this case the credit accrues to the team, not to the individual. If this team credit is usurped by the research director or the team leader rather than being shared by the team members, individual research workers will not be encouraged to work together on future endeavors.

Given all these factors, it is apparent why many agricultural research workers in LDCs prefer to concentrate on individual research projects aimed at generating new knowledge where they can directly receive professional recognition and rewards. In most national research systems in LDCs, there are too few positive rewards and incentives to encourage research workers to carry out technology development types of research. It is no wonder, as Singer suggests, that the meager research resources of the LDCs (estimated at 2 percent of the world's research and development expenditure) are frequently misdirected to research problems that are more relevant and useful to the rich nations.[16]

The next section will briefly describe the training strategies being employed by IRRI and CIMMYT in helping Third World nations achieve capacity transfer.[17]

The CIMMYT Wheat Training Program

The wheat training program in Mexico is an integral part of CIMMYT's overall outreach program to make improved wheat technology available to farmers in all major wheat growing regions of the Third World.[18] Strong national programs are an essential part of this international wheat improvement strategy, both in the process of developing and disseminating improved wheat technology, and also in dealing with the technological spin-off problems (primarily disease epidemics) that are a potential threat to the precarious food balance in population dense nations.

When the wheat revolution began to spread beyond Mexico in the early sixties—particularly to South Asia and the Middle East—national wheat improvement programs in these areas were generally weak and poorly organized. CIMMYT used training programs to upgrade the technical skills of research personnel in an attempt to build strong, *independently functioning* national programs that are *interdependent* with other national programs and with CIMMYT for new genetic resources and technical information.

At all levels, CIMMYT stresses a "team" or integrated approach to wheat improvement. At the program level, the emphasis is on interdisciplinary teams that are well integrated in function. At the international level, the national programs and CIMMYT work together as part of an overall international wheat team to systematically share superior germ plasm and new varieties as soon as they are developed, as well as technical information on these genetic materials.

The major thrust of the wheat training program is directed toward middle-level research workers. The program revolves around three main educational objectives: (1) to impart to trainees the research skills and knowledge needed to run a wheat improvement program, (2) to encourage and develop the trainee's ability to create (synthesize) new forms of wheat technology, and (3) to foster specific types of attitudinal change among trainees.

Technical Research Skills

The first half of the regular eight- to nine-month training program in wheat improvement deals primarily with the mechanics of running an efficient, well-organized research program. Trainees learn all the essential research skills and techniques needed to manipulate and evaluate new forms of wheat technology. This training is accomplished through "on-the-job training."[19] Trainees follow the CIMMYT wheat program through each stage of the growing season (and the varietal development process) with each task or operation first being discussed in the classroom and demonstrated in the field. After the trainee has the opportunity to practice the skill and is "checked out" to insure that he is reasonably proficient, he proceeds to help carry out each research task or operation within the ongoing CIMMYT research program.

Technical Research Ability: Synthesis

Once the trainee learns the "nuts and bolts" of operating a research program, he can give increasing emphasis to the content or the materials passing through the research program. For example, the job of the breeding team is to create (synthesize) new genetic lines and varieties by combining and recombining diverse types of germ plasm. To be effective and efficient in developing improved high yielding varieties, the trainee must learn and become increasingly familiar with the various genetic characteristics and materials he is attempting to manipulate. For example, an experienced biological architect in the CIMMYT wheat program can walk up to an advanced generation plot—there are hundreds of such plots—and from visual inspection alone give the approximate pedigree of the line (from several hundred potential parent lines and varieties), give several reasons why the cross was made, and evaluate the line for those visual characteristics. By working side-by-side with experienced biological architects in the CIMMYT wheat program—and by asking and being asked the question: "why?"—trainees soon begin to develop an ability and an insight into the creative process of genetic engineering.

Attitudinal Objectives[20]

There is a common expression used in the CIMMYT wheat training programs: "The plants are talking to you, but you have to use your *eyes*

to hear what they are saying." In other words, wheat plants being grown under a variety of different conditions (favorable and hostile environments) respond differently to those conditions. A good observer is able to detect how plants react to each of these different environmental conditions and, using these data, to select those genetic lines with the greatest potential.

CIMMYT seems to use a similar selection technique for its trainees. For example, CIMMYT has been criticized by some visitors to the training programs in Mexico for "using" trainees for such routine tasks as inoculating segregating populations with rust spores. This is a job that CIMMYT needs to have done; it requires about ten days to two weeks of hard, back-breaking work, wading through muddy plots (many times in the rain), and injecting two tillers of each plant with a syringe full of disease inoculum.

After the first morning of this activity, there is no additional technical training value to be accomplished; however, what the CIMMYT staff learns about the "trainee population" during these two weeks is very important. Some trainees can disguise their displeasure for this type of work for a morning or two; but after a week or ten days, trainees are clearly segregating in their "reaction to hard field work." Some trainees may do the work while CIMMYT staff members are nearby, but then relax under a tree when they leave (representing an attitude of "compliance," given this type of behavior). Still others may call in sick for a few days to avoid the work (noncompliance), while others are out in the plots getting the work done. CIMMYT particularly wants to identify this last group of trainees who either "identify with," or have "internalized" positive attitudes toward this type of research.[21] CIMMYT believes it is this last group that will begin to make up the hard core of working scientists within the national wheat improvement program.

The training program in Mexico is viewed by the CIMMYT wheat team as only the first step in a long-term process of building effective wheat research workers and national wheat improvement teams. Because of this long-run perspective, the training program becomes both a manpower development tool for training skilled research technicians and an "early generation" selection tool for identifying potential "biological architects." Trainees are observed in Mexico and again back home on the job. Those who excel in attitude, outlook, intellectual ability, and technical know-how—in both working environments—are identified as prime candidates for academic fellowships. By giving these individuals additional educational opportunities, it is hoped they will become key biological architects in their own national wheat improvement programs in years to come.

Results[22]

This training strategy results in approximately 82 percent of former trainees still actively engaged in wheat research and production activities, with another 8 percent being indirectly or partially involved in wheat improvement work. Only about 10 percent of former CIMMYT Wheat trainees are no longer working in wheat improvement programs.

As shown in Table 1, the work performance of those former participants still actively engaged in wheat research and production programs (105 trainees of 130 total respondents) is high, as measured by the number of research experiments, replicated field trials, genetic crosses, and production plots completed. Furthermore, it emphasizes technology development as opposed to experimental research—particularly in the area of genetic technology.[23] It appears that the work behavior of CIMMYT trainees, once back home on the job, is quite consistent with CIMMYT's training objectives.

CIMMYT appears to be very effective in producing research workers who can develop improved genetic technology, but this success has not yet been realized in producing the other half of the wheat improvement team which can develop the complementary package of practices. This

TABLE 1 AVERAGE NUMBER OF RESEARCH AND PRODUCTION ACTIVITIES COMPLETED BY CIMMYT WHEAT TRAINEES ACTIVE IN WHEAT IMPROVEMENT PROGRAMS, 1972

Type of Activity	Number & Percent of Trainees Conducting Each Activity (N = 105) N	%	Mean Level per Trainee (N = 105)
A. Laboratory or Greenhouse Experiments	13	12.4%	1.37
B. On-Station Field Experiments	56	53.3%	5.62
C. Genetic Crosses	56	53.3%	227.10
D. On-Station Replicated Applied Research Trials	65	61.9%	7.24
E. On-Farm Replicated Applied Research Trials	44	41.9%	4.74
F. On-Farm High Yielding Production Plots	37	35.2%	3.71

weakness probably stems from the fact that the CIMMYT research program concentrates on widely adapted genetic technology, with production technology being viewed as a location-specific problem. The fact remains that wheat production agronomists are sorely needed in most national programs to develop appropriate production recommendations that will enable farmers to fully and economically exploit the production potential of the superior varieties that are being developed.

The IRRI Training Programs

The training programs at IRRI in the Philippines are an important part of the institute's international activities. The research and rice production training programs make up the major thrust of the IRRI's training activities. Their impact on national research capacity is described and analyzed here.

