Wheat Special Report No. 16

A Guide to the CIMMYT Crop Management & Physiology Subprogram

January 1993

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Note on Citing this Wheat Special Report

By sharing research information in this Wheat Special Report on a Guide to the CIMMYT Crop Management and Physiology Subprogram, we hope to contribute to the advancement of wheat breeding and to the importance of shared knowledge. However, the information in this report is shared with the understanding that it is not published in the sense of a refereed journal. Therefore, this report should not be cited in other publications without the specific consent of Dr. E. Acevedo, leader of the CMP Subprogram.

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PREFACE

This wheat special report provides an introduction to the CIMMYT Wheat Program's Crop Management and Physiology (CMP) Subprogram. It is designed to help acquaint donors, visiting scientists, and other interested persons with the Subprogram's structure, activities, objectives, philosophies, and selected recent accomplishments.

Specific CMP projects and their respective investigators are listed in Annex 2. The updated details on these projects can be found in the 1992 version of the Wheat Program's annual project documentation.

E. Acevedo
Leader, Crop Management & Physiology Subprogram

CHAPTER 1
INTRODUCTION

Emphasis in presenting developments and achievements of Crop Management and Physiology (CMP) will be placed on the period dating from 1988. This is when the strategic plan was formulated (although not published until 1989), when the EPR was executed, and when R.A. Fischer, himself an agronomist and physiologist, became Director of the Wheat Program. CIMMYT's efforts before 1988 in wheat agronomy and physiology are adequately covered in the historic perspective (Chapter 2) of this Special Report.

1.1 CIMMYT's Strategic Plan

The CIMMYT Strategic Plan established criteria for setting research priorities. Following these criteria, greater relative growth (57%) in CMP activities was anticipated to the year 2000 than in any other activity except Social Sciences. There was a general consensus that crop management was becoming more constraining to wheat productivity than germplasm availability. Of course, the Plan anticipated that CIMMYT's germplasm activities would still dominate the center, even by 2000.

The Plan briefly discussed challenges in CMP expansion and outlined the need to be more collaborative with national programs, while focusing more on strategic research in areas of broad application and less on local adaptive research.

Also outlined was a role for CIMMYT as a clearing house for CMP knowledge on wheat, and as developer of diagnostic tools and methodologies of general utility, including those dealing with sustainability and marginal land issues. With respect to general CM training, the Plan anticipated a reduction in CIMMYT's role, with devolution of responsibility to national programs, but with an increase in specialized and advanced CMP training at base.

1.2 External Program Review (EPR)

The EPR in 1988 had no major quarrel with directions outlined for wheat CMP, although there were some misgivings about the extent to which the perceived reduction (or shift from adaptive to strategic) in outreach crop management research (CMR) was possible. The framework for strategic CMP was supported and the need for mega-environment and sustainability perspectives was emphasized. It also specifically referred to physiology, urging more attention to yield potential and salt and drought stress. Finally, some concern was expressed about the decentralization of general CM training.

One issue that arose during the EPR was the possible merging of wheat and maize CMP activities under a single disciplinary department, leading to a specific recommendation for the establishment of an across-commodity Crop Production Research Group. This issue was subsequently dealt with at length in the final version of the Strategic Plan. It was concluded by management that arguments against such a merger outweighed those in favor, and the present situation is one of informal, but regular meeting of scientists in wheat and maize CMP to discuss common problems; also common lab facilities have been newly created.

1.3 Five-Year Plan

In 1989, prior to setting about the medium-term planning, CMP activities had to be defined and classified as essential (E) or desirable (D), according to the earlier TAC guidelines. The activity groups delineated at the time were as follows:

- Support to breeding programs through better agronomic management of nurseries and trials, with a view to decreasing costs and improving efficiency.

- Support to breeding programs through physiological studies aimed at identifying useful selection criteria for yield potential and resistance to abiotic stress.

- Strategic component agronomy research: elucidation of principles underlying response of wheat to agronomic factors, and the interactions between such factors, genotypes, and environments. Through simple rules and crop models to increase the ability to predict optimum factor levels across environments. Examples of factors include seeding strategies, fertilizers, and water.

- Strategic cropping system sustainability research: Studies of all factors affecting the long-term productivity of major wheat cropping systems such as rice-wheat in South Asia or wheat-maize in tropical highlands.

- Adaptive crop management research, which refers to research to adapt relatively well understood technology to new situations or countries, e.g., the East Africa Cereals Project.

- Crop management training to impart appropriate theoretical knowledge and practical skills to agronomic researchers at various career levels.

- Consulting in crop management, which refers to a one-to-one sharing of knowledge relevant to crop management with senior national program scientists.

Divisions between these activities are not always clear cut (obviously physiological understanding must underpin all strategic work), nor is their assignment to essential (E) or desirable (D) status straight forward. Nevertheless, we consider moderate levels of activity under the first four categories as E, while the more traditional adaptive crop management research and training are only D because CIMMYT is not the only suitable supplier. Admittedly, we argue that some of our crop management training is unique and hence E. Finally, consulting is an inevitable consequence of having scientists working in all six areas and, as such, is largely essential.

Taking these definitions into account, Table 1.1 shows the situation with respect to activities and staffing in 1989. The three senior scientist (SS) E activities in 1989 were in agronomic support to breeders, strategic component agronomy, and rice-wheat crop system research. The four SS D activities were warmer area wheat agronomy in South America (UNDP-supported) and Eastern Africa and Bangladesh adaptive CMR (both CIDA-supported), and general CM training at base.

The CIMMYT 1989-94 Five-year plan, developed in the knowledge of the EPR report and Strategic Plan, mapped out the moderate expansion anticipated for CMP through to 1994 (Table 1.1), principally increasing the number of senior scientists in essential activities from 3 to 5 (i.e., growing from 13% of the Wheat Program's E activities to 16% of these). In total, SS were to grow from 7 to 9, with the 4 scientist positions in D activities (including the CM training, which could be argued was part D and part E) supported by special project funds. The two new E activities were to be at base in physiology, and in strategic component agronomy, respectively.

1.4 Current Activities and Plans

As is common, plans often go astray. The D position in training was lost due to a resignation and coincident pressure to reduce core supported D activities. A leadership change meant SS physiology was boosted while bringing a SS into strategic component agronomy. Finally, renewed UNDP support (1990-1993) for heat tolerance work enabled another associate scientist to be appointed (Table 1.1).

The UNDP-supported work in South America continues, as does the CIDA-supported work in East Africa; CIDA renewed the Bangladesh project. Two new post-doctoral scientists and three pre-doctorals make up the remainder of the current CMP team in 1993.

A comprehensive cover of all current research activities at base are presented in this report. Research highlight results from CIMMYT/Mexico over the past 2 years are presented in Chapter 3, while results from outreach activities are to be found in Chapters 4 and 5, prepared by outreach CMP scientists. The bulk this report, however, comprises of a set of papers prepared by CMP scientists on the activities that we think are high-priority areas for wheat CMP in the immediate future. Most activities are ongoing and build on recent past experience, while others are new, some of which are currently unfunded. The papers are grouped according to the activity areas given earlier. Since use of the mega-environment framework is common throughout the papers, descriptions of the mega-environments are included in Annex 1. Annex 2 lists 42 projects currently underway within the Subprogram. Special projects and collaborative projects with advanced institutions are listed in Annex 3.

1.5 Future Issues

While the Strategic Plan was formulated only 5 years ago with a careful assessment of the likely future scenario, some recent developments may be relevant to CMP plans--Concern about environment, sustainability, and natural resources has risen more than anticipated and seems to be driving the substantial expansion of the CG system and the great emphasis on natural resources being proposed in TAC's most recent priorities paper (AGR/TAC:IAR/91/14): indeed it is proposed that natural resources receive 20% of financial resources and germplasm development only 15%. While natural resources could cover a number of the listed wheat agronomic research activities, there is a tendency at least among donors and others, to consider anything in the commodity basket as not involving, or even detrimental to, natural resources. A reflection of this may also be seen in the earlier TAC paper in which existing CG centers at that time were to be divided into commodity centers and ecoregional centers, with again the implication that the important natural resource work was to be done in the latter, while the former were largely global germplasm improvement centers. These developments may be taken as an opportunity for seeking greater support for wheat CMP at CIMMYT, especially that part related to land and resource-saving, but given the additional factor of likely reduced real overall financial support to centers like CIMMYT they could be more grounds for concern than optimism.

1.6 Acknowledgments

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Table 1.1. Principal activities in the Wheat CMP Subprogram and the allocation of scientists years[a] to each in 1989, 1994 (5-Year Plan), and in 1991 (actual).

Activity Category	1989			1994			1991			
	SS	AS	PD	SS	AS	PD	SS	AS	PD	GS
Agronomic support to breeders	1	0	0	1	0	0	1	0	0	0
Physiologic support to breeders	0	0	1	1	0	1	1	1	1	1
Strategic component Agronomy	1	0	1	2	1	0	0	1	0	1
Strategic cropping system sustainability	1	0	0	1	0	1	1	0	0	1
Adaptive crop management res.	3	0	0	3	0	0	2	0	1	0
Training in crop management res.	1	0	0	1	0	0	0	0	0	0
Consulting in crop management	0	0	0	0	0	0	0	0	0	0
Total	7	0	2	9	1	2	5	2	2	3

[a] Scientists are where the major part of their activities take place; hence no scientists are in the consulting row, although all participate in this activity.

SS = senior scientist, AS = associate scientist, PD = post-doctoral scientist, GS = graduate student.

CHAPTER 2

HISTORY OF WHEAT CROP MANAGEMENT AND PHYSIOLOGY RESEARCH AT CIMMYT/MEXICO

2.1 Background

Research in Crop Management and Physiology (CMP) was initiated within the CIMMYT Wheat Program in Mexico in 1970. A formal wheat production training course was also initiated that same year. Prior to 1970, wheat agronomic research in Mexico was conducted either by the CIMMYT Soil Science Program or through close cooperation with agronomists working in the Mexican national research system, INIA. Certainly, however, the most exciting agronomic activities during those years prior or immediately after 1970 occurred in bilateral cooperative programs in such countries as India, Turkey, and Pakistan. CIMMYT or CIMMYT-associated scientists, working in these countries alongside national program counter-part scientists, developed and demonstrated the management recommendations that allowed the yield potential of the new semidwarf varieties to become a reality in farmers' fields. Never before and perhaps never again will agronomists have a similar opportunity to combine new varieties with new agronomic practices to achieve such a widespread and immediate impact. This phenomenon not only set the tone for future wheat breeding efforts at CIMMYT, but also established a high level of expectation for potential contributions from CIMMYT's CMP research.

Perhaps the best way to describe the past 20 years of CMP activities at CIMMYT is one of a nearly continuous case of identity crisis. Table 2.1 lists the titles that the program has been assigned since 1966 and the corresponding staffing patterns. Both reflect the recurring swings that have occurred between emphasis on physiology and on agronomy. This uncertainty in direction in the Mexico-based CMP program has most likely stemmed from two factors.

Since the CIMMYT Wheat Program is primarily focused on the development and distribution of improved germplasm, there has been a tendency to expect the physiologists to identify specific traits and pertinent screening techniques to assay for these traits, which can be readily used (quick and dirty) by breeders with a corresponding improvement in their breeding efficiency. Unfortunately few new, direct screening criteria/procedures have been identified by physiologists that CIMMYT breeders have been able to adopt easily. This apparently led to doubts about the relevance of such research particularly at an institution with a mandate such as CIMMYT had/has. Such reasoning obviously overlooks the valuable contributions from physiologists that were and are being made in understanding factors that influence the expression of wheat yield, particularly in the low latitude, wheat production environments. This new understanding has obviously had a valuable effect on how CIMMYT breeders now approach selection in segregating populations and in their selection efficiency. But, it appears that such thinking led to the de-emphasis in physiological research by the CIMMYT Wheat Program, starting in 1976, until it had formally disappeared by 1979.

By 1983, however, research activities that included defined physiological implications were again being conducted and, at present, research in crop physiology is receiving strong support with considerable renewed expectations for development of useful selection criteria and procedures that breeders can apply.

Table 2.1. Historical Evolution of Program Title and Staff Numbers for the Crop Management and Physiology Subprogram.

		Base International Staff			Base Post-Docs		Outreach
Year	Program Title	Agronomist	Physiologist	Training	Agronomist	Physiologist	Agronomists
1966	Soil Science[a]	0	0	0	0	0	6
1967	Soil Science[a]	0	0	0	0	0	6
1968	Soil Science[a]	0	0	0	0	0	4
1969	Soil Science[a]	0	0	0	0	0	5
1970	Soil Science[a]	0	1[c]	1	0	0	7
1971	Physiology and Agronomy	0	2[cd]	1	0	0	9
1972	Physiology and Agronomy	0	1[d]	1	0	0	11
1973	Physiology and Agronomy	0	1[d]	2	1	2	6
1974	Physiology and Agronomy	2	1[d]	2	0	2	6
1975	Agronomy/Physiology	1	0	2	1	1	4
1976	Agronomy/Physiology	1	0	1	0	1[e]	4
1977	Agronomy/Physiology	1	1	1	0	0	3
1978	Agronomy/Physiology	1	1	1	1[d]	0	2
1979	Agronomy	1	0	1	0	0	3
1980	Agronomy	3	0	0[f]	1	0	3
1981	Agronomy	3	0	0[f]	2	0	3
1982	Agronomy	1	0	1	2	0	3
1983	Agronomy	2	0	1	2	0	5
1984	Agronomy	2	0	1	1	0	4
1985	Agronomy	3	0	1	0	0	6
1986	Agronomy	2	0	0[f]	2	0	5
1987	Agronomy	2	0	1	1	0	4
1988	Crop Management & Physiology	2	0	1	1	0	4
1989	Crop Management & Physiology	2	0	1	1	1	4
1990	Crop Management & Physiology	1	1	1	1	1	4
1991	Crop Management & Physiology	2	2	0[f]	1	1	3

[a] Separate program serving both Wheat and Maize programs with one senior staff member in 1966 and 1967 and two senior members in 1968, 1969 and 1970.