IRRI Research Training Program

The IRRI research training program is an integral part of the institute's ongoing research activities and its international cooperative programs. The institute is committed to strengthening national rice research programs, and IRRI's leaders see the research training program as a resource that national programs can use in upgrading the technical proficiency of their staff members.

IRRI's research training approach centers around the research project. Trainees are expected to focus on a serious production problem in their home country and to carry out one or more research projects that will generate new knowledge and possible solutions.

Research trainees work closely with a senior IRRI scientist and frequently carry out research projects that are an integral part of the advisor's overall research. In some cases, these research efforts result in jointly authored research papers that report important research findings and contribute to the growing body of knowledge about rice production in the tropics.

Although some advanced research trainees come to IRRI to learn specific research skills and techniques, or to conduct research projects that are beyond the scope of their national program (because of the lack of adequate scientific equipment), the major objective of the project approach is to provide participants with a solid research experience—teaching them each step involved in planning, designing, executing, and reporting on a research project. At each step of the way, trainees learn by doing. In terms of educational objectives, the major focus of the project approach is on *analysis,* using research as a tool to generate new knowledge about production problems and their possible solutions, and/or to test suspected relationships between production factors. The knowledge

generated from these projects may be used in the development of improved rice technology that will increase rice production in the tropics.

There are two exceptions to the project training approach. (1) Nondegree trainees in varietal improvement do not conduct research projects but work largely as research assistants in IRRI's ongoing rice breeding program. Again these trainees learn by actually carrying out each task involved in a varietal improvement program and, at the same time, become familiar with the germ plasm currently being used in the IRRI program. (2) Agricultural engineering technicicans are given short-term training so they can evaluate and demonstrate IRRI-developed machinery in their own countries under local conditions.

Research trainees work in a disciplinary department at IRRI, but the Saturday Seminar has become the institutional mechanism by which both trainees and staff learn recent research findings in other departments. By sharing research results with staff members in other disciplines, scientists can frequently gain new insights and perspectives on important rice production problems which may lead to cooperative efforts between departments. When these multidisciplinary team efforts occur, they demonstrate to trainees how an effective research institute can organize its scientific resources in different ways to solve production problems.

The institute is conveniently located next to the University of the Philippines College of Agriculture, and about one-third of IRRI's research trainees combine an M.S. degree program at the college with research training at the institute. IRRI scientists believe that combining a degree program with a solid research experience enables trainees to perform more effectively after returning home; it also gives them the necessary educational credentials to move into leadership positions in their respective national programs. In general, IRRI research trainees are a highly educated group. At the time the participant follow-up survey was taken in 1973, 41 percent of the research trainees had M.S. degrees, 43 percent had either received or were working toward Ph.D. degrees, while only 16 percent of the group were still at the B.S. degree level.

Results

Former IRRI research trainees reacted in very positive terms when assessing their training experience at the institute. IRRI selected both research and teaching personnel from national institutions, and more than 90 percent of all research trainees indicated that the training had been of use to them since returning home. In addition, approximately 71 percent of former trainees (who were working when the survey was taken) were still actively involved in rice research or production programs.

In considering the main educational objective associated with the proj-

ect training approach (i.e., analysis), it seemed consistent to expect trainees to continue working in experimental (analytical) research after returning home. To verify this hypothesis, the work behavior of former trainees was examined to determine which types of research were being emphasized (see Table 2). As expected, more knowledge-generating types of research (field, laboratory, and greenhouse experiments) were being carried out than research activities associated with the direct development of rice technology (agronomic field trials and genetic crosses).[24]

Another factor considered in determining the type of research being emphasized by IRRI research trainees was the form of research output, particularly since research papers are the primary output from knowledge-generating types of research. First, it was found that 106 research trainees had been able to publish (or present) a total of 187 research papers based on the research work they completed while at IRRI. Second, trainees were asked if they had been able to publish or present any research papers based on research conducted since returning home. In the two-year period (1971-72), 130 former research trainees produced 370 techincal papers. Since only 154 trainees indicated they were actively

TABLE 2 AVERAGE NUMBER OF RESEARCH AND PRODUCTION ACTIVITIES COMPLETED BY IRRI RESEARCH TRAINEES ACTIVE IN RICE RESEARCH AND PRODUCTION PROGRAMS, 1972

Type of Activity	Number & Percent of Trainees Conducting Each Activity (N = 154) N	%	Mean Level per Trainee (N = 154)
A. Laboratory or Greenhouse Experiments	65	42.2%	1.61
B. On-Station Field Experiments	85	55.2%	3.48
C. Genetic Crosses	46	29.9%	19.90
D. On-Station Replicated Applied Research Trials	57	37.0%	1.55
E. On-Farm Replicated Applied Research Trials	38	24.7%	1.17
F. On-Farm High Yielding Production Plots	39	25.3%	1.46

engaged in rice research and production programs when the survey was taken, and only another five percent of former trainees were working in other crop research programs, it was concluded that knowledge-generating types of experimental research are heavily dominating the work behavior of former IRRI research trainees.[25]

IRRI Rice Production Training Program

The IRRI rice production training program was established in 1964 in response to a growing need for competent rice extension specialists who could: (1) diagnose serious rice problems; (2) grow a rice crop using the high yielding rice technology being developed by IRRI; and (3) communicate these skills, methods, and techniques to rice producers through efficient extension methods.[26] Later, as it became apparent that IRRI could not begin to train all the rice production specialists needed by national programs, its focus was shifted to "training the trainers" of rice production specialists. The logic of this approach was to create a multiplier effect within each national program whereby large numbers of field extension workers could be trained to use and demonstrate the new improved rice technology.

The rice production training program is a six-month course conducted during the wet rice growing season beginning in early June each year. The behavioral objectives of the present program, in addition to the three original objectives mentioned above, are: (1) for trainees to be able to conduct applied research trials to modify the modern rice technology (package of practices) to fit local growing conditions in their home countries and/or regions; and (2) to be able to organize and teach in-service rice production training programs for extension personnel in their home country programs.

To achieve these behavioral objectives, trainees spend about half of their time in the classroom gaining up-to-date knowledge about modern rice production in the tropics, and the other half in the field practicing this knowledge, acquiring new skills in rice production, and communicating this technical information. One of the most outstanding features of the training methodology is that the classroom instruction, which imparts extensive technical information about all aspects of modern rice production, is carefully organized around and integrated with the practical field training. What is learned in the classroom is directly relevant to the problems faced in the field. Second, the course is highly efficient in that it is completely organized before the trainees arrive (lectures, field practice, field trips, etc. are all scheduled), so that each hour is accounted for in terms of the instructor responsible and the behavioral objectives to be achieved. In addition, most technical lectures, field practice, exercises, etc. are reproduced and made available to trainees so each has a rice

production training manual and a complete set of technical lecture notes to use both during the training program and after returning home.

Results

Questionnaire responses show that nearly every former rice production trainee was satisfied with the overall training, and approximately 90 percent of the trainees indicated they were making some or full use of the training. The number of respondents who indicated they were in job assignments where they could make direct use of their training was less satisfactory. Although 81 percent of the respondents indicated that they were working in rice production programs, only about 42 percent were in positions directly associated with the stated behavioral objectives of the program.

In regard to the primary behavioral objective of the program, it was found that only nineteen respondents (12.8 percent) were working as full-time rice production trainers. Although two-thirds of the respondents indicated that they had worked, at one time or another, in organized rice production training programs, in most cases these duties were in addition to their regular job assignments. In addition to the nineteen respondents, it was found that another thirty-six respondents (24.3 percent) were working as rice extension specialists, and eight trainees (5.4 percent) were involved with rice production programs as general agricultural extension workers. In all of these cases, trainees were considered to be directly involved in assignments associated with the behavioral objectives of the program.

Approximately one-fourth of the rice production trainees are research workers in their home countries. In fact, nearly 10 percent of former rice production trainees are currently working in rice breeding. How or why these trainees were selected for this program, rather than the research training program in varietal improvement, was not established. Although rice production training is probably quite useful and appropriate for many rice research workers, their selection appears inconsistent with the stated objectives of the rice production training program.

The remaining trainees have moved into other types of job assignments since returning home (many in administrative positions); but some are still associated with rice production work. Eleven participants were attending a university when the survey was taken, and probably many of these will eventually return to rice production activities.