[b] Includes all agronomists assigned to regional and bilateral outreach programs.

[c] Joint appointment apparently serving both Wheat and Maize Program.

[d] Agronomist/Physiologist.

[e] Physiologist/Agronomist.

[f] Other staff members conducted the production training course.

On the other hand, agronomic research within the Wheat Program at base has always been forced to confront the question: "How can one conduct agronomic research in Mexico relevant to other wheat-growing areas in the world, given that agronomic recommendations, other than general aspects, appear to be location-specific?" Grappling with this question has led to situations where new agronomic research initiatives have been started only to be side-tracked or cancelled because of a lack of an appropriate answer. It partially explains why a good deal of the applied agronomic research at base either 1) began to focus on pressing problems involved with the management of the CIMMYT Wheat Program's own trials and nurseries at the different experiment stations in Mexico; 2) was incorporated into the production training course where its main purpose was to provide methodology training in sound agronomic research; 3) or was limited to characterizing the performance of new materials emanating from the Crop Breeding Programs.

Presently, through the application of the mega-environment concept, it is envisioned that areas in Mexico that represent important (with reference to the developing world) wheat producing mega-environments can be identified where useful agronomic research can be conducted. This research will have application to these areas in Mexico and should also generate relevant results for potential extrapolation to other countries with the same or similar mega-environments. The application of crop modelling to data coming from this research should also increase its relevance and utility. Inherent, however, in this approach is the need to engender a closer collaborative relationship with the relevant Mexican national research institutions working in the selected areas.

2.2 Evolution of CMP Research Objectives

As mentioned above, there has been a continual change in emphasis in CMP activities at base. This is readily reflected in the stated objectives over the past 20 years. For example, in the 1970-71 CIMMYT annual report (the first report coinciding with the initiation of the Physiology and Agronomy Program), wheat physiology research objectives were outlined as follows: "To determine the important physiological and morphological characteristics leading to high grain yield. This should permit more effective selection of parents and progeny in the breeding program." In the same report, the objective of wheat agronomy research was "to determine optimum cultural practices for new wheat being developed in the CIMMYT program." Similarly, the production training approach was given as follows: "The training at CIMMYT is applied. Trainees learn how to attack problems. They learn techniques. They learn to live together and work together as a team. At all stages, they are an integral part of the CIMMYT resident program and work with and under the supervision of CIMMYT staff. Trainees receive instruction in all aspects of research, including all disciplines, so that their understanding of these different fields is broad".

The year 1973 brought about the first significant change in program objectives/activities. This coincided with the arrival of an agronomy post-doctoral fellow whose main function was the development of agronomic practices for triticale. Attention was also initiated concerning weed control at CIMMYT stations, first at Toluca and El Batan and later at CIANO. On-farm agronomic research activities were also initiated, emphasizing triticales. Wheat physiology research objectives remained similar, but with the inclusion of new trials addressing yield potential expression under both simulated drought conditions in northern Mexico and more tropical conditions at different elevations in central Mexico. Production training objectives remained essentially unchanged.

During the 1974-1978 period, agronomic research, although continuing to emphasize triticales, broadened to include considerations of both bread wheat and durum wheat and barley as well. Perhaps more substantial, however, was the innovative research that was initiated to thoroughly characterize the importance and methods for control of the grassy weeds, wild oats (*Avena fatua*) and canary grass (*Phalaris minor*), which are major problems in many wheat production areas in developing countries.

Also during this period, physiology research initiated studies to evaluate how the application of several different physiologically based selection criteria within F_2 populations could be related to the yield performance of subsequent progenies resulting from the selected F_2 plants. Traits measured on F_2 plants that were significantly related to subsequent F_4 progeny yields were grains per main spike ($r = 0.20$), flag leaf width ($r = -0.21$), kernel weight ($r = -0.24$), leaf fire ($r = -0.25$), harvest index ($r = 0.25$), and leaf permeability measurement at 98 days ($r = 0.22$) and at 111 days ($r = 0.41$). The correlation coefficient for most traits were lower when evaluated for F_5 progeny yields from the same populations, but leaf permeability at 112 days ($r = 0.32$) remained highly significant. Breeder visual assessment of yield potential in the same F_2 populations was not significantly correlated with either F_4 or F_5 progeny yields.

Considerable effort was also directed towards assessing the relationship between bread wheat leaf angle and yield. Results reported in 1978 from a comprehensive trial comparing a large number of genotypes with varying leaf angles were inconclusive.

Production training underwent changes during the 1974-1978 period. The training venue was moved from the CIANO station in northwestern Mexico with emphasis on irrigated agriculture to the rainfed altiplano near to the El Batan station. New training objectives were also advanced "to provide experience in a production research program that uses on-farm testing; to develop methodologies that characterize farmer recommendation domains; to use appropriate scientific methodologies in the execution of off-station testing; and to understand the nature of farmers and their biological economic and social constraints." (Taken from the 1978 CIMMYT Report on Wheat Improvement).

The Physiology Section in the same 1978 CIMMYT Wheat Report concluded as follows: "The physiology program of the CIMMYT Wheat Program has now been terminated, and work will not be continued on selection criteria for high yield potential and the limitations to yield potential." 1978 was a watershed year in terms of program direction.

The objectives of the Wheat Agronomy Program were stated in the 1980 CIMMYT Report on Wheat Improvement as follows:

- Training of post-doctoral fellows in agronomic principles and practices to prepare them for CIMMYT regional programs.

- Training young scientists from national program in production agronomy.

- Development of weed control, fertilizer, and irrigation recommendations for use on the breeders' nurseries in Mexico.

- Investigations into agronomic problems commonly found in many locations throughout the world.

In the 1981 Report, objective 4 above was modified to read as conduct of "some agronomic studies that are not highly site-specific."

In this same 1979-1981 period, production training courses were offered in both northwestern Mexico at CIANO and in the altiplano near El Batan. From 1982 to the present, however, the training course has only been offered in the rainfed altiplano.

In 1981, Agronomy was delegated to the position as one of the "Base Support Programs" serving the crop improvement programs. By 1983, however, research activities again included some physiological trials such as "a number of experiments to help develop useful screening procedures for breeding programs. This work also included the evaluation of the performance of the most promising advanced material in several suboptimal environments" (Agronomy section of the 1983 CIMMYT Report on Wheat Improvement). Research was also initiated at this time to evaluate the improvement in genetic yield potential under optimum conditions for both bread and durum wheats developed by CIMMYT and its predecessor institutions over the period from the early 1950s to the early 1980s. The impact of these studies were probably instrumental in providing impetus to again broaden research activities within CMP to formally include relevant aspects of both physiology and agronomy.

In 1986, the objectives of the agronomy program were to:

- Improve trial and nursery operations and to support experiment stations management.
- Investigate the agronomy of new materials developed by the breeding programs.
- Assist the breeding programs in defining physiological stresses and by developing techniques for their screening. (Emphasis was given to drought).
- Develop an interface between agronomy and pathology to investigate related crop management issues.
- Conduct relevant on-farm trials (Mainly testing advanced materials from the breeding programs in the Yaqui Valley, Sonora).
- Conduct the production training course.

At some point during 1987-1988, the name was changed to the current title, Crop Management and Physiology, and received the designation as a "Subprogram" within the Wheat Program. Research objectives remained relatively unchanged until 1990 when the following outputs of the CMP Subprogram were summarized as follows to participants in the 1990 Presentation Week:

- Summarization, integration and validation of principles relating to the component agronomy of major wheat environments.
- Increased understanding of the sustainability issues of wheat production systems.
- Improved agronomic nursery management to facilitate various types of screening and observations. Understanding of genotype X management interaction.
- Increased understanding of morpho-physiological yield potential traits and stress resistance traits.
- Progress in the validation of selection criteria and strategies for drought, salt, and high temperature tolerance in wheat.

This list essentially summarizes the research areas currently being pursued or under active consideration by the CMP Subprogram.

A major attempt is being made to devolve production training courses (similar to the 6-8 month course offered at CIMMYT for over 20 years) on a regional basis at a key country in each region (Argentina for Latin American, Kenya for Africa, a still undecided location for Asia). The normal production training course was not offered by CMP in Mexico during 1990 in order to assist Argentina in establishing the first regional course. A short (one month) advanced-level agronomy course was offered instead in Mexico during early 1990.

Two successful regional wheat crop management training courses for Spanish speakers (in 1991 and 1992) were conducted in Pergamino, Argentina; the third such course is scheduled for July 5-Dec. 17, 1993. The last crop management training course for English speakers in Mexico was offered (July to December 1991) by the CMP.

2.3 Achievements

A discussion of the important achievements that have occurred since the formal initiation of agronomic and physiological research in the CIMMYT base Wheat Program needs to consider kinds of achievements as well as the time frame within which they occurred, especially given the shifts in research emphasis outlined above. There were basically two kinds of achievement obtained over the past 20 years: 1) trained people and 2) relevant information generated through research.

Training has been a constant activity kept at near par importance with research, be it in-service training courses, pre- and post-doctoral training, attending to visitors or training through travel to interact with national program scientists. During these past 20 years, close to 400 trainees have participated in the production training courses. These young scientists have returned to form the core of wheat agronomic research in their countries. Over 25 young post-doctoral fellows have passed through the program and many have accepted international staff positions within the Wheat Program, especially in outreach or in other IARCS and international organizations like the World Bank.

Nearly all of the outreach agronomists in the Wheat Program were either post-docs or went through an orientation period in agronomy at base. It is of interest to note that at least five wheat agronomy post-docs were selected for outreach agronomist positions with CIMMYT's Maize Program. Clearly training has been well served and has produced results.

Space does not allow a thorough presentation of research highlights. Therefore a rather brief summary is given below following, to some extent, periods of time reflecting research emphasis.

There is no question that the 1970-1975 period was the hallmark time for wheat crop physiology research at CIMMYT. The stated objective of developing an understanding of the physiology of yield in wheat, particularly for the low latitude environments, was admirably met. The numerous publications produced by R.A. Fischer and his colleagues from this era speak for themselves. The role this information has played at CIMMYT in focusing a better understanding of wheat performance and in pointing out avenues for further research both at CIMMYT and by scientists elsewhere is clear.

During the same period, the pioneering work on triticale agronomy and on the characterization of wild oat and canary grass parameters by M.A. McMahon must be mentioned. Similarly McMahon's role in integrating relevant on-farm research into the production training course must be recognized as well as his role in initiating the strong support agronomy has continued to provide for improved management in trials and nurseries on the experiment stations.

From 1976-1981, P. Wall's studies concerning the use of physiological traits for early generation selection for yield deserve mention. In addition, Wall must be recognized for following up on the earlier wild oat/canary grass research at CIANO by investigating integrated measures for their control involving use of rotations, tillage methods, preplanting irrigation for wheat, and herbicides.

The 1981-85 period can be best characterized as a time of rather large staff numbers and rapid turnover (Table 2.1). Most agronomists were in Mexico for rather short periods as agronomists on staff or as post-doctoral fellows, before moving into outreach programs (both wheat and maize). P. Wall, D. Saunders, P. Hobbs, and D. Tanner were in this group moving into Wheat outreach and S. Waddington, J. Ransom, and R. Knapp moved into Maize outreach. M. Osmanzai joined ICRISAT's outreach program. During this period, useful research supporting the breeding programs and station management was carried out. Also, some of the most dynamic production training occurred. The most recognized research from this period was the characterization in the improvement in yield potential of bread wheat and durum wheat varieties in Mexico resulting from three decades of breeding at CIMMYT; (published by Waddington et al.).

The period from 1985 to the present has been characterized by staff turnover at higher levels; both program directors changed and three changes in the head of CMP subprogram occurred. Throughout these changes, the objectives mentioned above for this period were followed.

Considerable progress was made in continuing to improve management recommendations for trial/nursery conduct at stations on Mexico, including better weed control practices, alternative yield trial planting options, and improved crop rotations on the stations.

Progress has also been made in further reducing the effect of factors that may be limiting the potential expression of genetic yield potential at the CIANO station.

Improvement in simulating drought for screening purposes at CIANO, both with flooded-basin irrigation and by use of a line source gradient system has been made.

Further agronomic characterizations of new genotypes from the crop improvement programs have continued, many times designed to include comparisons of these new materials with landmark genotypes developed by CIMMYT over the past 30 years to facilitate assessment of genetic progress. Yield potential per se, response to nitrogen, response to improved soil management, and expression of leaf rust resistance as measured by yield loss are factors that have been assessed using this historical perspective.

Finally, research to study aspects of production sustainability in wheat-based systems has begun. As a part of this, we feel that a close association of agronomist with pathologist as well as breeders must evolve if sustainability issues are to be well defined and well researched. Research bringing these disciplines more closely together has been initiated.

The utility of crop models within this effort is also being explored. The full expression of the renewed role that physiology is and will play is still evolving. It is hoped and assumed that the proper balance between agronomy and physiology will be found that continues to be consistent with the fulfillment of the CIMMYT Wheat Program mandate.

CHAPTER 3
RESEARCH HIGHLIGHTS

The research highlights from CIMMYT Headquarters in Mexico discussed in this Chapter have been supplied by Dr. Ken Sayre (1985-91), Dr. Mathew Reynolds (1989-91), and Dr. Ivan Ortiz-Monasterio (1989-91). Other important research highlights are provided in Sections 4.2.1, 4.2.2, 4.2.3, 5.1, and 5.2 of this documentation, along with outreach activities.