Effect of Different Training Strategies on Work Behavior

It was established in this study that the work behavior of trainees in each of the three groups differed widely following their return to national job assignments. At the same time, however, there were great

similarities in the general background characteristics of the trainees. Therefore, the purpose of this section is to develop an adequate explanation for these differences in work behavior by examining the major independent and intervening variables.

No attempt is made to characterize one training program as being better or worse than another; rather, the objective is to learn from the strengths and weaknesses of each training strategy. All training programs included in this study are generally well organized and well received by former trainees. To establish this point, two major trainee assessment variables are contrasted in Table 3.

TABLE 3 GENERAL TRAINEE ASSESSMENT OF EACH TRAINING PROGRAM

Type of Training Assessment	CIMMYT Wheat Trainees	IRRI Research Trainees	IRRI Rice Production Trainees
Trainee's overall satisfaction with the training program:			
very satisfied	65.4%	55.6%	64.0%
somewhat satisfied	32.3%	35.5%	34.7%
neutral or dissatisfied	2.3%	8.9%	1.3%
total	100.0%	100.0%	100.0%
Trainee's use of training in his present job assignment:			
full use of training	46.4%	39.4%	48.6%
some use of training	47.2%	55.5%	42.1%
little or no use of training	6.4%	5.1%	9.3%
total	100.0%	100.0%	100.0%

There is little or no difference as to how individual trainees have perceived the use of their training, as well as how they have assessed their training experience at each center. Therefore, from the viewpoint of the individual trainee, each training program has been effective in achieving its specified training objectives.

As mentioned, however, trainees are performing differently in their present job assignments. Data on individual trainee work behavior are presented in Figures 1 and 2 for the three training groups, based on the subgroups of trainees who actually indicated direct involvement (when the survey was taken) in a wheat improvement or rice research and production programs. The percentage of trainees indicating such direct involvement for each training group is as follows: CIMMYT wheat trainees,

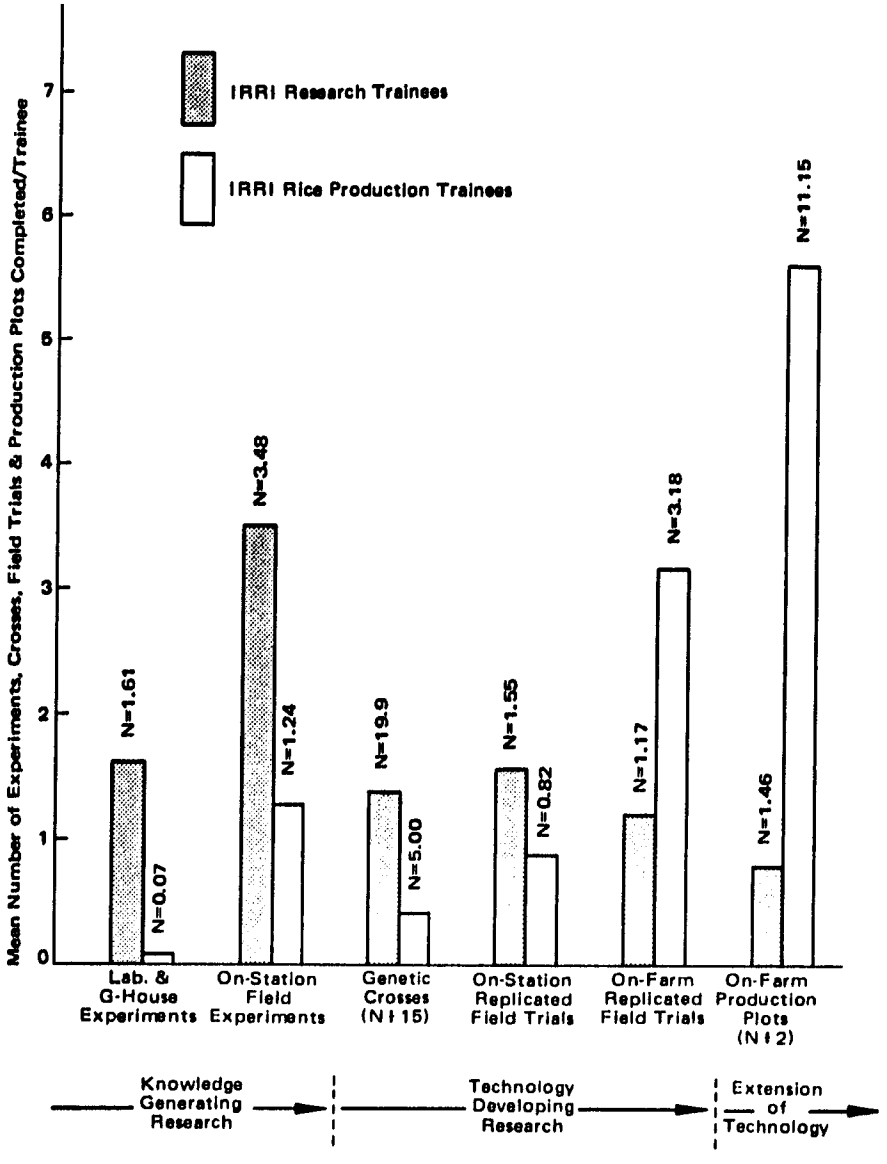


FIGURE 2 WORK BEHAVIORAL PATTERNS OF FORMER IRRI RESEARCH AND PRODUCTION TRAINEES

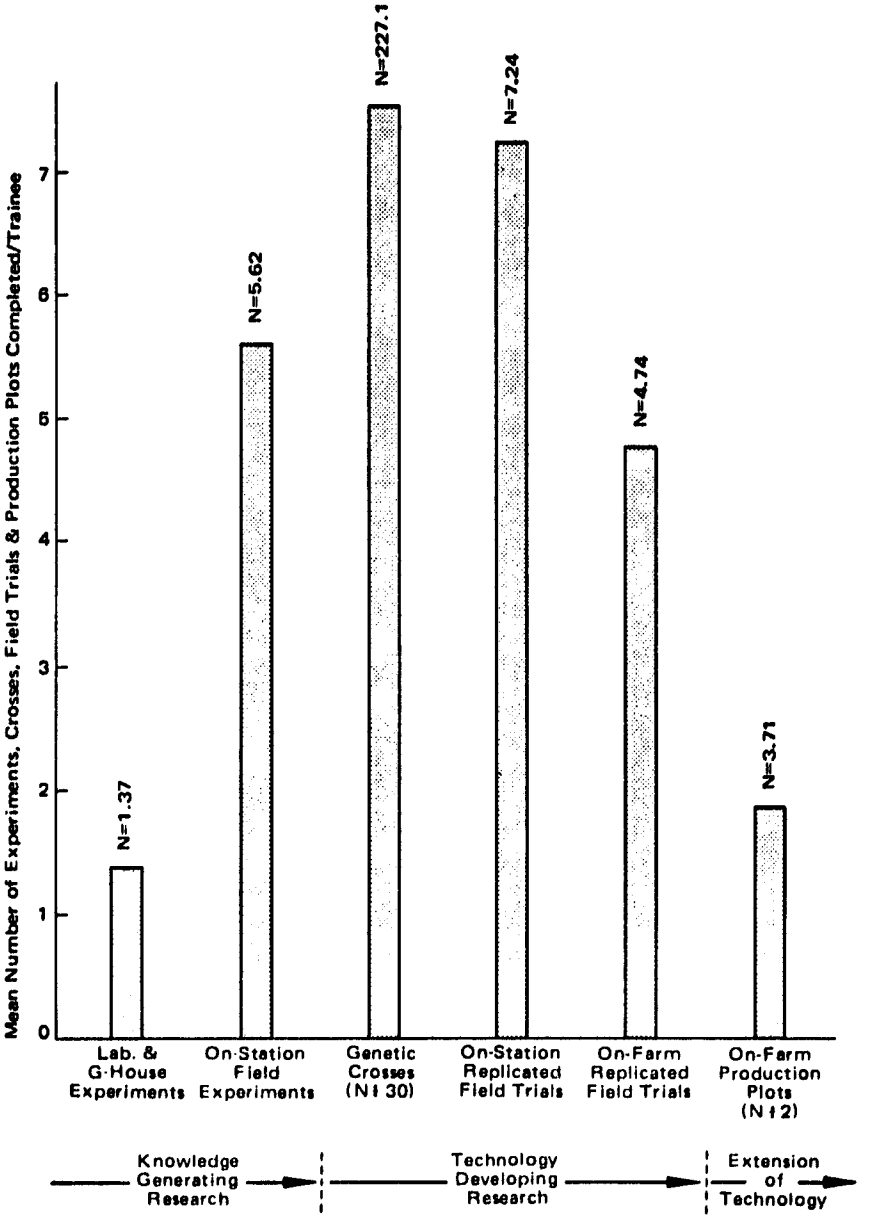
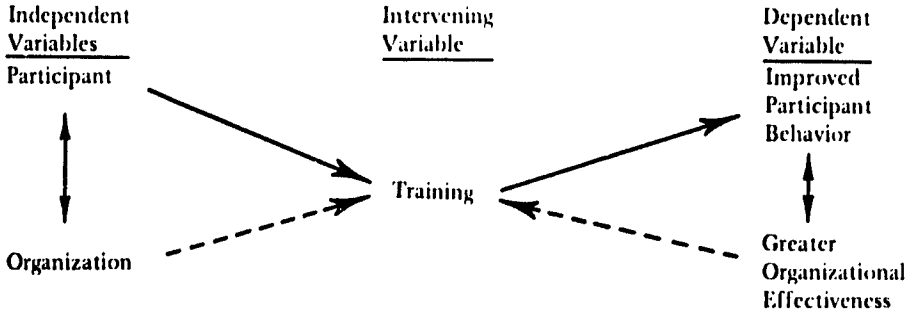