3.1 Support to Trial and Nursery Management

Marked improvement has been made in weed control, particularly at the CIANO station in northwestern Mexico, where handweeding costs have been reduced by more than two-thirds since 1986. Similar progress is being made at El Batan and Toluca where weed pressure and the spectrum is more complex.

Another activity has involved research to reduce soil-related factors that appear to constrain the expression of genetic yield potential at the CIANO station (CIANO is the station in Mexico that CIMMYT breeders use to assess improvements in yield under optimum production conditions).

Research was initiated in 1986 to determine the effect of deep knifing (to a depth of approximately 65 cm) to break soil compaction layers. Also, the addition of organic matter was investigated in these low organic matter level soils, either as application of chicken manure to wheat or plow-down of a legume green manure crop (Sesbania) produced before wheat. It became clear that these soil management factors were generating consistently higher yields than previous yield trial management practices.

To test this, in 1988, a set of 16 bread wheat varieties released in Mexico and representing important CIMMYT/CIANO breeding achievements from 1962 to 1988 were studied. A comparison was made between the current yield trial management practices versus these same practices plus application of chicken manure and use of knifing. Both situations had sesbania plowed down before planting and weeds, diseases and insects were controlled. The linear regression lines for grain yield versus year of variety release for both management situations indicated three conclusions:

- The use of chicken manure and knifing increased yields of all genotypes by an average of about 20%.

- The regression slopes, estimating rate of yield improvement over time, differed with a significantly higher slope for the improved management practices.

- The regression coefficients also differed with the larger value associated with improved management, perhaps providing a better estimate of the improvement in genetic yield potential over this 30-year period.

As a result of these trials, modifications in yield trial management are being implemented by CIMMYT at CIANO. In addition, further research to determine the nature of the dramatic effect of chicken manure on wheat yield is being conducted.

In 1989, a series of planting method trials were initiated to compare the performance of bread wheat and durum wheat and triticale planted in the conventional 8-row (20 cm between rows) x 5-m long plots versus on two 75-cm beds (2 rows/bed, 15 cm apart) x 5 m long.

The original purpose of these trials was to see if CIMMYT yield trials at CIANO could be conducted on beds instead of in the flooded-basin (melga) system currently in use. Considerable savings in both operational costs and land would be realized through conducting yield trials on beds.

Table 3.1 presents the results of 2 years of comparison for several bread wheat genotypes. There is a general trend for lower yields on beds versus melgas. The range in yield reduction, however, was from approximately 1% up to almost 17%, indicating a genotype X planting method interaction. There was a tendency for the shorter and/or more compact, erect-leaf types to have greater yield reductions. These results have a direct bearing on wheat production in northwestern Mexico since many farmers now produce wheat using beds. Closer attention may be needed to assure that appropriate varieties are recommended to farmers using bed planting systems instead of drilled, stands. The crop programs, however, are now evaluating the role yield trial planting on beds may have in their yield testing programs.

Table 3.1. Comparison of mean yields over 2 years for nine bread wheat genotypes in melga plots verus bed plots.

Genotype	Yield (kg/ha at 12% H_2O)			
	Melga	Bed	Yield Diff.	Yield Red. %
Oasis 96*	8,329	7,034	1,005	12.1
Bacanora 88	7,595	6,898	697	9.2
Cumpas 86	6,928	6,064	864	12.5
Opata 85	6,975	6,425	550	7.9
CIANO/PRL	7,163	6,549	614	8.6
PRL II/CM65531	6,639	6,036	603	9.1
BUC/4/TZPP//IR46/CN067//3/PRT	7,373	6,877	496	6.7
CMH74A.630/SX//CN079	6,838	6,073	765	11.2
URES/PRL	6,976	6,872	104	1.4
IA558/4/KAL/BB//CJ/3/ALD/5/YAV	7,155	5,959	1,200	16.8
Mean	7,071b	6,417a	654	9.2

* Data for 1 year only; not included in means.

3.2 Investigations of the Agronomy of New Materials

Trials have been conducted since 1988 at CIANO to assist the breeding programs in the assessment of increases in genetic yield potential. They involve bread and durum wheats, triticales, and on occasion barley. They are designed as individual trials at the crop level, but with an experimental layout that allows a comparison of yields each year between crops. Each crop trial includes seven or eight varieties developed by CIMMYT and released in Mexico since the first important semidwarfs up to the most recently released varieties. In addition, each year the breeding programs provide six or seven new, advanced lines to include for comparison with the corresponding historical set. The trials are grown under the most optimum conditions possible, including support nets to prevent lodging, control of diseases, insects and weeds, maintenance of optimum water status, and optimum nutrition including the knifing and chicken manure treatments outlined in Section 3.1. The trials are conducted annually at the CIANO station and provide two types of information:

- Assessment in changes in genetic yield potential of new materials compared to the historical set and, by observations made on the trials, an understanding of the nature of these changes.

- Since the historical sets of varieties for each crop are grown each year under the same optimum management conditions, they provide an excellent data set to interpret more precisely yearly climatic variations as they affect these recurring genotypes.

The trials also will allow an estimation of production trends (sustainability) over time at the CIANO station unconfounded by biotic stresses.

In 1990 and 1991, a quadratic regression provided the best fit to the data although in 1991 there was little difference between the fit for both the linear and the quadratic regressions. The data demonstrated an apparent reduction in the rate of increase in genetic yield potential from the late 1970s to the present.

Similar regressions were obtained for the seven historical durum wheat varieties included in the trials in 1990 and 1991, respectively. As for the bread wheats, the quadratic regression provided the best fit in both years for durum wheats.

In 1988, trials were conducted in cooperation with Dr. Wolfgang Pfeiffer (bread wheat breeder at that time) to compare the performance of the same set of 16 bread wheat varieties included in the yield trial management study mentioned above to different stress conditions. These stresses included late season heat and both pre- and post-anthesis drought at CIANO. Yield potential has markedly increased over time in all situations except for the post-anthesis drought stress environment. Yield expression under high yield conditions was likely the most important criterion used for selecting these varieties over the past 30 years.

3.3 Development of Screening Techniques for Abiotic Stresses

Effort has been devoted to evaluate potential genotypic differences in bread wheat ability to compete with weeds and to develop useful screening techniques to measure these differences. Trials were established by planting a series of bread wheat genotypes with contrasting morphologies mixed with or without a vigorous variety of common oats to simulate heavy, early weed pressure. Potential screening observations were made on the plots with only wheat and were then related to wheat and oat biomass parameters measured in the mixed plots. It was found that measurement of wheat canopy light interception at ground level at first node in the wheat only plots was strongly related to both oat biomass production (negatively) as well as wheat biomass production (positively) in the mixed plots. There was no relationship between wheat biomass production and % light interception at first node in wheat planted alone. Since light interception can be rapidly measured (20 seconds/plot) and its linearity related to ground cover, this method looks promising for breeders to select for weed-competing ability.

Development of field screening methodologies to assess drought resistance/tolerance has been carried out at the CIANO station for several years. In 1984, equipment was purchased to implement drought-screening using a line source system. The initial years were devoted to developing a reliable system. For the past 3 years, each breeding program has supplied up to 75 genotypes each for screening by the line source system. Crossovers were observed in the genotypic performance along the line source for bread wheat, durum wheat, and triticale, using the Eberhart and Russell stability analysis.

3.4 Interface with Agronomy and Pathology

There has been some effort to investigate how agronomic management factors interact with the expression of Karnal bunt. However, because of lack of an appropriate inoculation procedure useful for large-scale agronomic trials, little progress has been made. Currently, grain samples from relevant agronomic trials are routinely submitted to pathology for Karnal bunt analysis to determine if any pertinent relationships between different agronomic management factors and Karnal Bunt can be observed. In 1990-91, it was observed that KB incidence increased with N rate at planting.

In 1990, trials in cooperation with pathology were implemented to determine yield losses from leaf rust by bread wheat varieties possessing different types/levels of resistances used by the bread wheat breeding program at CIMMYT over the past 25 years. First-year results (in a year with very heavy leaf rust pressure) indicated that several genotypes with partial resistance (slow rusting) had low yield losses similar to immune, hypersensitive types. Susceptible genotypes suffered yield losses from leaf rust approaching 80%. This will be evaluated again in the coming cycle at CIANO.

Trials have also been conducted at the CIANO, Toluca, and El Batan stations to determine the potential effect of soilborne diseases on yield expression. These trials have used comparisons of yield/yield components and assay of soil pathogens under fumigated versus non-fumigated soil conditions. Levels of *Helminthosporium* and *Fusarium* spp. were found (among others) that were related to yield differences. Cooperative trials are underway to further investigate these and other soilborne pathogens and to develop usable management factors (rotations, residue management, tillage, etc.) that may reduce detrimental effects of these pathogens at the El Batan station.

3.5 On-Farm Trials

Trials are conducted each year on farmers' fields in the Yaqui Valley using farmers' production practices to compare current widely-used bread and durum wheat varieties with new advanced lines being considered for release as new varieties. This is done in cooperation with CIANO colleagues. It should be pointed out that these trials are a unique assessment in Mexico of the performance of new CIMMYT-derived materials under high yield potential conditions on farmers' fields.

During the 1990-91 cycle at CIANO, an agronomic diagnostic study of farmer production practices and crop growth characteristics was initiated involving over 50 farmers' fields in the Yaqui Valley. This study helped identify priority factors constraining yields in this production system. The diagnostic methodologies may be useful for implementation by national programs. For details on this study, see Wheat Special Report No. 6 (Wheat Production and Grower Practices in the Yaqui Valley, Sonora Mexico).

3.6 Nitrogen Trials

Nitrogen, being a major factor in cereal production, receives special attention from CMP.

3.6.1 Genetic gains, nitrogen use efficiency and stem N-NO_3

Ten bread wheat cultivars released in the Yaqui Valley of Mexico representing 35 years of breeding (1950-85) were used to measure genetic gains and nitrogen use efficiency (NUE) (grain produced per unit of nitrogen supplied as fertilizer) under different levels of nitrogen.

Genetic gains from 1950-85 measured in absolute terms were different under 175 kg N ha^{-1} (73 kg grain per year) compared with 0 N applied (36 kg grain per year). However, when measured on a relative basis, no differences were found. The genetic gains in grain yield at both levels of N were a 1% gain per year. Genetic gains were also measured in the period of semidwarf improvement only (1962-85). In this period, no differences in gains among levels of nitrogen were found, either when measured on an absolute (39 kg grain per year) or relative basis (1% gain per year).

Nitrogen use efficiency was measured for varieties released during two periods. In the first period (1950-85), progress in NUE was 1.1, 1.0, 1.2, and 1.9% per year, when evaluated under 0, 75, 150, and 300 kg N ha^{-1}, respectively. The slopes were not significantly different among the levels of N, suggesting that progress has been similar at all levels of N.

NUE may be divided into its two components, uptake efficiency (UPE) and utilization efficiency (UTE), with the objective of identifying the contribution of each of these components to total NUE. When the germplasm was tested at 0 kg N ha^{-1}, 75% of the progress in NUE was explained by UPE and 25% by UTE. At 75 kg N ha^{-1}, it was 50% for each of the components. At 150 kg N ha^{-1}, 30% of the progress in NUE was explained by UPE and 70% by UTE. At 300 kg N ha^{-1}, 37% of the progress in NUE was explained by UPE and 63% by UTE.

During the second period (1962-85), progress in NUE was 1.1, 0.4, 0.6, and 0.9% per year, when evaluated at 0, 75, 150, and 300 kg N ha^{-1}, respectively. There were no statistical differences in the slopes, suggesting once again that progress in NUE has been similar at all levels of N.

At 0 kg N ha^{-1}, the progress in NUE is explained exclusively (100%) by UPE. At 75 and 150 kg N ha^{-1}, ~~it~~ was explained by 50% for UPE and 50% by UTE. At 300 kg N ha^{-1}, progress in NUE was explained in 33% by UPE and 67% by UTE.

CIMMYT's germplasm has been selected at approximately 150 kg N ha^{-1}, therefore resulting in parallel progress in UPE and UTE. This characteristic may help explain part of the wide adaptation of CIMMYT's material. These results also suggest that, under low levels of N, the contribution of UPE to NUE is greater. In contrast, at high levels of N, UTE is greater.

The use of stem $N0_3$-N values as a diagnostic tool to establish the nitrogen status in the wheat plant was tested. High correlations between stem $N0_3$-N and yield were found the sampling was done at the first node stage, Zadoks 31, in durum wheat (r=0.90) and triticale (r=0.86).

3.6.2 Triticales' response to nitrogen

A group of complete and substituted triticales were compared at four levels of nitrogen: 0, 75, 150 and 300 kg N ha^{-1}. Complete triticales out-yielded substituted triticales at all levels of nitrogen in both grain yield and above ground biomass.

Substituted triticales had more spikes/m^2 compared to completes, whereas completes had more grains/spike at all levels of nitrogen. Consequently, both triticale groups had the same number of grains/m^2 at all levels of nitrogen. Completes had a higher thousand grain weight than the substituted triticales, thus accounting for the consistent difference in yield between triticale groups.

3.6.3 Nitrogen management

There has been interest on the part of both CIMMYT and CIANO breeders about how CIMMYT-derived bread wheat varieties will respond to N management to improve bread making quality. A series of trials have been conducted at CIANO to investigate this, particularly the use of late applications of N (at mid- to late-boot stage to improve quality). Tables 3.2 and 3.3 present the % flour proteins and loaf volumes, respectively, for five Mexican varieties grown at CIANO under optimum conditions and with 0, 30, or 60 kg/ha N applied at mid-boot stage. All varieties demonstrated increases in both protein and loaf volume. No significant increase in grain yield occurred with the delayed top-dressed N. It would appear that N management to improve baking quality is feasible.

Table 3.2. Effect of delayed top dressing of nitrogen on flour protein content for five Mexican bread wheat varieties.