FIGURE 3 WORK BEHAVIORAL PATTERNS OF FORMER CIMMYT WHEAT TRAINEES

83.3 percent (N = 105); IRRI research trainees, 71.3 percent (N = 154); and IRRI rice production trainees, 78.8 percent (N = 108). See Tables 1 and 2 for additional data.

It is clear from the data presented that CIMMYT wheat trainees are completing more research activities associated with the development of biological technology than are IRRI research trainees.[27] While this difference in research emphasis was expected, the extent (i.e., level) of these observed differences was not anticipated. Since these differences have an important influence on the type of national research capacity that develops, a detailed esamination of the factors that contributed to these differences was warranted.

To account for these differences, an analysis was made using a conceptual model of the training process developed by Lynton and Pareek (see Fig. 3).



Source: Lynton, R.P. and Pareek, Udai, *Training for Development*, Richard D. Irwin, Inc., and the Dorsey Press, 1967, p.18.

FIGURE 4 A MODEL DEPICTING THE ROLE OF TRAINING IN BEHAVIORAL AND ORGANIZATIONAL CHANGE[28]

First, an examination was made of the two major independent variables: (1) personal characteristics of individual trainees, and (2) characteristics of trainees in their work organizations for each training group. Then, differences in the main intervening variable--the actual training strategy and approach employed by each institute—were considered.

Personal Characteristics of Trainees

Several key variables describing the personal background and characterictics of trainees were tabulated to determine if there were any significant differences in the types of trainees being selected for each program.[29] Table 4 summarizes data on those characteristics that might be expected to influence work behavior.

In terms of background characteristics, there are two apparent differences between the two research training groups which could affect work performance. First, as documented in Table 4 is the difference in educa-

TABLE 4 PERSONAL CHARACTERISTICS OF TRAINEES IN EACH TRAINEE GROUP

Personal Characteristics of Trainees	CIMMYT Wheat Trainees (N = 130)	IRRI Research Trainees (N = 234)	IRRI Rice Production Trainees (N = 148)
A. Mean age when entering the training program (in years)	30.6	30.4	32.4
B. Percentage of trainees who grew up in rural areas	61.4%	59.5%	77.0%
C. Percentage of trainee fathers who were engaged in agricultural jobs	47.5%	36.7%	45.8%
D. Percentage of trainee families whose main source of income was from agricultural sources	47.7%	43.2%	55.5%
E. Educational level of trainees when entering the training program			
Less than B.S. degree	21.1%	1.8%	22.4%
B.S. degree or equivalent	57.8%	62.3%	65.0%
M.S. or Ph.D. degree	21.1%	35.9%	12.6%
Total	100.0%	100.0%	100.0%
F. Present educational level of trainees			
Less than B.S. degree	20.5%	–	17.5%
B.S. degree or equivalent	41.7%	16.2%	56.6%
M.S. degree or equivalent	27.6%	41.2%	19.6%
Ph.D. degree	10.2%	42.6%	6.3%
Total	100.0%	100.0%	100.0%

tional level. Although the IRRI research group is more highly educated—this factor may somewhat influence the type of research conducted (which appears to be the case)—this factor would not be expected to have a negative influence on the overall amount of work completed.

The second major difference is nationality and the possible influence of cultural factors on work behavior. The IRRI research group is primarily from countries in South, Southeast, and East Asia; whereas CIMMYT trainees are primarily from North Africa, the Middle East, South Asia, and South America. Because there was insufficient overlap between the two groups to measure the impact of nationality or culture on work

behavior, the importance of this influence remains unknown. However, based on the investigator's experience in agricultural training programs, where he worked with a wide variety of cultural groups, there was nothing in this experience to suggest that cultural background would have a *determining* influence on the type and amount of work performed.

Characteristics of Trainees in Their Work Organizations

The next set of variables to be examined in attempting to explain differences in the work behavior between the two research training groups concerns the role of the trainee in his work organization when the survey was conducted. Table 5 presents data on certain selected variables that could be expected to influence the dependent variable.

There is no difference between research groups regarding the level of their present positions in their work organizations, but there are other important differences which could directly contribute directly to the observed differences in work behavior. First, there is a substantial difference in the proportion of trainees doing field research work. Since the work behavior of IRRI research trainees tends to emphasize experimental field research (as reported in Table 5 and Fig. 1), the fact that only about 45 percent of the IRRI research group (contrasted with nearly 75 percent for the CIMMYT group) are engaged in field research would be expected to have an important negative influence on the mean level of field research activities completed per trainee. Second, the important difference between the two groups in regard to crops worked with (71 percent of CIMMYT trainees worked full-time on wheat research, whereas only 41 percent of IRRI research trainees worked full-time on rice research) would also be expected to have some influence on the total amount of wheat/rice research completed.

These findings raise two obvious questions: (1) why are there such large differences between the two research training groups with respect to these two variables; and (2) what actual impact are these differences having on the amount of work completed by trainees?

Although there are no clear-cut answers to the first question, certain facts are known. First, IRRI selects trainees from educational as well as research institutions for its research training program. With 16 percent of former IRRI research trainees now working in full-time teaching positions within agricultural colleges or universities, this group accounts for more than half the difference between the CIMMYT and IRRI research groups. Second, of those IRRI research trainees who are doing research work, more than one-third are engaged in laboratory/greenhouse research; this group accounts for the remainder of the difference.

Less easy to explain is the fact that only 41 percent of the research workers included in the IRRI research group are working full-time on

rice research, yet most come from countries totally dependent on rice as the major food stapel. The only apparent reason is that the IRRI research group is trained in disciplinary departments and is more highly educated, which again would be an impetus to further disciplinary

TABLE 5 VARIABLES DEPICTING THE ROLE OF TRAINEES IN THEIR WORK ORGANIZATION FOR ALL THREE TRAINING GROUPS

Characteristics of Trainees in Their Work Organization (when survey was taken)	CIMMYT Wheat Trainees (N = 130)	IRRI Research Trainees (N = 234)	IRRI Rice Production Trainees (N = 148)
A. Types of organizations where trainees are working:			
National research organizations	88.0%	56.9%	20.0%
National extension organizations	6.4%	1.9%	47.9%
Agricultural college or university	2.4%	27.3%	12.1%
Other	3.2%	13.9%	20.0%
Total	100.0%	100.0%	100.0%
B. Level of trainee's position in his work organization:			
Policy level	4.0%	4.7%	2.9%
Senior level	41.9%	46.5%	32.1%
Middle level	50.1%	45.0%	54.0%
Lower level	4.0%	3.8%	11.0%
Total	100.0%	100.0%	100.0%
C. Type of work trainee is engaged in:			
Mainly administrative work	11.6%	12.1%	22.7%
Mainly field research work	74.4%	44.7%	22.0%
Mainly lab./greenhouse research	6.6%	24.1%	3.8%
Mainly field extension work	5.8%	3.0%	28.8%
Mainly teaching or training	1.6%	16.1%	22.7%
Total	100.0%	100.0%	100.0%

TABLE 5 – *Continued*

Characteristics of Trainees in Their Work Organization (when survey was taken)	CIMMYT Wheat Trainees (N = 130)	IRRI Research Trainees (N = 234)	IRRI Rice Production Trainees (N = 148)
D. Crops worked with by the trainee in his job assignment:			
Only works with wheat/rice	71.4%	40.7%	32.8%
Works with wheat/rice and other crops	19.9%	31.5%	48.2%
Does not work with wheat/rice in his present job assignment	8.7%	27.8%	19.0%
Total	100.0%	100.0%	100.0%

specialization. Once back home in their national programs, which are concerned with several different crops (rather than a single crop as is the case with IRRI), it appears likely that these scientists may be called on to divide their research time with other crops in addition to rice. For example, a pathologist may be assigned to study fungus diseases of several economic crops rather than work on all different diseases of rice, such as bacterial blight, blast (a fungus disease), and tungro (a virus disease).

Trainees who have gone through the CIMMYT training program which operates within an interdisciplinary research structure, have tended to continue their focus on wheat improvement rather than specialize on research problems within a particular scientific discipline.

The second question raised above concerned the impact differences in trainee job assignments have on the overall work behavior of trainees. The procedure used to address this question contrasted the work behavior of two subgroups of trainees from each of the two research training groups—those mainly doing field research work and those working only on wheat/rice research—to determine if the observed differences in work behavior could be explained by either of these two independent variables, or if the differences still persist. Results of these analyses are found in Tables 6 and 7.

As the data indicate, the observed differences in behavior for those research activities most closely associated with the development of improved genetic and production technology (types C, D, and E) continue to be present even when considering just those subgroups mainly doing field research and those doing only wheat/rice research respectively.

TABLE 6 ANALYSIS OF VARIANCE OF WORK BEHAVIOR OF INDIVIDUAL TRAINEES MAINLY WORKING ON FIELD RESEARCH FOR CIMMYT AND IRRI RESEARCH TRAINING GROUPS†

Type of Activity Completed	CIMMYT Wheat Trainees (N = 79)	IRRI Research Trainees (N = 72)	*t* values	Level of Significance°
A. Laboratory and greenhouse experiments	1.76	0.61	1.1068	n.s.
B. On-station field research experiments	6.82	4.07	1.7757	n.s.
C. Genetic crosses	279.50	26.30	5.8646	**
D. On-station replicated applied research trials	8.95	2.00	4.3683	*
E. On-farm replicated applied research trials	4.95	1.68	2.4003	*
F. On-farm production plots	3.17	2.46	0.4226	n.s.

† Data reported is the mean level of each activity completed per trainee during the main wheat or rice growing season of 1972.

° The following statistical notations are used: n.s., not significant; *significant at the .05 level, **indicates the difference is highly significant at the .01 level.

Therefore, although a smaller proportion of IRRI research trainees are working in field research and a smaller proportion are only working full-time on rice research, thees differences in job assignments still do not explain the major differences in observed work behavior between the two research training groups.

To reiterate, it was not possible to account for the differences in work behavior between the two research training groups by considering the two main independent variables: (1) the differences in the personal background characteristics of the individual trainees in each group and (2) the characteristics of trainee job assignments in their work organizations. These findings, therefore, direct the inquiry to the intervening variable—the training itself—to see if the differences in training could account for the observed differences in work behavior.

TABLE 7 ANALYSIS OF VARIANCE OF THE WORK BEHAVIOR OF INDIVIDUAL TRAINEES WHO ARE ONLY WORKING ON WHEAT/RICE RESEARCH FOR THE CIMMYT AND IRRI RESEARCH TRAINING GROUPS†

Type of Activity Completed	CIMMYT Wheat Trainees (N = 81)	IRRI Research Trainees (N = 82)	*t* values	Level of Significance°
A. Laboratory and greenhouse experiments	1.72	1.12	0.5778	n.s.
B. On-station field research experiments	5.89	3.84	1.3358	n.s.
C. Genetic crosses	261.20	28.00	5.5943	**
D. On-station replicated applied research trials	8.36	1.52	4.4190	**
E. On-farm replicated applied research trials	4.43	1.26	2.6425	**
F. On-farm production plots	3.77	1.99	1.1194	n.s.

† Data reported is the mean level of each activity completed per trainee during the main wheat or rice growing season of 1972.

° The following statistical notations are used: n.s., not significant; *significant at the .05 level; **indicates the difference is highly significant at the .01 level.

Differences in Training As An Intervening Variable

The training objectives, methodology, and strategy of the two research training programs considered here are markedly different. Both training approaches were described earlier. The key points that appear to directly link them to the differences in work behavior are as follows.

IRRI has employed analysis as the main educational objective associated with the research project approach to training. In following this type of program, the trainee learns first-hand how to design, carry out, and report on a research experiment. In so doing, he learns how to think analytically—a prerequisite for any successful research worker. Having this ability and skill, however, does not prepare a research worker for all types of research work. In particular, he does not learn the research skills and methods associated with organizing and operating a research program aimed at developing improved agricultural technology where the primary

educational objective is synthesis (an objective that characterizes the CIMMYT wheat training program).

The CIMMYT wheat research program is essentially a highly organized "genetic assembly line" which has standardized procedures and routinized tasks to increase the efficiency and output of a wheat improvement research program while minimizing error. By systematically and effectively mixing the gene pool through large numbers of genetic crosses and by systematically screening the progeny of these crosses, particularly through the extensive use of early generation testing procedures (evaluation), the biological architects at CIMMYT believe they can maximize the probability of producing superior germ plasm. CIMMYT wheat trainees appear to have learned and adopted this research approach to wheat improvement, given their observed behavior.

The different approaches to research training pursued by IRRI and CIMMYT are having an important and measurable influence on the work behavior of research workers in less-developed countries. In the one case, research workers tend to emphasize experimental research aimed at generating new knowledge about rice production in the tropics. The other training group tends to emphasize and to be very efficient and productive in conducting research aimed at developing improved wheat technology.

Transforming National Research Capacity: A Postscript

As Ruttan and Hayami point out, one of the most serious constraints on the international transfer of agricultural technology is limited experiment station capacity for the production of biological technology.[30] The central theme of this study has been to analyze how two international research centers have addressed this problem through their training programs. In making this analysis, however, it became increasingly clear to the investigator that there was a more basic issue involved than just a difference in training objectives and methodologies. More important were the working assumptions made by each center concerning the ability of national research systems to organize their scientific resources. Although this is a complex issue, each center's response provides some valuable insights into the problem.

CIMMYT's response is essentially based on the premise that the national wheat improvement programs it is working with are not functioning effectively because they are unable to organize their scientific resources to solve practical production problems. The problem is essentially two-fold.

First is the problem of focus or research objectives. CIMMYT's response to this perceived institutional problem was to concentrate on one specific production problem—the need for improved genetic technology

—and through its training strategy to carefully and systematically build this relatively simple research function into each national program. Thus, organizational change was a specific, but implicit, training objective.

Second is the problem of functional integration, or the ability of a national program to effectively organize and mobilize its scientific resources around the objective of producing biological technology. By identifying this inability as a serious institutional problem, it follows that technical personnel, in addition to lacking relevant research skills and methods, would also lack the skills and spirit of working together in organized, cooperative team efforts. More precisely, they lacked the organizational skills and perspective necessary to integrate their research functions around a specific research objective. Thus, it was found that CIMMYT trainees in cereal technology spent one-fourth of their time in the wheat breeding program so they would clearly understand and appreciate the functional relationship between their work in cereal technology and in the breeding program. Likewise, each training group spent a substantial amount of time working in each of the other respective research programs that are functionally involved in developing improved genetic technology.