Variety	Level of Top Dressed Nitrogen[a] 0	 30 kg/ha	 60 kg/ha	 $\bar{X}$
	Percentage			
INIA 66	12.35	12.30	13.05	12.57a
Tonichi 81	9.00	10.88	11.78	10.85bc
Seri 82	9.70	10.63	11.55	10.63c
Genaro 81	10.50	11.25	11.97	11.24b
CIANO 79	10.18	11.05	11.65	10.96bc
$\bar{X}$	10.53c	11.22b	12.00a	-

[a] Means within a row or column followed by the same letter were not significantly different at the 0.05 probability, level according to Duncan's Multiple Range Test.

Table 3.3. Effect of delayed top dressing of nitrogen on loaf volume for five Mexican bread wheat varieties.

	Level of Top Dressed Nitrogen[a]			
Variety	0	30 kg/ha	60 kg/ha	$\bar{X}$
	Percentage			
INIA 66	808	828	875	837a
Tonichi 81	641	676	724	680c
Seri 82	693	721	789	734b
Genaro 81	701	747	753	734b
CIANO 79	681	734	744	720b
$\bar{X}$	705c	741b	777a	-

[a] Means within a row or column followed by the same letter were not significantly different at the 0.05 probability, level according to Duncan's Multiple Range Test.

An experiment on management of nitrogen for higher yield and grain quality in bread wheat gave the following results: There was no difference in yield if 150 kg N ha^{-1} as urea were applied: a) 100% at planting, b) 50% at planting and 50% with the first irrigation (31 days after emergence), or c) 100% with the first irrigation. However, flour protein was higher in treatment c) when compared with treatment a) and b). In fact, flour protein in treatment c) was the same as applying 300 kg N ha^{-1} as urea at planting. There were no differences in flour protein between treatments a) and b).

3.7 Organic and Inorganic Fertilization of Wheat

A long-term trial looking at the effect of subsoiling, summer crop, application of chicken manure, and different rates of nitrogen had shown a consistent yield increase in wheat by the use of chicken manure. Several trials were established with the objective of evaluating if the positive effect of chicken manure could be explained by a chemical factor such as: a) a contribution of micronutrients or b) a more favorable $NH_4/N0_3$ ratio.

Two trials were established with the objective of evaluating micronutrient response in the presence and absence of chicken manure. No response to micronutrients was found.

A trial using N-Serve (a nitrification inhibitor) was established with the objective of creating different $NH_4/N0_3$ ratios. It was difficult to maintain different $NH_4/N0_3$ ratios under field conditions. Therefore, this hypothesis has not been fully tested yet.

3.8 Drought Responses

During the 1989-90 cycle, a set of 20 bread wheat genotypes, selected for superior drought performance by the CIMMYT bread wheat program based at ICARDA in Syria, was compared in the line source with 40 genotypes from the CIMMYT/Mexico-based program. Also included were 15 bread wheat genotypes from the International Drought Trial (IDT). A continuous 600-700 kg/ha yield advantage for the CIMMYT-based developed lines over the gradient was obtained compared to lines selected in Syria. We are trying to repeat the same trial at ICARDA.

Testing has also been carried out by simulating different drought situations in flooded-basins at CIANO. This is the methodology commonly used by the breeding programs. Trials were conducted using the same set of 15 bread wheat genotypes included in the IDT. These genotypes had also been sent to cooperating countries for planting under prevalent drought conditions, including ICARDA. Table 3.4 presents a series of correlations between yields obtained at CIANO for both no-stress and post-anthesis stress situations and for yield at the ICARDA Tel Hayda Station (rainfed) versus the yields obtained at eight other locations. It is of great interest that both CIANO no-stress and stress yields were similarly correlated to the other locations and were better correlated at more sites than Tel Hadya yields. It should be added that the 15 bread wheat genotypes in the IDT included lines not only derived at the CIMMYT base program but also from CIMMYT-ICARDA, Argentina and India.

Table 3.4. Correlations between IDT bread wheat genotype yields at CIANO/Obregon and ICARDA vs other locations.

	CIANO/Obregon		ICARDA
Locations	No Stress	Mod-Post stress	Tel Hadya
Ludiana, India	0.10	0.10	0.02
CIANO/Obregon, Mexico	0.70**	1.00	0.49
Sidji-Bel-Abbes, Algeria	0.58*	0.62**	0.55**
Indore, India	0.24	0.06	-0.24
Amman, Jordan	0.34	0.33	0.51*
Jessore, Bangladesh	0.62*	0.75**	0.28
Islamabad, Pakistan	0.25	0.46	0.31
ICARDA Tehadya, Syria	0.53*	0.49	1.00
Faisalabad, Pakistan	0.47	0.52*	0.21
Dromolaxia, Cyprus	0.54*	0.51*	0.77**
Setif, Algeria	0.36	0.29	0.22
Mean all locations	0.80**	0.75**	0.78**
Location mean less CIANO	0.76**	0.63*	-
Location mean less ICARDA	-	-	0.66*

The line source environment, in which a gradient of water is applied to the crop on a weekly basis, is artificial in terms of water distribution patterns both temporally in the soil profile and spatially. Its use has generated interest in defining which types of drought environment the line source methodology can simulate effectively.

An experiment was implemented in Obregon to examine the hypothesis that the line source moisture gradient can simulate the following drought environments:

- The residual soil moisture scenario where the soil moisture profile recedes as the season progresses, giving an increasing intensity of drought stress. This is typical of a nonirrigated wheat crop sown after the rainy season.

- A preanthesis drought where the crop experiences stress up until heading stage, after which stress is relieved by abundant rain. Such an environment is typical of parts of South America.

The experiment was conducted with 20 genotypes of variable performance based on previous line source screenings. The drought environments were simulated by gravity irrigation with a single irrigation at sowing representing the residual moisture environment, and for the preanthesis stress environment, one further irrigation was applied at heading to relieve stress. A double line source arrangement was used for the comparison. This gave either a continuous gradient of water stress, or a preanthesis gradient of water stress, which was relieved at heading by activating a second line source.

The main effects for the gravity irrigated treatments gave yields of 6.5 t/ha for the control treatment, 4.5 t/ha for the preanthesis stress, and 3.0 t/ha for the residual moisture. Line source yields ranged from 5.1 t/ha to 0.6 t/ha, based on arbitrary divisions along the gradient.

The important question in comparing drought screening methodologies is the genotypic rank for yield compared favorably between the screening environment and the target environment. The rank correlation between genotypes in the residual moisture treatment and any line source environment, including those whose mean yields were close to 3 t, was zero. The rank correlation between the preanthesis stress environment using gravity irrigation and the simulation of preanthesis stress environments in the line source was significant and explained 40% of the variation, despite the fact that the yields were approximately 1 t lower in the line source simulation. However, the correlation between the control and preanthesis stress in the gravity irrigation treatments also explained 35% of the variation.

Based on a single year's data, the line source drought screening methodology appears to be somewhat effective at simulating the preanthesis drought environment, but ineffective in simulating the residual moisture type drought.

3.9 Physiology of Yield Potential

Spring wheat yields, even in optimal growing environments such as the Yaqui Valley of northwestern Mexico, fall well short of record yields. The objective of these experiments was to improve our understanding of the physiological constraints to realizing maximum yields. In particular, the interaction between genotype and the two major environmental factors, light and soil resources.

A selection of CIMMYT varieties and advanced lines were grown for three cycles in two environments: two seasons in Obregon and one season in El Batan. At the crop stage of early booting, treatments were imposed so as to increase the level of light penetration into the plant canopy, and to decrease competition for soil resources. This was achieved by manipulating field grown plants planted in plots of four or six 20-cm rows.

In all three cycles, there was a highly significant response to both treatments. In the high light environment, the average response to extra light was a 2-t increase in yield, and on top of this the additional response to reduced root competition gave, on average, 1 more ton of yield. The genotype*treatment interaction was highly significant, and some genotypes responded far more than others to one or both factors. Based on the first two sets of data in which the high yield potential genotypes seemed less responsive to elevated levels of the factors light and soil resources, a number of hypotheses were tested in the following cycle to help explain the results:

- High yield potential genotypes are more light use efficient than low yield potential genotypes at normal canopy light levels. One aspect of this hypothesis is being tested with genotypes contrasting in leaf angle from similar genetic backgrounds.

- High yield potential genotypes are more soil resource use efficient than low yield potential genotypes. This hypothesis was tested by repeating the experiment in a third season and imposing a treatment of extra irrigation and nutrition. The results suggest that the response to reduced root competition is not a consequence of the relative ability of genotypes to absorb water or nutrients.

- High yield potential genotypes are more determinate in their growth, producing less non productive tillers in the vegetative phase than low YP genotypes. This hypothesis was tested by counting the number of shoots in each genotype at booting and comparing this to the number of spikes at maturity. The data do not support this hypothesis.

The data indicate that there is genetic variability in bread wheat varieties for light use efficiency by the crop canopy, and for the interaction between growth response and the soil environment. Two of three cycles of data suggested that these factors were important in determining yield potential.

3.10 Heat Stress Responses

Although wheat is traditionally grown in temperate climates, many countries with warmer climates are taking an interest in growing wheat in the winter cycle despite the lack of well adapted germplasm and management recommendations. CIMMYT has taken an active role in these problems through outreach activities, and to some extent through improving resistance of germplasm to the disease pressures of the tropics. Still lacking are a set of selection criteria that can be used to produce heat tolerant germplasm, and a package of agronomic recommendations to maximize their yield potential under hot conditions. To this end a series of experiments have been launched in collaboration with the national programs of Bangladesh, Brazil, India, Nigeria, Sudan, Syria, and Thailand. Two trials are being conducted by each national program: The International Heat Stress Genotype Experiment and The International Heat Stress Management Experiment. The genotype experiment involves a limited growth analysis of 16 diverse genotypes and is intended to identify genotype*temperature interactions in growth and development and hence elucidate potential selection traits and selection environments in breeding for heat tolerance. The management experiment is intended to reveal what levels of the following management strategies are optimal in hot climates: fertility treatments (organic and inorganic); number and timing of irrigations; deep cultivation to remove compaction zones; straw mulch to cool soil temperature during stand establishment. One obstacle to reaching general conclusions on the problems of wheat at high temperature is that a range of hot environments exist. The advantage of international collaboration is that our results can be extrapolated to a broader range of environments than if data were collected in one or two sites in Mexico. Furthermore, each collaborator is encouraged to suggest modifications to the experiments (especially the management experiment) based on the experience in their own environment. The experiments are also being conducted in

Mexico at Tlaltizapan and late sowing dates at Obregon. In addition, data, such as canopy temperature, light interception, and nutritional status of leaf tissue, are being collected to elaborate mechanisms of heat tolerance.

In the genotype experiment, three cycles of data from Tlaltizapan show that the trait most highly correlated with yield is final biomass (see Wheat Special Report No. 14, Results of the 1st International Heat Stress Genotype Experiment). The correlation explains between 50% and 80% of the variation. In two cycles of data, canopy light interception at heading was positively correlated with yield, and in one cycle canopy temperature was negatively correlated. In the management experiments, the crop showed up to 25% yield response to the addition of animal manure, while the response to extra irrigation or increased inorganic nutrition was not statistically significant. The response to organic matter applications at high temperature have been observed before by CIMMYT outreach staff.

Biomass appears to be a useful selection trait for heat tolerance, with canopy temperature and light interception worth investigating further. Incorporation of organic matter as a management practise in hot climates seems to give a highly favorable growth response.

CHAPTER 4
PRESENT FOCUS OF STRATEGIC CMP RESEARCH AT CIMMYT

The present focus of wheat management and physiology research at CIMMYT's Headquarters follows closely the recommendation of the 1989 External Program Review and CIMMYT's Strategic Plan and Five Year Budget. The research can be defined as strategic in nature; it considers the sustainability of production systems; it deals with methodologies; and it is heavily oriented to the support of plant breeding. Mega-environments 1, 2, and 5 (see Annex 1) are the major targets since they represent a sizeable amount (above 50%) of developing world wheat production. In particular, ME1 (irrigated wheat) receives CMP's closest attention. The research can be summarized in the following major categories:

- Component agronomy of the wheat crop.
- Sustainability of major wheat cropping systems.
- Support to breeding.

Specific projects for each of the above research categories have been developed and are underway (see complete list in Annex 2). A senior scientist in the Subprogram is in charge of each project. Each project involves the formalization of a research area by each CMP senior research staff. The projects are reviewed by peers and checked for adherence to CIMMYT's strategies and priorities and reflection of CIMMYT's focus and trends. They will be used as the basis for pursuing special project support if the activities go beyond what is considered essential by CIMMYT's Wheat Program.

At present various projects are at various phases of development. Updated versions are given in the following sections. Note that project activities related to sections 4.2.4 and 4.3.2.2 are just being started; projects under section 4.1.3 and 4.3.2.1 are being submitted for financial support and not started yet.

4.1 Component Agronomy

In these sections, we present recently developed projects on strategic research of the agronomic components of the wheat crop grown under irrigation (ME1). In these projects, a farming system perspective is maintained, but emphasis is given to the wheat crop components.

4.1.1 Definition of Agronomic Principles for ME1 and General Issues

Leader:	Dr. Ivan Ortiz Monasterio
Research Committee:	
Wheat Program:	Dr. Ken Sayre Dr. R.A. Fischer Dr. Edmundo Acevedo Dr. Peter Hobbs

Overall Aim: To develop a group of principles and practices in Mega-environment 1 for maximizing wheat production, while making optimum use of inputs and resources.

Introduction

Agronomy may be viewed as a group of principles and practices that are used to maximize the production of a crop, with optimum and efficient uses of inputs and resources. It is postulated that agronomic principles can be applied to any wheat crop; therefore, they are independent of the environment in which the wheat crop is grown. They are derived from disciplines such as crop and plant physiology, soil science, etc. Agronomic practices are those that may change from environment to environment in order to fulfill a given principle.

Some of the initial hypotheses for the study of these principles may be derived from the literature and others may be derived from new experimentation. However, all of them will require experiments for their validation. Modeling will also provide a valuable tool to validate some of these principles and study their interactions.

In this project, ME1 will be used as the focus to develop agronomic principles and their corresponding practices. The current definition of ME1 has been developed from a breeder's perspective: ME1 represents irrigated land with low rainfall and a temperate climate (5 to 18^{o}C), where rises in temperature occur after anthesis. Currently, ME1 is primarily being defined in terms of parameters affecting yield potential (radiation and temperature). Later, divisions may be found within ME1 that may merit special treatment.

Developing countries with representative areas of ME1 are shown in Table 4.1. This ME produces 40% of the wheat crop in the developing world (CIMMYT, 1989b,c). Considering the importance of ME1, the economic payoffs to research may be extremely high.

Table 4.1. Countries producing wheat (bread wheat and durum) under ME1, area and production.

COUNTRY	Area (000 ha)	Production (000 t)
Afghanistan	1,000	1,700
Chile	90	360
China	8,610	29,274
Egypt	593	2,802
India	14,450	34,095
Iran	510	663
Iraq	561	1,010
Jordan	5	9
Libya	50	120
Mexico	370	1,702
Morocco	70	140
Nepal	125	226
Pakistan	5,850	11,700
Syria	175	350

Source: CIMMYT Economics Program, 1991.

There is an estimated 3% increase in demand for food grains in the 1990s (Byerlee 1990). There has been a 1.0% increase in yield due to the release of varieties in the last twenty-nine years (Ortiz-Monasterio et al. 1990). Increases in the area sown to cereal crops will make virtually no contribution to future increases in cereal production. In fact, total area sown to cereals is likely to fall (Byerlee 1990). Consequently, if future food demands are to be met, increased productivity will be mostly by the improvement of agronomic management and its interaction with breeding.

Our objectives in this project are to develop agronomic principles for the following agronomic factors:

- Planting date,
- Canopy architecture,
- N fertilization and water management, and
- Weed free period and weed control.

We hope that by developing these principles a powerful tool will be available to agronomists in national programs to increase wheat production and productivity.

Agronomic Principles

1) Planting date

Background--Overall estimates in India of the percentage of wheat planted late under irrigated conditions are 40% (Byerlee 1990). In the Punjab of Pakistan under the rice-wheat system, it is 47%, and in the cotton-wheat system, it is 84%. Delayed wheat planting is generally estimated to lead to a loss of 1% in yield per day beyond the optimum planting date and may be a major cause of the low and declining productivity of wheat in many systems (Byerlee and Siddiq 1990). The main factor responsible for the delay in planting date is the limited time for adequate soil preparation between harvest of the previous crop and the planting of wheat. However, information on the optimum planting date is necessary so that the farmer has a target date to aim for. Later, experiments on tillage systems and relay intercropping will be important for actually solving the problems of late planting.

Specific objectives include:

- Assessing the usefulness of the photothermal quotient and a modified photothermal quotient (that will take into account temperature during the grain filling period) as a tool to predict the optimum planting date.
- Applying the information gained with the photothermal quotient into a Geographical Information System (GIS). Using the GIS database for temperature and radiation or recording data where necessary, maps will be developed with the optimum planting date in ME1 areas.

Technical work plan--It has been established that maximum yield is determined by the following yield components: 1) spikes/ m^2, 2) spikelets/spike, and 3) kernel weight. These can be summarized in two main components: kernels/m^2 (K) and kernel weight (W). In order to maximize yield, both of these components have to be maximized.

Midmore et al. (1984) reported that in central Mexico variation in yield was closely associated with variation in grain number m^{-2} (r=0.98) which, in turn, was associated with total dry weight/m^2 at anthesis (r=0.97) and photothermal quotient (PTQ) over the 30 days preceding anthesis (r=0.88). Fischer (1985) found a positive linear relationship between K and the photothermal quotient. PTQ being mean daily total radiation for an interval, divided by the mean temperature less 4.5°C and having units MJ m^{-2} day^{-1} $^{o}C^{-1}$. He concluded that this index in the 20- to 30-day period preceding anthesis, was a simple yet reasonably precise linear predictor of K. The close relationship between K and PTQ may be used to predict the optimum planting date that will maximize K. In areas without heat stress during grainfill the PTQ may be used without any modifications. On the other hand, adjustments will have to be made in areas with heat stress around or after anthesis. Several authors have shown the effect of high temperatures during grain-fill. Tashiro and Wardlaw (1989) found that high temperatures commencing at first anthesis reduced grain number by about 11%, but the effect was no longer evident when high temperatures were imposed commencing 7 days after first anthesis. In addition, Sofield et al. (1977) and Chowdbury and Wardlaw (1978) have reported that the effects of temperature on grain-filling are complex. The duration is shortened as temperature is increased and the rate of grain-filling is not increased by raising the mean temperature above the range 21-25° C. Therefore, increasing temperature above this range results in decreased weight per grain. Tashiro and Wardlaw (1989) studied the stage during grainfill most affected by heat stress and they found that grain weight per ear at maturity was reduced by high temperature stress at all stages of development, but showed the greatest response 12-15 days after anthesis.

A characteristic of some areas in ME1 is the presence of rises of temperature after anthesis. Therefore, a modification of the PTQ (MPTQ) to account for rising temperatures during grainfill (kernel weight) would have to be considered to be able to test this concept in those areas of ME1.

The hypothesis of this principle is that maximizing PTQ or MPTQ should establish which planting date would maximize yield in terms of radiation and temperature when other factors are not limiting. The optimum planting date will change among different cultivars. Considering that CIMMYT's spring genetic material released in ME1 is photoperiod-insensitive, all the information needed is how many growing degree days a variety requires to anthesis and maturity. With this information, we can back calculate which is the best planting date for the individual cultivars. This can be done by making the highest PTQ or MPTQ value coincide 30 days before anthesis.

This hypothesis could be tested using data sets from planting date experiments and their corresponding weather data (radiation and temperature) in locations within ME1.

Use of a GIS would be extremely valuable in both phases of this project. In the first phase, meteorological data for ME1 and the corresponding planting date data for several years and locations within ME1 will have to be gathered. Having access to a GIS could permit the manipulation of large numbers of locations to test the concept of the photothermal quotient.

In the second phase, once the PTQ is known, long-term climatic records can be used in all the areas of ME1 to determine which planting date has the highest probability of yielding the climatic conditions that would optimize PTQ or MPTQ.

The planting date data should be of plantings in the traditional method (drilled or broadcast), so that we can assume close to full light interception. Data sets should be used that have varieties with different maturities.

If data sets with yield, days to anthesis, days to maturity, and corresponding climatic data (temperature and radiation) are difficult to find, planting date experiments will be established. Cooperators in different areas of ME1 will be contacted for the establishment of these experiments.

The use of the CERES (Crop Estimation through Resources and Environmental Synthesis) Wheat Model would be another way of testing the photothermal quotient principle. This could be done by comparing the predictive power for yield of the photothermal quotient vs the CERES Wheat model, assuming that all other factors except for radiation and temperature are not limiting.

2) Canopy architecture

Background--We are searching for the canopy architecture that will maximize yield and will also allow flexibility in the management of the crop. This is being approached from two perspectives: 1) the plant distribution in the field (a function of plant density, row spacing and planting date) and 2) plant morphology (height, leaf angle, tiller spread).

Concerning plant distribution, the sowing of wheat in beds as compared to a drill situation is currently being studied. In the Yaqui Valley already more than 50% of the farmers grow wheat in beds. Many advantages have been associated with the growing of wheat in beds: lower seed rate; better water management; less lodging; more alternatives in the timing, method, and products for weed control; better drainage; more options for timing, placement and sources of fertilizers. All of these alternatives in management are essential if an improved use of inputs is to be achieved. In studying plant morphology, a genotype by plating method (drilled vs beds) interactions has been found. There are some genotypes (generally associated with upright leaves or short types) such as Cumpas T88 and Oasis F86 that can reduce their yield by 854 (11%) and 1295 (16%) kg ha^{-1} respectively if grown in beds (75 cm, with two rows 20 cm apart) vs a drilled situation (20 cm between rows). On the other hand, there are other genotypes, such as Rayon F89 (URES/PRL), in which yield is not affected by planting method. Therefore, with the adoption of the appropriate plant types the use of beds as a planting method seems feasible. As mentioned before, the flexibility provided by the management of wheat in beds is essential for the improvement of input use efficiency.

The hypothesis of this principle is that, when close to full light interception is achieved at a critical stage of development (about Zadoks 39), then that row spacing and density maximize yield for a given planting date and variety if other factors are not limiting.

Specific objective--To develop a set of rules that will indicate which is the optimum row spacing and density that will maximize yield, considering genotype and planting date in ME1.

Technical work plan--There is strong evidence of the relationship between light interception during the entire growing season and annual dry matter production of several crops (Monteith 1977, Gallagher and Biscoe 1978). The current research effort in this area is based on the premise that a critical growth stage of development exists in which close to full light interception (90%) has to be achieved in order to maximize yield. Therefore, experiments that include contrasting plant types at different row spacings and different planting dates will be necessary to identify the row spacing and the critical stage of development for maximizing yield. Contact has been established for the incorporation of the "hedgerow model" presently being developed for soybeans (SOYGRO) and peanut (PNUTGRO) (Boote et al. 1988, 1989, 1990) into the simulation model CERES Wheat. This model, if validated, will be a useful tool not only for the verification of results across ME1, but also as a recommendation tool for extension agents.

3) Nitrogen fertilization and water management

Background--In developing countries, nitrogen accounts for about two-thirds of the fertilizer nutrients applied. The highest rates of nitrogen in the developing world are applied under irrigated conditions representative of ME1 (CIMMYT 1990a). Examples of average nitrogen rates applied in areas of ME1 are Mexico, Yaqui Valley (230 kg N ha^{-1}); India, Punjab (150 kg N ha^{-1}); Pakistan, Punjab (100 kg N ha^{-1}) and Egypt, Nile Valley (200 kg N ha^{-1}). In addition, there is evidence that the efficiency of applied nitrogen is low, with some estimates ranging between 28 and 33% (Byerlee and Siddiq 1990). In the wheat rice rotation some of the problems associated with low nitrogen use efficiency are the following (Hobbs et al. 1991):

- Most of the farmers apply nitrogen after the irrigation rather than before.
- Some of the late nitrogen applications are too late to have an effect on yield (after booting).
- Gradual decline in the organic matter content of the soil in the Tarai. Farmers are using more nitrogen to maintain yields.
- Late planted wheat responds less to nitrogen than when planted on time.

Our current understanding of the nitrogen needs by spring wheat are as follows:

Emergence: Dry matter production and thus nitrogen requirement is rather low prior to stem elongation (Z31). However, moderate amounts of nitrogen are required to promote tillering. Nitrogen fertilization in excess of the amount which the plant can utilize creates the potential for leaching losses of the nitrogen. Moreover, plants with excessive initial growth are more prone to lodging.

Stem elongation: This stage signals the beginning of the most rapid phase of wheat growth. Two important factors are occurring during this time. First, the final number of kernels per head is being determined. Second, the highest demand for nitrogen uptake is initiated. There is low probability of nitrogen leaching due to the extensive nature of the wheat root system by Z31, and the large amount of nitrogen uptake during this period.

Boot stage: Our research has shown no yield increases from nitrogen fertilizer applications after the boot stage. However, there is an increase in grain protein content and grain quality. Applications of nitrogen fertilizer at this stage should only be considered if the farmer receives a premium for higher protein content in the grain.

Management should be directed at providing adequate but not excessive amounts of nitrogen at the critical stages of development. Therefore, improved strategies for nitrogen management have to be developed and made available to people in national programs.

Specific objective--To develop a nitrogen management strategy that will maximize the use and the efficiency of the use of nitrogen by the crop, with the minimum impact on the environment.

Technical work plan--Two aspects have to be addressed in order to improve the efficiency of applied nitrogen: 1) the correct timing and rate of application have to be determined and 2) the best source and method of application. In studying the best timing and rate of application, a good diagnostic tool is necessary to determine both soil and plant N nutrient status. Soil NO_3 values in areas of low rainfall are good indicator of initial soil fertility. Soil samples should be taken al least at a depth of 0-30 and 30-60.

Basal stem NO_3-N has shown promise as indicators of cereal N status in Australia and Cyprus (Papastylianou and Puckridge 1981, Papastylianou et al. 1982, and Papastylianou 1986) and recently it has been very successful in Arizona (Knowles et al. 1991a,b).

The aspect of timing and rate using soil and tissue tests is currently being evaluated using the following strategy:

- Prior to planting, take soil NO_3 samples at 0-30 and 30-60 cm. These values should tell the farmer if any nitrogen needs to be applied between planting and the first irrigation for maximum economic yield (MEY).

- Prior to any irrigation (this will change with the irrigation scheduling of the area), take stem NO_3-N samples to decide if any and how much N needs to be applied for MEY and maximum economic quality (MEQ).

The use of the diagnostic tool of stem NO_3 seems to be most appropriate for calcareous soils with low organic matter content. These type of soils provide mostly NO_3 nutrition; therefore, the high correlation between stem NO_3 and yield.

The area of sources and methods of application will have to include the use of farm yard manure, green manures, or plant residue incorporation to at least maintain if not increase the organic matter content in the soil.

The use of computer models to aid in deciding the best time and rate of nitrogen fertilization as well as the aspect of sources and methods of applications is at present being address by a collaborative project between CIMMYT and IFDC (see Section 4.1.3).

Fertilization and water management should be studied together because the availability and strategies of nitrogen application will be dependent on moisture availability.