Following the logic of this strategy, it was expected that once a "critical mass" of trained research workers was present in a wheat improvement program, that program would function effectively. As this happened, it was expected that each national program would: (1) work out its own research structure (i.e., division of labor) to fit local needs and requirements and (2) take over the necessary informal on-the-job training of new personnel. Once this transformation had been achieved, CIMMYT expected national wheat improvement programs to be functionally competent to identify local production problems and meet long-term technological needs. Observations made by the investigator, while pretesting the survey questionnaire in the field, suggests that this strategy is working.

IRRI's response to the problem of how national research programs organize their scientific resources is based on a different policy decision. On one hand, IRRI officials and scientists expressed serious concern that some national programs lack the ability to organize and direct their research resources toward solving local production problems. On the other hand, however, IRRI leaders have expressed a sensitivity and concern that their international activities do not dominate the research capability of national programs.[31] By taking an explicit policy decision against direct institutional intervention, IRRI was then placed in a position taking, as a given, the ability of national programs to organize their scientific resources.[32] Furthermore, IRRI's research training strategy, while not resulting from this policy decision, is logically consistent with it.

IRRI is operating on the basis of the same type of institutional

relationship that a college of agriculture (as an educational institution) would have with a functionally effective experiment station (as a work organization). The college provides graduate students with a good theoretical background in a field of study, along with a solid research experience in designing, conducting, and reporting on a research project. Once hired by an experiment station for a particular research position, however, a student is given specific research responsibilities (tasks)—which are functionally integrated with the station's overall research program—that he is expected to carry out. Since it is unlikely that the student knows how to carry out these responsibilities, he will generally be assigned to work closely with a senior scientist in the same program. After a season or two of this informal, on-the-job type of training, the inexperienced research worker will develop sufficient skill competency to function independently in carrying out his assigned tasks.

IRRI, by using the research project approach and by training research workers in separate disciplinary departments, does not address institutional problems, such as poorly defined or inappropriate research objectives and the lack of functional integration, through its training strategy.[33] The observed work behavior of former IRRI research trainees, as they return home to concentrate on knowledge generating types of research, raises obvious questions about IRRI's training strategy. While trainees study production problems relevant to home country conditions, it appears that in most cases their research effort—as it contributes to the overall national research capacity—lacks sufficient emphasis on and attention to the problem of producing biological technology.

Conclusion

This study is built on the premise that as poor nations of the tropics and subtropics shift to modern agricultural production systems, they will need effective research institutions to meet long-term technological needs. Experience suggests that in some of these national research institutions, technology development research activities are frequently neglected[34] or are relegated to less qualified and/or motivated research personnel,[35] while more highly educated scientists concentrate on more theoretical research inquiries. However, if national agricultural research systems are to be relevant and useful to agricultural producers, then knowledge generating research activities must be, to a large degree, directed by and integrated with the technology developing research function. Furthermore, this technology developing research system must be capable of effectively and efficiently transforming new knowledge into improved agricultural technology. Where the national research capacity for producing biological technology is weak or lacking, then these national research systems will remain functionally impotent in their

ability to solve serious production problems; and these nations will remain largely dependent on external agencies (particularly the international research centers themselves) for new sources of improved technology. An analysis of the observed work behavior of former IRRI and CIMMYT research trainees supports the proposition that different training approaches (i.e., different educational objectives and training methodologies) and institution-building strategies can have an important impact on the type of national research capacity that develops. Therefore, international centers must be fully cognizant of these potential influences on the technological capability of national research systems when designing their training and outreach programs.

NOTES

1– V.W. Ruttan and Yigiro Hayami, "Technology Transfer and Agricultural Development," *Technology and Culture* 14:2(April 1973):124-5.

2– These international movements of wheat and rice varieties are well documented in Dana G. Dalrymple, "Imports and Plantings of High-yielding Varieties of Wheat and Rice in the Less Developed Nations," Foreign Economic Development Report No. 14 (Washington, D.C.: Foreign Economic Development Service, USDA in cooperation with U.S. AID, February 1972).

3– Both CIMMYT and IRRI made exotic and elite germ plasm available to cooperating national programs during this period; to some degree these efforts still continue.

4– Cf. *Building Institutions to Serve Agriculture* (Lafayette, Ind.: Purdue University, Committee on Institutional Cooperation, 1968), p.9; Willard W. Cochrane, *The World Food Problem* (New York: Thomas Y. Crowell Co., 1969), pp.218-19; A.H. Moseman, *Building Agricultural Research Systems in the Developing Nations* (New York: The Agricultural Development Council, 1970), pp.29-30.

5– Derek J. de Solla Price, "The Structures of Publication in Science and Technology," in *Factors in the Transfer of Technology*, ed. William S. Gruber and Donald G. Marquis (Cambridge, Mass.: The MIT Press, 1969), pp.94-97.

6– Sterling Wortman made this point rather succinctly: "That agricultural research must be undertaken at central experiment stations or in the laboratories of national research organizations or college of agriculture is well understood; frequently, however, the further steps of identifying and testing packages of technology in each distinct farming region of a nation and finally at the ultimate experimental site–the individual farm–are erroneously excluded." See Sterling Wortman, "The Technological Basis for Intensified Agriculture," in *Agricultural Development: Proceedings of a Conference Sponsored by the Rockefeller Foundation, April 23-25, 1969 at the Villa Serbelloni, Bellagio, Italy* (New York: The Rockefeller Foundation, 1969), p.31.

7– Biological architects are high level research workers who develop improved biological technology. They are the "master builders" or the "research inventors" who manipulate and integrate new and/or different factors, materials, knowledge, etc. to create improved agricultural technology. In terms of a research hierarchy, the biological architect is on at least the same intellectual level as any senior research scientist. In fact, although the biological architect may use less sophisticated research tools, the cognitive or intellectual demands placed on him are frequently more complex than those problems faced by scientists conducting analytical research. Unfortunately, however, the technology developing function within the overall research process is generally considered (by the scientific community) inferior to the knowledge-generating function (science). Therefore, less talented research technicians are frequently assigned to these technology development roles, which may be one reason why many of these research programs, particularly in LDCs, have been so ineffective in producing improved agricultural technology.

8– Benjamin S. Bloom, et. al., *Taxonomy of Educational Objectives, Handbook I: Cognitive Domain* (New York: David McKay Company, 1956), p.144.

9– Ibid., pp.162-72.

10– Ibid., p.162.

11– Ibid., pp.185-92.

12– See Ruttan and Hayami, "Technology Transfer," pp.141-3.

13– Cf. E.O. Heady, "Priorities in the Adoption of Improved Farm Technology," in *Economic Development of Agriculture*, ed. E.O. Heady (Ames: Iowa State University Press, 1965), pp.164-5; Hans W. Singer, "A New Approach to the Problems of the Dual Society in Developing Countries," *United Nations International Development Review* 3(1971):24; Lester Brown, *Seeds of Change* (New York: Praeger, 1970), p.52; and C.P. McMeekan, "What Kind of Agricultural Research?" *Finance and Development* 2:2(1965):73.

14– For a more detailed analysis of this problem, see Burton E. Swanson, "Training Agricultural Research and Extension Workers from Less Developed Countries" (PhD diss., University of Wisconsin, 1974), pp.18-42.

15– See H.L. Wilcke and H.B. Sprague, "Agricultural Research and Development by the Private Sector of the United States," *Agricultural Science Review* 5:3(1967):3.

16– Singer terms this condition "an internal brain drain"; ("New Approach," p.24).

17– This paper is concerned only with the training activities of IRRI and CIMMYT. For more information on IRRI, see *Rice, Science and Man* (Los Banos, Philippines: IRRI, 1972). For more information on CIMMYT, see Burton E. Swanson, *Institution Building: The International Wheat Technology Development and Transfer System*, in this volume. For general background information on international agricultural research organizations, see J.G. Crawford, "International Agricultural Research: An Encouraging Venture in International Collaboration" (Paper presented at the Conference on Resource Allocation and Productivity in International Agricultural Research, Airlie House, Va., 26-29 January 1975); and Nicholas Wade, "International Agricultural Research," *Science* 188(1975):585-9.