4) Weed control

Background--The weed *Phalaris minor* has spread very rapidly in the rice-wheat and central areas of the Punjab over the past two decades. This weed causes average losses of about 500 kg/ha in about 30% of fields classified as seriously infested (Byerlee et at. 1984).

Specific objectives--Strategic research in weed control for ME1 could be approached in different ways:

- Establish the critical weed-free period for different types of weeds. Emphasis could be given to the predominant weeds of ME1 such as *Avena* sp. and *Phalaris* sp.

- Develop a selection methodology for improved competing ability against weeds. First, through the identification of morphological characteristics that could give better competing ability against weeds. Second, through the evaluation and development of screening techniques that would allow for an efficient way of screening large numbers of lines for the characters identified. Alternatively, through a selection index, based on the morphological characteristics identified.

- Screen the germplasm bank for identification of possible lines with allelopathic compounds against major weeds in ME1. Screening germplasm for identification of lines least affected by allelopathic compounds of these major weeds would also be beneficial. Porwal and Gupta (1986) found that root exudates of *Avena fatua*, *Phalaris minor*, and *Chenopodium murale* decreased shoot and ear length and dry matter production by wheat. If any lines can be identified that have an allelopathic effect on weeds or lines that are less affected by allelopathic compounds from weeds, then they could be passed to the biotechnology group for identification of the genes conferring this trait. If the identified lines have a good agronomic type, they could directly be evaluated for their agronomic performance under ME1.

- Study the biology of the major weeds present in ME1 under conditions of ME1, since most of the research on weeds such as *Avena* sp. is done under temperate conditions often not representative of ME1. This should provide valuable information that could be used for the development of better strategies for control.

Crop Modeling

Computer models can be powerful tools in many areas. However, they need to be validated first and many times calibrated for a given region. If validation and calibration are successful, models offer many applications:

- Provide direction for research, assessing what is known and what is unknown or poorly understood.

- Contribute as a teaching aid. Modeling is multidisciplinary in nature, therefore it is valuable for integration..

- Allow the evaluation of management practices over long periods of time. This will be very important in sustainability work.

- Aid in studying interactions of different agronomic practices.

Models and GIS should provide a powerful tool to expand our results across ME1.

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4.1.2 Improvement of Input-use Efficiency in Irrigated Wheat Production

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Crop Production:	Dr. Oscar Moreno

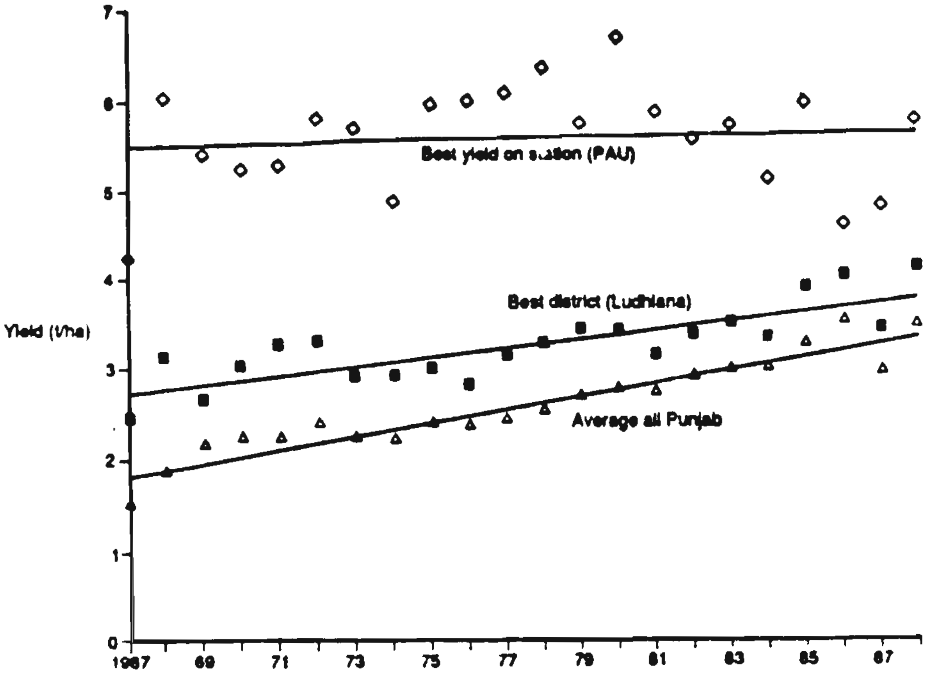
Background

Irrigated, low rainfall, temperate areas in the developing world comprise mega-environment one (ME1) in CIMMYT's classification of wheat producing areas (Rajaram and Fischer 1989). ME1 represents the most important wheat mega-environment delineated by CIMMYT in both current total wheat production (approximately 42%) and anticipated potential yield increases.

Examples of important areas within ME1 are the Indus Valley in Pakistan, the Gangetic Valley in India, the Nile Valley in Egypt, irrigated valleys in Chile and Peru, irrigated valleys in northwest Mexico (including the Yaqui Valley) and irrigated areas in Central Mexico (the Bajio) where wheat is grown in the dry winter season. Wheat is also produced in similar production systems in the Sudan, Nigeria, Bangladesh, and parts of China with the constraint of higher temperatures and/or humidity (ME5).

ME1 can be presently characterized by the following. First, average farmer yields have not substantially increased during the past 5-10 years in several major ME1 areas including the Yaqui Valley in Mexico and the Punjab of India (Figure 4.1 from Byerlee 1990 and Figures 4.2 and 4.3). In addition, the genetic yield potential of new varieties has not demonstrated significant increases over varieties currently in use during this same period (Figures 4.4 and 4.5). This leads to concern that the future for potential yield and production increases, particularly derived from new, higher-yielding varieties, may be rather small, barring a major breakthrough in yield potential.

Furthermore, in areas like Central and Northwest Mexico and the Indian Punjab, average farmer yields are approximately 60-80% of the current "best" yields obtained at experiment stations. Better farmers obtain yields at near par with these best station yields. Improved agronomy may lead to continued increases in farmers' yields, further reducing the yield gap, but such technologies must be within economic feasibility for farmers. In short, further dramatic, sustained yield increases may be difficult to obtain over the near term in some major areas comprising ME1. There are, however, other areas in ME1 where current farm yields are considerably below yields obtained in experiment stations (Byerlee 1990). Improved agronomic management can certainly play the major role in these areas in the near term to reduce this yield gap.



Source: Punjab Agricultural University.

Figure 4.1. Farmers' yields and potential yield of wheat, Punjab, India. Source: Byerlee (1990).

Second, essentially all areas included in ME1 are characterized by the potential to produce a wide range of crops that compete for the same time, space, irrigation water, farmer resources and favorable climatic conditions with wheat. Crop choice by farmers usually is determined by market conditions subject to government policies guiding production prices and subsidies.

In many wheat areas of ME1, current wheat production areas/levels occur because of direct or indirect government interventions that may favor wheat production. It is doubtful if wheat could compete as well or would be as widely grown in some of these areas without such interventions. Given current low world wheat prices and the trends by many governments to convert to more free market policies, the current competitive advantage of wheat may diminish in some ME1 areas given the real costs of production and wheat prices.

Both of these rather broad but realistic characteristics defining several major ME1 wheat producing areas, strongly argue for innovative research to develop rational technologies to increase the efficiency of input use in irrigated wheat at the farm level to improve production cost effectiveness and wheat competitiveness. This research initiative must also be conducted with objectives consistent with issues of production sustainability. One additional consideration of most ME1 areas, is concern for the sustainability of the common, intense production systems (rice-wheat, cotton-wheat, soybean-wheat, maize-wheat) over the long term.

Objectives

The broad objective of this project will be to develop a research strategy that addresses improvements in the efficiency of agronomic input use for irrigated wheat production areas defined by ME1. Potential agronomic input categories relevant for investigation will include: 1) plant nutrients (high emphasis on N); 2) irrigation water; 3) tillage operations (emphasizing improving crop residue management and reduction of power requirements including mechanical, animal and human for tillage operations) 4) planting practices (methods/seed rates); 5) weed, insect, and disease control (emphasis on

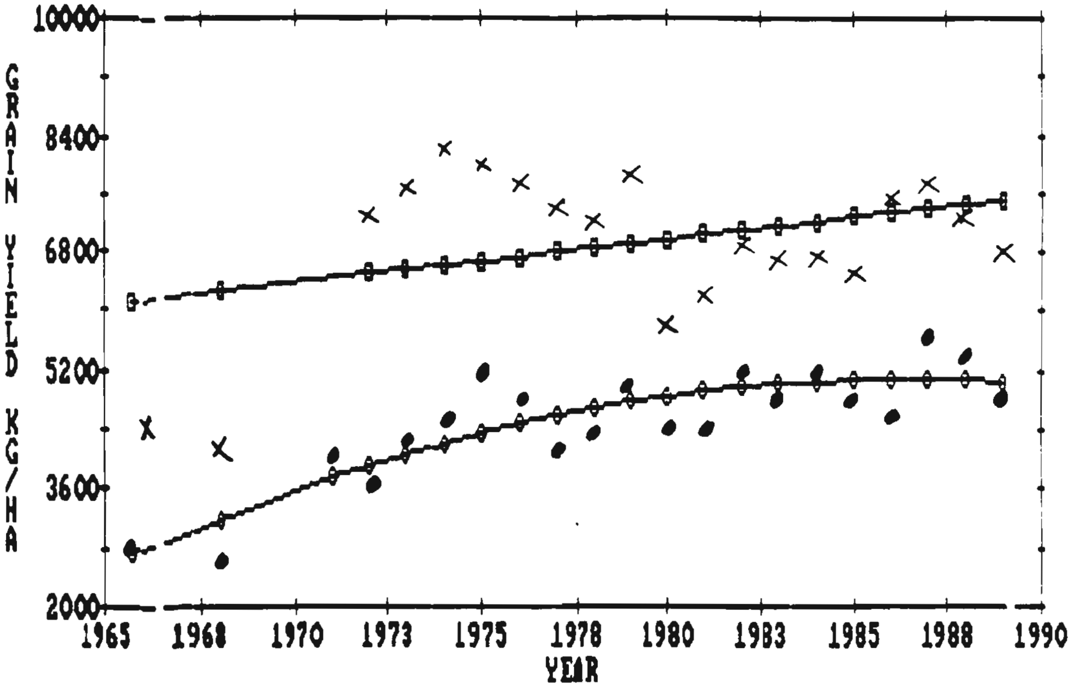


Figure 4.2. Mean yield and potential yield of bread wheat for the Yaqui Valley.

▯ Yield of highest yielding bread wheat in the ISWYN at CIANO
o Average Yaqui Valley yield

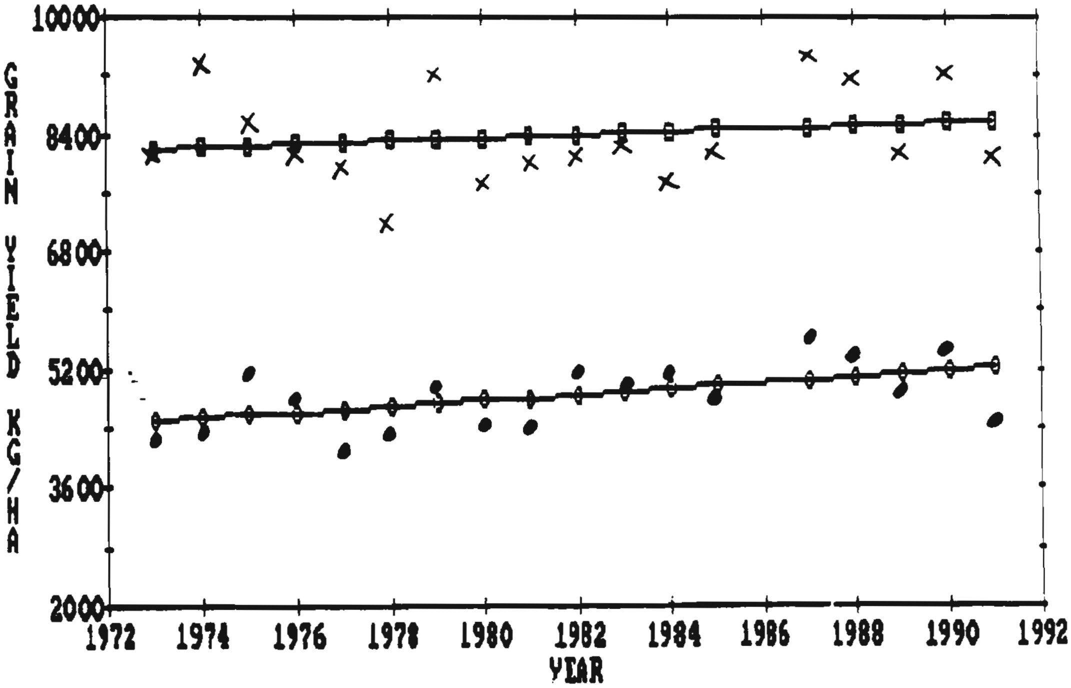


Figure 4.3. Mean yield and potential yield of durum wheat for the Yaqui Valley.

▯ Yield of highest yielding durum wheat in the normal trials at CIANO
o Average Yaqui Valley yield

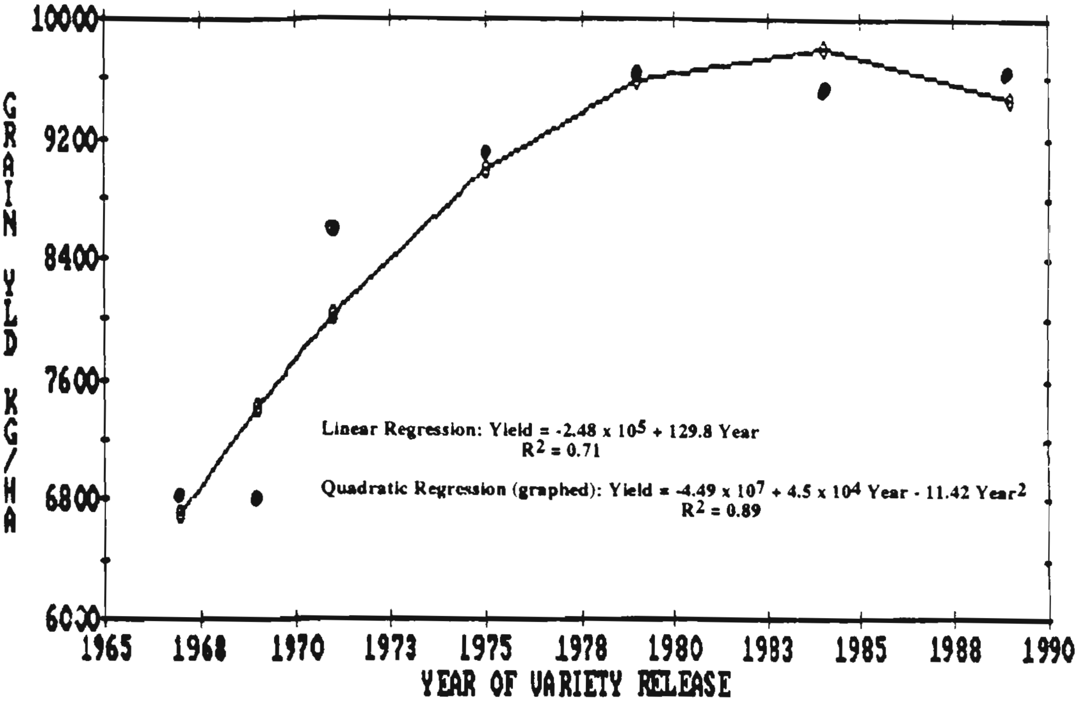


Figure 4.4. Durum wheat grain yield trend, 1990.

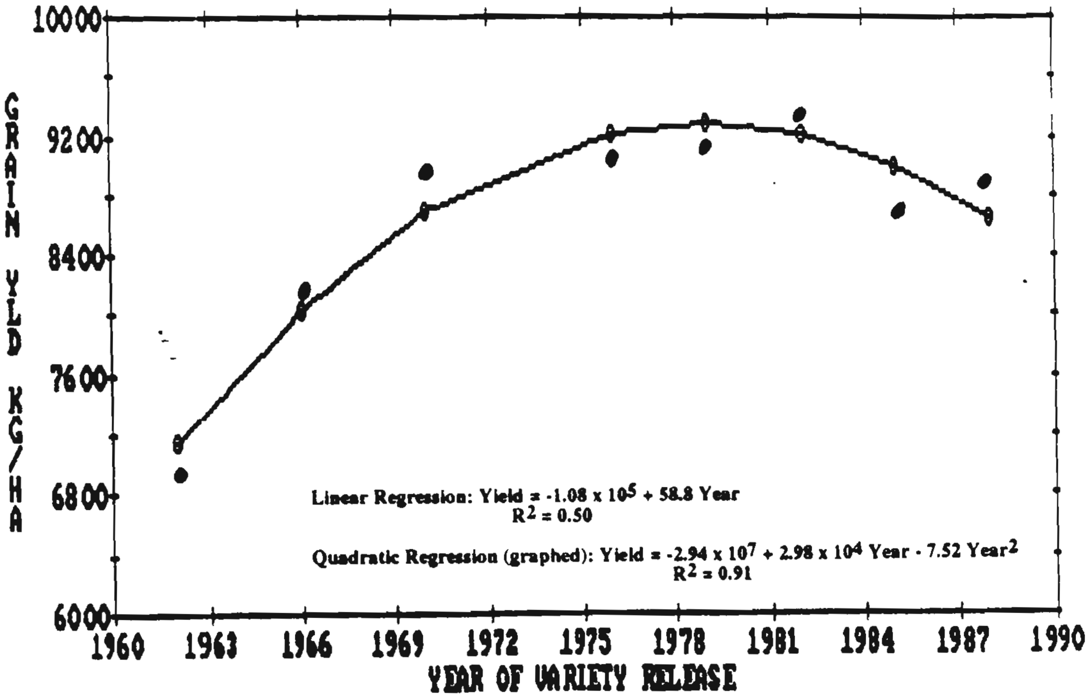


Figure 4.5. Bread wheat grain yield trend, 1990.

integrated weed control); 6) crop rotations and 7) varieties. Clearly improving the efficiency of inputs used in wheat production especially fertilizers and pesticides, is relevant to both National Programs and CIMMYT considering the increased world-wide concern for environmental issues.

Strategies for improving efficiency can encompass yield increases attributable to better management of current input use levels and/or maintenance of current yield levels with corresponding, significant reductions in specific input use levels. Recent results from research conducted by CIANO in the Yaqui Valley indicate that current yield levels could be maintained with up to a 50% reduction in some input costs (Dr. Oscar Moreno, Pers. comm.). These strategies should recognize that soils in many ME1 areas must be considered to be "fragile" primarily because of susceptibility to development of salinity problems on the one hand, and indications of potential yield sustainability problems related to emerging soil nutrient, disease and/or still undefined factors resulting from intensive cultivation, on the other. Therefore resulting strategies must be judged on the basis of long-term production sustainability, not solely on their immediate effects on yield and/or economics of production costs.

The project will attempt to develop a research process to achieve the broad objectives given above. To be relevant, however, this research process should be capable of useful extrapolation to national program research organizations in ME1 for their adoption. Specific objectives, then, will be as follows:

- To develop and refine an on-farm survey and agronomic diagnosis methodology that will lead to identification of factors that constrain yields, but more specifically, situations where input levels used by farmers do not meet production expectations (see Appendix 4.1.2 for a description of these diagnosis procedures). This diagnosis should be an iterative process, modified as needed to provide the continuously required information defining farm conditions over time.

- To re-focus existing on-station research involving input management to emphasize efficiency and to develop relevant, new on-station trials directed at more relevant issues resulting from new knowledge obtained through the iterative diagnostic process.

- To subsequently develop practical on-farm research investigations that test, verify, and ultimately demonstrate to farmers appropriate technologies that can improve input use efficiency, (returns to costs) and/or alleviate existing yield constraints. This also is an iterative process.

Proper achievement of these objectives should lead to average farmer yields that either show a more pronounced increasing trend without marked increases in input costs and/or at least remain stable with significant, corresponding reduction in input costs.

Operational Framework

This project constitutes a part of the CIMMYT base crop management research effort in Mexico. It will, however, need to evolve activities on farmers' fields to achieve relevance. This is not normally considered the *brief* of center-based staff. Factors constraining yields or leading to low input use efficiency in ME1, however, are logically best expressed and defined by observing and working in farmers' fields. To do this, a sound agronomic survey/diagnosis methodology must be implemented. Furthermore, appropriate agronomic research on station occurs when the emphasis is on solving well-defined farmer relevant problems. And certainly, the best method to test potential solutions to these problems involves a return to farmers' fields and intimate farmer involvement in judging the soundness of these solutions.

The CIMMYT agronomists based in Mexico will concentrate this effort in the Yaqui Valley in Sonora, northwest Mexico as a part of the ongoing research normally conducted during the winter cycle at the CIANO experiment station.

To ensure relevance, the project will require close coordination and collaboration between CIANO and CIMMYT wheat agronomy. Participation from both sides in all aspects (diagnostics, on-station research, and on-farm testing and verification) will be a pre-requisite, particularly in on-farm activities. The research activities will then focus on yield constraints and potential input use inefficiencies that may exist in the Yaqui Valley as an appropriate area for developing research tools/methodologies and hopefully, research results that can be extrapolated to other ME1 areas, at least as first approximations to solving similar problems.

Useful research results should be of direct and immediate application to farmers in the Yaqui Valley and nearby, similar areas. The project will complement and extend existing CIANO efforts in wheat agronomy and reduce current duplications in research activities between CIANO and CIMMYT. The on-farm research phase will be extremely useful for CIANO since little on-farm research is presently conducted.

CIMMYT wheat agronomists must evolve and maintain a broader viewpoint that balances international responsibilities to identify and research production factors broadly applicable to ME1 with activities that may be more specific to Mexico. The latter, however, can be justified to a large degree by the following:

- The Yaqui Valley and CIANO have been intimately involved with the CIMMYT Wheat Program since its inception. The Yaqui Valley has been and still is the initial showcase for the potential utility and eventual impact of CIMMYT's contribution to wheat production in the developing world, especially in relation to improved germplasm. CIMMYT has a vested interest to determine why wheat yields on-station and in farmers' fields have not markedly increased in the Yaqui Valley for the past 5-8 years. As mentioned above, this phenomenon is occurring in other ME1 areas and merits investigations to understand how it can be changed.

- It should be realized that the physical presence of an international center like CIMMYT in a country does not mean that adequate collaboration between the host country national programs and the international center automatically occurs. Collaboration between breeders from the respective institutions usually is more likely to occur through germplasm exchange. Collaboration in agronomic research is more difficult to achieve as has been CIMMYT's experience in the wheat program in Mexico; therefore, this project can be looked upon as an opportunity to develop a relationship between CIMMYT and CIANO wheat agronomists similar to that found in the outreach environment. However, CIMMYT scientists will be cognizant of potential ramifications of the project activities in Mexico that are pertinent to other ME1 areas. CIMMYT outreach scientists with activities in ME1 areas are invited to take an active interest in the project. The project, as it evolves, can become a useful focus for interaction with visitors/visiting scientists from ME1 regions and for training purposes.

Implementation Procedures

The agronomic survey/diagnostic process was initiated in the Yaqui Valley during the 1990-91 cycle (Meisner et al. 1992). This effort provided new/additional information identifying factors constraining yields and/or resulting in inefficiency in current input uses. This diagnostic cycle allowed:

- Development of on-station trials in the 1991-92 cycle to follow-up new insights.
- Specification of additional diagnostic efforts needed in the 1991-92 cycle and future years to clear up dubious factors.

Both CIANO and CIMMYT, however, already have existing research activities concerning yield constraining factors or input use inefficiencies. Collectively, these trials are mainly involved with irrigation management, fertility management (including N and organic matter), seeding methods/rates, weed, insect and disease control, tillage practices (including reduced tillage and straw management), crop rotations (including relay-cropping) and advance line evaluation. An assessment is needed to determine relevance of these trials for continuation and/or possible modification viewed against the background of the new diagnostic information.

The nature of the collaborative relationship between CIANO and CIMMYT within the project is evolving. Both entities have taken part in the diagnostics process. As mentioned above, extensive on-station trials are in progress. During the current cycle, exchange of information concerning the nature of on-station trials occurred with some collaboration in trial design. It is suggested that this phase of the research remain somewhat flexible. Ideas need to be exchanged, trial results shared, discussed and used. What is important is that the on-station trials conducted by both institutions are problem-oriented and avoid duplication of effort. The broader ME1 focus of CIMMYT agronomic trials versus the more specific orientation of CIANO trials argues for both institutions to continue to conduct independent on-station trials following detailed discussions and delineation of respective research emphasis.

The on-farm research phase requires a solid commitment of manpower and resources from both institution to a set of common trials. Currently, on-farm trials are restricted to testing advanced bread and durum wheat lines with CIMMYT staff most directly involved. CIANO has installed seeding method/rate demonstrations with farmers in several locations. This was markedly increased in the 1991-92 cycle since both CIANO and CIMMYT possess on-station trial results that merit initiation of on-farm verifications. An early establishment of a vigorous on-farm research program is viewed as critically important to gain early experience and expertise and to involve carefully selected farmers in the technology verification process at an early stage.

Research Support-CIMMYT

It is conceived that the research proposed here can be used as a framework to identify well defined, component research topics amenable for development of special projects with associated special project funding. A clear example is the recently prepared proposal for collaboration between IFDC and CIMMYT to study N use efficiency parameters for irrigated wheat production. This special project, if approved for funding, will take part of the research activities proposed here. A similar project concerning evaluation of and the potential importance of bread wheat genotype differences in their ability to compete with weeds in being developed.

As more experience is gained concerning factors constraining yields or input use efficiency, this knowledge can be used to generate interest from funding organizations to support other special projects associated with the overall research area of increasing the efficiency of using agronomic input is wheat in ME1.

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Appendix 4.1.2
On-Farm Diagnostic Wheat Research in the Yaqui Valley, Mexico

Objectives and Justification

On-farm diagnostic research is a modern term for research that had occurred less formally in the past when researchers tried to recognize and evaluate limiting factors affecting crop yield. There are many publication in the literature concerning on-farm diagnostic research (see accompanying bibliography). Byerlee et al. (1989) has delineated on-farm diagnostic research into three categories:

- Informal surveys with growers.

- Crop production surveys integrating agronomic and socioeconomic variables.

- Farming system surveys covering broader aspects of the farming system and the system interactions.

Regardless of the above categories, techniques, or approaches used, the goal of on-farm diagnostic research is to evaluate those factors in growers' fields which either limit crop yield or cause yield over time to be unsustainable. Usually such evaluations provide a basis for future research either as on-farm trials or on experiment stations.

Many modern techniques for quantifying potential limiting factors of crop yields have become more widely used and available even to developing countries. Thus, there has been a shift from the use of the traditional category of using informal surveys with growers to the use of crop production surveys. Instrumentation and techniques now widely used and available include: soil and plant tissue analysis, canopy temperature meters, soil moisture instrumentation, penetrometers, leaf area meters, porometers, photosynthesis meters, among others. Thus, while the use of informal grower surveys remains a vital part of diagnoses, researchers can measure many agronomic parameters. Such data coupled with the informal grower surveys can allow researchers to better quantify and then statistically prioritize those parameters limiting or causing unsustainable yields as a basis for further research.