18– The following section is a brief summary of the training objectives and methodology employed by the CIMMYT Wheat Program. For more detailed information on this training program and an evaluation of this strategy, see Swanson, "Training," pp.101-87.

19– For a detailed description of this training methodology, see Dugan H. Laird, *Training Methods for Skills Acquisition* (Madison, Wisc.: American Society for Training and Development, 1972), pp.22-4.

20– See Swanson, "Training," pp.117-23, for detailed information about and examples of how CIMMYT attempts to achieve its attitudinal objectives.

21– The terms compliance, identification, and internalization are taken from and based on a theoretical framework of attitudinal change developed by H.C. Kelman, "Compliance, Identification and Internalization: Three Processes of Attitudinal Change," *Journal of Conflict Resolution* 2(1958):51-60.

22– The data used in this paper to analyze the performance of CIMMYT and IRRI trainees was based on an international survey of former participants conducted in 1973. Responses to mail questionnaires were obtained from more than 78 percent of the nearly 700 former trainees who had participated in one of the three training programs included in this study. A detailed analysis of these follow-up data for each training group can be found in Swanson, "Training."

23– Laboratory, greenhouse, and field experiments are defined in this paper as "knowledge generating" types of research; genetic crosses and on-station and on-farm applied research trials are classified as "technology developing" types of research. See Swanson, "Training," pp.14-18.

24– This conclusion is partially based on the assumption that individual research experiments take more time to plan and execute than applied research trials. The methodology of applied research trials can frequently be standardized and routinized to minimize time spent on planning, experimental design, and analysis.

25– The publication record for former CIMMYT trainees during the same period was that 39 of the 105 active wheat research workers had published or presented a total of 101 technical papers.

26– The rice production training program is specifically designed for rice extension workers. However, since one-fourth of the trainees in this program were research workers, this program is summarized briefly here.

27– An analysis of variance for the three technology development variables–for the two research groups depicted in Figures 1 and 2–indicates that these differences are statistically significant at the .01 level.

28– R.P. Lynton and Udai Pareek, *Training for Development* (Homewood, Ill.: The Dorsey Press, 1967), p.18.

29– To explain differences in the work behavior of trainees within training groups, I developed several different multivariate linear regression models, using key independent variables, in an attempt to predict different types and/or levels of work performance. None of the independent variables used in these analyses were found to have much influence (i.e., explain much variance) on the dependent variable.

30– Ruttan and Hayami, "Technology," p.124.

31– See Colin A. McClung, "IRRI's Role in Institutional Cooperation in Asia," *Rice, Science and Man*, p.38.

32– "The basic philosophy of these agreements was quite clear on an important point: they were in no sense intended to lead to the establishment of branch stations of the International Rice Research Institute. Rather, they were designed to foster improvements in the host countries' research and development programs. The degree and pace of IRRI's involvement *would be set by the decisions of local authorities* [emphasis added] and the work would be directed solely toward problems of concern to local rice scientists and rice farmers." Ibid., p.28.

33– It should be noted that several countries from which IRRI receives substantial numbers of trainees (e.g., Japan, Taiwan, Korea) are assumed to have rather effective research systems at the present time. Therefore, this type of research training may be quite appropriate in meeting their needs. However, if these programs are in fact relatively strong and functioning effectively at the present time, there would appear to be little justification for IRRI to expend its scarce training resources on research personnel from these countries, when the important rice growing countries of the tropics have weak research systems.

34– Moseman, *Building Agricultural Research Systems*, p.58.

35– Wortman, "The Technological Basis," p.21.

Appendix

TABLE 1 CIMMYT WHEAT NURSERIES DISTRIBUTION – 1974

Type of Crop	Name of Experiment	Africa (21 countries)	Asia (10 countries)	Central America (2 countries)	Europe (22 countries)	Middle East (12 countries)	North America (3 countries)	Oceania (2 countries)	South America (11 countries)	Subtotals by Experiment	Totals by Crop
BREAD WHEAT	Crossing Block (CB)	7	5	1	1	5	8	0	8	35	
	F2 Irrigated	12	17	1	7	4	18	0	10	69	
	F2 Dryland	10	16	1	8	5	15	0	15	70	
	F2 S x W	7	13	1	9	9	18	3	10	70	
	8th International Bread Wheat Screening Nursery (IBWSN)	33	24	2	17	18	19	4	20	137	
	5th Elite Selection Yield Trial (ESYT)	7	4	0	1	2	10	0	6	30	
	11th International Spring Wheat Yield Nursery (ISWYN)	22	18	1	24	13	24	2	16	120	
	5th International Septoria Nursery (ISEPTON)	8	1	1	7	3	8	1	5	34	
	3rd Multiline (8156)	7	8	0	0	3	8	0	4	30	
	Normal Height (F2, F3, & F5)	2	1	0	0	0	0	0	0	3	
	11th ISWYN (Short set)	1	0	0	2	0	2	1	0	6	
	Bread Wheat Subtotals	116	107	8	76	62	130	11	94		604

Table 1--*Continued*

Type of Crop	Name of Experiment	Africa (21 countries)	Asia (10 countries)	Central America (2 countries)	Europe (22 countries)	Middle East (12 countries)	North America (3 countries)	Oceania (2 countries)	South America (11 countries)	Subtotals by Experiment	Totals by Crop
	Crossing Block (CB)	5	2	0	1	7	0	0	2	17	
	F2	8	4	0	11	9	8	0	10	50	
DURUM WHEAT	F2 (Special sets)	4	0	0	0	3	0	0	0	7	
	6th International Durum Screening Nursery (IDSN)	13	5	0	20	17	17	1	12	85	
	5th Elite Durum Yield Trial (EDYT)	6	3	0	6	5	5	0	5	30	
	6th International Durum Yield Nursery (IDYN)	15	7	0	17	13	12	0	11	75	
	Durum Wheat Subtotals	51	21	0	55	54	42	1	40		264
	Crossing Block (CB)	4	5	0	1	3	6	0	6	25	
	F2 Irrigated	4	6	1	4	1	9	0	5	30	
	F2 Dryland	5	6	0	3	1	8	0	7	30	
	F2 S & W	1	3	0	9	0	12	0	5	30	
TRITICALE	6th International Triticale Screening Nursery (ITSN)	18	17	1	14	6	21	2	18	97	
	6th International Triticale Yield Nursery (ITYN)	15	11	1	13	7	17	2	9	75	

	1st Forrage Lines (FL)	6	1	0	2	3	12	2	4	30	
	2nd Triticale Disease Resistance Nursery (TDRN)	2	1	0	1	0	3	0	3	10	
	6th ITYN (Short set)	1	0	0	0	0	1	0	0	2	
	Triticale Subtotals	56	50	3	47	21	89	6	57		329
BARLEY	Crossing Block (CB)	1	2	0	1	3	2	0	3	12	
	F2	3	3	0	4	6	5	0	4	25	
	2nd International Barley Observation Nursery (IBON)	10	6	0	4	11	9	0	5	45	
	Barley Subtotals	14	11	0	9	20	16	0	12		82
	Totals by Geographic Area	237	189	11	187	157	277	18	203		1279

Source: Dr. Maximino Alcala, head of CIMMYT's International Wheat Nursery Program.

TABLE 2 INTERNATIONAL WHEAT NURSERY TRIALS BY COUNTRIES

Region & Country	1971	1972	1973	1974
AFRICA				
Algeria	3	24	40	49
Angola	0	0	0	4
Cameroon	0	1	2	2
Egypt	6	10	71	23
Ethiopia	12	17	27	35
Ghana	1	0	0	0
Kenya	5	8	14	13
Lesotho	2	1	2	2
Malagasy Republic	0	0	0	1
Morocco	16	6	27	16
Nigeria	1	0	3	9
Rhodesia	0	0	0	8
Senegal	0	1	4	4
Somalia	1	0	0	4
South Africa	6	8	30	17
Sudan	3	1	8	11
Tanzania	2	3	9	4
Tchad	0	0	2	3
Tunisia	21	24	27	27
Uganda	0	0	2	1
Zaire	0	0	0	2
Zambia	0	0	2	2
Totals:	84	104	270	237
ASIA				
Afghanistan	3	6	13	10
Bangladesh	17	1	5	6
China	0	1	0	0
India	20	30	98	90
Indonesia	0	0	2	1
Japan	1	1	4	4
Nepal	0	6	7	15
Pakistan	3	21	45	47
South Korea	0	5	12	10
South Vietnam	0	0	0	1
Thailand	3	1	5	5
	47	72	191	189

Table 2—*Continued*

CENTRAL AMERICA				
Guatemala	4	7	12	10
Honduras	0	0	1	1
Totals:	4	7	13	11
EUROPE				
Albania	0	0	0	5
Austria	0	0	4	3
Bulgaria	1	1	5	4
Czechoslovakia	0	0	0	1
Denmark	1	2	5	8
England	5	3	12	14
Finland	0	0	1	3
France	2	2	15	18
Greece	1	1	5	9
Hungary	1	2	5	10
Ireland	0	0	0	1
Italy	7	1	4	9
Netherlands	1	0	2	5
Norway	1	0	0	0
Poland	5	4	6	17
Portugal	5	6	9	10
Romania	5	4	8	8
Russia	3	8	34	20
Spain	7	5	12	22
Sweden	3	5	3	3
Switzerland	4	2	2	3
East Germany	1	0	0	0
West Germany	1	1	1	2
Yugoslavia	4	3	10	12
Totals:	58	50	143	187
MIDDLE EAST				
Cyprus	1	1	12	10
Iran	8	10	23	20
Iraq	3	10	0	7
Israel	7	10	11	11
Jordan	3	7	0	11
Lebanon	20	18	32	27
Libya	1	5	0	8
North Yemen	0	0	0	4
Saudi Arabia	0	0	0	4

Table 2—*Continued*

South Yemen	0	0	0	5
Syria	2	0	0	13
Turkey	25	35	38	37
Totals:	70	96	116	157
NORTH AMERICA				
Canada	11	13	25	39
Mexico	49	63	87	149
U.S.A.	62	82	81	89
Totals:	122	158	193	277
OCEANIA				
Australia	5	2	9	13
New Zealand	4	3	3	5
Totals:	9	5	12	18
SOUTH AMERICA				
Argentina	28	46	68	69
Bolivia	0	2	3	9
Brazil	17	35	51	40
Chile	7	20	26	23
Colombia	5	10	11	9
Ecuador	5	8	13	16
Guyana	0	0	1	1
Paraguay	0	6	6	7
Peru	6	14	20	24
Uruguay	1	4	2	3
Venezuela	0	0	1	2
Totals:	69	145	202	203

Source: Dr. Maximino Alcala, head of CIMMYT's International Wheat Nursery Program.

TABLE 3 SIZE AND TYPE OF INTERNATIONAL WHEAT NURSERIES BY YEAR

BREAD WHEAT NURSERIES

Year	No.	Lines	Reps.	No. of Sets	Bulletin
International Spring Wheat Yield Nursery (ISWYN):					
1964	1st	25	3	34	Yes
1965	2nd	25	3	70	Yes
1966	3rd	50	3	80	Yes
1967	4th	50	3	80	Yes
1968	5th	50	3	80	Yes
1969	6th	50	3	80	Yes
1970	7th	50	3	90	Yes
1971	8th	50	3	100	
1972	9th	50	3	100	
1973	10th	50	3	120	
1974	11th	50	3	137	
International Bread Wheat Screening Nursery (IBWSN):					
1967	1st	1216		15	
1968	2nd	1355		20	
1969	3rd"a"	287		25	
1969	3rd"b"	1125		30	
1970	4th"a"	270		40	
1970	4th"b"	1150		55	
1971	5th	336		65	
1972	6th	315		100	
1973	7th	330		120	
1974	8th	500		140	
Elite Selection Yield Trial (ESYT):					
1970	1st"a"	25	4	20	
1970	1st"b"	25	4	20	
1971	2nd"a"	25	4	20	
1971	2nd"b"	25	4	20	
1972	3rd	25	4	15	
1973	4th	25	4	20	
1974	5th	25	4	30	
Spring Wheat X Winter Wheat Segregating Populations (F_2 S X W):					
1973	1st	*		25	
1973	2nd	*		10	
1974	3rd	315		10	

TABLE 3—*Continued*

Latin American Disease and Insect Screening Nursery (LADISN):

Year	No.	Lines	No. of Sets	Bulletin
1972	1st"a"	794	20	*
1972	1st"b"	939	10	*
1973	2nd	557	30	*
1974	3rd	*	*	*

Regional Disease and Insect Screening Nursery (RDISN):

1970	1st	1800	6	*
1971	2nd	2400	10	*
1972	3rd	2400	40	*
1973	4th	2400	40	*
1974	5th	2400	40	*

International Septoria Nursery (ISEPTON):

1970	1st	76	15
1971	2nd	108	25
1972	3rd	155	25
1973	4th	131	25
1974	5th	*	*

Multiline Nursery (S156):

1973	1st	285 1	30
1973	2nd	291	30
1974	3rd	256	25
1974	4th	*	*

Crossing Block:

1973 (June)	255	25
1973 (Nov.)	350	10
1974 (June)	264	35
1974 (Nov.)	*	*

Segregating Populations (F_2):

Year	Populations	No. of Sets
1973 (Dryland)	*	75
1973 (Irrigated)	*	75
1974 (Dryland)	*	70
1974 (Irrigated)	*	70

DURUM WHEAT NURSERIES

International Durum Yield Nursery (IDYN):

Year	No.	Lines	Reps.	No. of Sets	Bulletin
1969	1st	16	3	50	Yes
1970	2nd	25	3	50	Yes
1971	3rd	25	3	50	Yes

TABLE 3—*Continued*

Year	No.	Lines	Reps.	No. of Sets	Bulletin
1972	4th	25	3	50	
1973	5th	25	3	75	
1974	6th	*	3	*	
International Durum Screening Nursery (IDSN):					
1969	1st	138		20	
1970	2nd	232		35	
1971	3rd	256		40	
1972	4th	223		55	
1973	5th	165		75	
1974	6th	244		85	
Elite Durum Yield Nursery (EDYN):					
1971	1st	25	4	25	
1971	2nd	25	4	25	
1972	3rd	25	4	25	
1973	4th	25	4	25	
1974	5th	25	4	30	
Crossing Block:					
1973	1st	*		3	
1974	2nd	*		*	

Segregating Populations (F_2):

Year	No.	Populations	No. of Sets
1973	1st	*	80
1974	2nd	69	50

TRITICALE NURSERIES

International Triticale Yield Nursery (ITYN):

Year	No.	Lines	Reps.	No. of Sets	Bulletin
1969	1st	16	3	50	Yes
1970	2nd	16	3	50	Yes
1971	3rd	25	3	50	Yes
1972	4th	25	3	50	
1973	5th	25	3	75	
1974	6th	25	3	75	
International Triticale Screening Nursery (ITSN):					
1969	1st	47		25	
1970	2nd	70		30	
1971	3rd	75		50	
1972	4th"a"	108		40	
1972	4th"b"	123		40	
1973	5th"a"	100		50	

TABLE 3–*Continued*

Year	No.	Lines	Reps.	No. of Sets	Bulletin
1973	5th"b"	100		50	
1974	6th	*		100	

Segregating Populations (F_2)

Year	No.	Populations	No. of Sets
1973	1st	150	30
1974	Irrigated	126	30
1974	Dryland	175	30
1974	S X W	50	30

Other Nurseries:

Year	Type	No. of Sets
1973	Crossing Block	10
1974	Crossing Block	30
1974	Forage Line Nursery	30
1974	Triticale Disease Resistance Nursery (TDRN):	10

BARLEY NURSERIES

International Barley Observation Nursery (IBON):

Year	No.	Lines	No. of Sets
1973	1st	381	20
1974	2nd	163	35

Crossing Block:

1973	1st	*	1
1974	2nd	*	3

Segregating Nurseries (F_2)

1973	1st	56	20
1974	2nd	*	25

Source: Dr. Maximino Alcala, head of CIMMYT's International Wheat Nursery Program.

* Complete Information for 1974 was not available when this study was prepared.

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