Wheat research within the Yaqui Valley has been ongoing for many years, especially since the growers in the valley and the Mexican government formed CIANO (Centro de Investigaciones Agricolas del Noroeste) in 1955. Much of the on-farm diagnostic research accomplished by CIANO and CIMMYT within this region was based on the use of informal surveys with the area growers. CIMMYT economists have conducted such informal surveys over the past years, providing a database for economic research. The evolution of past diagnostic research within the valley from informal surveys to crop production surveys involved a cooperative research effort by CIANO and CIMMYT agronomists and economists during the wheat cycle 1990-91 in the Yaqui Valley. During a meeting with the CIANO and CIMMYT staff in the fall of 1990, many CIANO researchers expressed an interest in making this diagnostic surveying into the systems approach. Thus, after fulfilling the objectives during the 1990-1991 wheat cycle, if the interest by CIANO continues, perhaps a more comprehensive systems approach in diagnostic research could prove vital to the interests of CIANO, Yaqui Valley growers, and CIMMYT.

The objectives of this research were to:

- Further develop on-farm diagnostic research techniques using the crop production survey within the Yaqui Valley with the hope that such techniques can be transferred to and used in other areas of the world.
- Determine yield limiting factors as a basis for future on-farm trials and experiment station research for the Yaqui Valley.
- Facilitate the evolution of the present crop production survey of diagnostic research into the third category of diagnostic research, the systems approach, whereby not only would the wheat crop cycle be observed, but observations on the yield constraints of all crops raised during the year be made.

Materials and Methods

Fifty-two farmers in the Yaqui Valley were surveyed (Meisner et al. 1992). These farmers were selected from the random sample previously selected in 1981 by the CIMMYT economics section and surveyed four times since 1981. The criteria for site selection was made by the resource factor of soil, choosing those farmers with fields within the more clayey soils of the region (representing 60% of the valley) and those sites with salt problems. An informal survey of farmers and detailed observations of farmers' soil and wheat crop over the season provided the database.

A questionnaire similar to the one prepared by D. Flores in 1989 was used to gather background information from the farmers. In addition, the following data were collected from a marked, 20 x 20-m plot, chosen from within a farmer's field. Criteria for field and plot selection included accessibility and lack of apparent soil variability (i.e., level, not near or far from irrigation source), yet typifying the whole field.

Observations Made:

- Soil assessment by digging a pit and typifying the soil characteristics, collecting soil for determination of: bulk density, volumetric water content, soil fertility of plow layer and sub-soil, and nematode population assay.
- Soil penetrometer readings starting from within the plant row to various distances from the plants.
- Plant density.
- Land preparation rating.
- Brief interview with farmer to deduce information on: Seeding date, rate, and treatment, land preparation, irrigation pre- or post planting, and planting methods.
- Soil infiltration rate.
- Disease, weed, nutritional, and insect pest ratings.
- Agronomic score 1-9.
- Ground cover score.
- Soil sample for rooting depth.

- Canopy temperature.
- Survey of farmer and farmer practices using questionnaire.
- Score of wheat phenology.
- Soil sample for fertility and nematode assay at harvest.
- Plant tissue sample for nutrition status, especially $N-NO_3$.
- Date of anthesis, and physiological maturity.
- Grains/floret ratio.
- Crop cut at maturity to determine:
  - a) fertile spikes/m^2
  - b) total biomass
  - c) grains/floret ratio
  - d) spikelets/spike ratio
  - e) thousand kernel weight
  - f) total grain yield

Complete details of this diagnostic survey are in Meisner et al. (1992).

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4.1.3 Improving the Nitrogen Use Efficiency of Irrigated Wheat in the Developing World

Submitted by:
International Maize and Wheat Improvement Center (CIMMYT)
and
International Fertilizer Development Center (IFDC)
16 May 1991

Background and Justification
A substantial proportion of the wheat crop in developing countries is grown under irrigation in areas of low rainfall with temperate and subtropical climates (ME 1), of which the Yaqui Valley of Mexico, the Nile Valley in Egypt, and the Ganges and Indus Plains of the Indian subcontinent are major examples (Table 4.1--Section 4.1.1). ME1 accounts for about 40% of wheat production in the developing world (CIMMYT, 1989). This environment represents a high-input system with substantial wheat yield potential. The economic payoffs to research are extremely high in terms of improving input use efficiency. The amount of land coming under irrigation has increased by 3% per year over the last 20 years. However, in the foreseeable future no major expansion could be anticipated. In fact, the total area sown to cereals in ME1 is likely to fall (Byerlee 1990). Therefore, the increased productivity of wheat in these areas is crucial if future food demands are to be met in developing countries.

The biggest production constraint in ME 1 is soil fertility, particularly nitrogen. In developing countries, nitrogen accounts for about two-thirds of the fertilizer nutrients applied. During the last 15 years there has been a dramatic increase in nitrogen fertilizer use for irrigated wheat (FAO 1987, World Bank 1987). Thus, nitrogen fertilizer represents a major economic input. However, the efficiency of nitrogen utilization is highly variable, but in general it is low, perhaps ranging from 25 to 33% (Byerlee and Siddiq 1990). In the Yaqui Valley of northwestern Mexico, for example, some 225- 250 kg of nitrogen are applied per hectare, yet wheat yields average 5.5 t/ha (25-30% N use efficiency). Nitrogen losses in these systems may be considerable, primarily a result of nitrate leaching, ammonia volatilization, and/or denitrification. The mechanisms whereby nitrogen is lost to the system differ, depending on climate, soil and cropping system. In general, nitrogen pathways are highly complex, and the strategies developed for improving nitrogen management and nitrogen use efficiency need to take account of site, soil, and seasonal patterns.

The increase in demand for wheat anticipated in the developing countries is 3% per annum (Byerlee 1990). This cannot be met by the use of new varieties which have shown a worldwide average increase in yield potential of 0.7% annually (Byerlee and Heisey 1989). To meet food demands and ensure food security in the developing world, increased productivity will have to be achieved mostly by better agronomic management, particularly through improved nitrogen fertilizer use efficiency. With improved input-use efficiency it would be economically feasible for wheat farmers to compete in the world market even at current low prices. A readily-achievable 5% increase in efficiency would result in considerable savings of foreign exchange for countries where fertilizer has to be imported. This could be brought about by reducing nitrogen losses. The added benefits to the environment in terms of reduced groundwater contamination and lowered nitrous oxide (N_2O) emissions would also be substantial.

Rationale
To achieve increases in nitrogen use efficiency, the critical interactions between crop growth, irrigation and fertilizer applications must be evaluated. A program of experimentation is proposed to fill in some of the gaps in scientific knowledge of the dynamics of nitrogen in

such systems. The results from the experimental program will be used to further develop decision support tools. In turn, these will be utilized to identify and assess optimal and sustainable management strategies concerning irrigation and fertilizer applications for farmers in this ME. The work proposed involves:

- Extension and refinement of an existing simulation model of the growth and development of wheat with respect to nitrogen dynamics.

- Development of a nitrogen recommendation expert system that is linked to the wheat simulation model.

Recent experience shows that there is considerable potential for integrating computer-based decision support tools into the research and development process. Increased efficiency in the transfer of technology horizontally and vertically, both in the design of appropriate soil fertility and crop management packages for smallholder farmers and in the extension of the results, can be achieved thereby. The application of systems methodology complements more traditional approaches to agricultural research, but is not a replacement for it. Two features of the methodology stand out: 1) repeatability across space, and 2) repeatability over time. The first allows the assessment, in an objective fashion, of crop performance in locations where field experimentation has not necessarily been carried out. The second provides the means for studying the dynamics of agricultural systems in terms of the changing circumstances of production and the vagaries of weather. The advantages of using simulation models include the following: a much wider variety of production possibilities can be screened than is possible with field trials; production alternatives can be screened with direct reference to the resource base of farmers; and production alternatives can be screened over many soil types and over many seasons, allowing production stability and sustainability over time to be investigated explicitly.

Expert or rule-based systems are computer programs that mimic the decision making behavior of experts in a particular field of enquiry. They can be used to help a decision maker choose among a set of alternatives in situations where human expertise is scarce or lacking altogether. In addition, expert systems form a simple-to-use framework for turning the results obtained from highly complex models of physical or mental processes into simple management recommendations that can be applied directly at the farm level. Decision support tools based on simulation models and expert systems thus offer considerable potential for both the derivation and the application of soil fertility and crop management recommendations.

Project Objectives

The goals of the project are to:

- Increase food production by improving the nitrogen use efficiency of wheat in the low rainfall irrigated areas of developing countries.

- Demonstrate innovative, but practical methods of formulating nitrogen-use strategies for sustainable crop production.

Specific objectives include:

- Carrying out experimental work, principally in the Yaqui Valley where CIMMYT's main wheat research station is located, to investigate various aspects of nitrogen use efficiency of the wheat crop under irrigation. It is proposed that the Yaqui Valley environment be used as a benchmark site for the major portion of the field work. Other satellite trials will be run at other locations (India and North Africa) in ME 1, to generate data sets that can be used for validation of the wheat model. A small network of experimental sites would be developed over the life of the project.

- Using the results of the experimental work as well as existing experimental data on soils, crops and weather to develop further and to refine various relationships in the CERES-Wheat simulation model. The areas that need development include: 1) genotype by water and nitrogen interactions; 2) plant tissue N concentration; 3) organic residue mineralization and N availability; and 4) ammonia volatilization and nitrogen leaching loss mechanisms that operate in this environment, with chemical fertilizers and organic residues.

- Using the knowledge generated to produce a validated simulation model and expert system for tactical and strategic decision making in ME1. These will be used specifically to investigate and define management strategies that are appropriate for any given location, with respect to: 1) the timing and quantity of irrigation and nutrient inputs, 2) the effects on yield, 3) the effects on grain quality (protein content), and 4) the nutrient losses that result.

- Determining the fate of applied nitrogen fertilizers and organic nitrogen over long periods of time in a wheat cropping system.

Project Outputs

The results of the experimental work will be used to construct tools that can be applied in ME1 at a number of levels:

- At the farm level to identify and assess sustainable management strategies that are directly applicable to smallholder farmers, by taking account of the local bio-physical and socio-economic environment within which wheat growing is practiced.

- At the research level, to gain a better understanding of the following: a) nitrogen uptake patterns in wheat under various management conditions (genotypes, irrigation, N rates); b) nutrient release rates from different types of N fertilizer material (controlled-release, coated) and manures; and c) how nutrient losses may be minimized in such systems. Further, the model can be used to delineate the characteristics of an ideal genotype-fertilizer-management package that optimizes yield whilst minimizing nutrient losses in this environment.

- At the policy level, the modeling effort allows the identification and prioritization of further research initiatives, and the possible impact of economic and environmental effects of the adoption of new genotypes, new fertilizer materials, and new management practices.

The potential benefits arising from this research, through the identification and application of more efficient management practices, are likely to be substantial. Increased nitrogen and water use efficiency and reduced nitrogen losses will have an important impact on sustainable agricultural systems, in terms of their environmental and socio-economic effects. These benefits enhance the opportunity for achieving wheat production increases at a pace required to meet the growing demand in the developing world, and in a way which will allow sustained production without damaging the environment.

The primary economic benefits may also be substantial. Globally, some 11 million tons of fertilizer nitrogen are used on wheat annually. A five percentage point increase in the average efficiency of nitrogen use by the wheat crop, from 30 to 35%, for example, is thus currently worth at least $US100 million, directly.

Project Workplan

Experimental--The experiments proposed will be carried out on diverse soil types and management conditions prevailing in selected areas of ME1. The treatments discussed below are diverse enough to provide a stringent test for the CERES-Wheat model and the N Recommendation Expert System. Once refined and validated, the model and expert system would constitute powerful tools for assessing sustainable production options in ME 1. Two distinct types of experiment will be carried out on a) large agronomic plots and b) smaller research plots. The type of data needed to refine and validate the crop model and expert system is described in Table 4.2. The experimental procedure proposed here differs from conventional agronomic trials in the type of measurements, in the degree of detail, and in the frequency of sampling. There is a dearth of such information, especially from the tropics and subtropics. Within the experiments, additional information will be generated in some treatments from microplots and small research plots. In microplots, fertilizer labelled with 15N will be used to determine the dynamics and transformation of N in the soil, patterns of N uptake by wheat, and pathways of N loss. This information will be used in defining appropriate relationships in the wheat model.

Table 4.2. Data requirements for refining and validating CERES-wheat and the N recommendation decision support system.

Type of Data	Primary Use
Daily Weather - maximum temperature - minimum temperature - rainfall - solar radiation	Minimum requirement
Site - latitude - runoff and drainage - soil color/albedo	Minimum requirement
Soil Property (by layer) - sand, silt and clay content - bulk density (moist) - organic carbon content - pH (water) optional: * lower limit water content * drained upper limit water content * saturated water content * rooting preference index * total N	Minimum requirement
Soil Initial Condition (by layer) - soil water content - soil nitrate and ammonium content	Minimum requirement

Wheat Genotype Data - emergence date - anthesis date - maturity date - yield components under nonlimiting condition	Minimum requirement
Management Data - planting date - plant population - row spacing - irrigation scheduling (amount, date) - fertilizer scheduling: amount, date, type, method	Minimum requirement
Within-Season Soil Data (by layer) - soil nitrate and ammonium - soil moisture	Model validation/ refinement
Within-Season Harvest - biomass, LAI, plant components	Model validation/ refinement
Within-Season Tissue Analysis - N concentration in components - NO_3- concentration in stem	Model validation/ N recommendation

Adapted from IBSNAT (1988).

Experiments will be designed to allow soil sampling for soil moisture and nutrients, and plant analysis during the course of the growing season in all trials. In a wheat cropping system study the above sampling will be continued to include the crop following wheat.

Field work will be carried out under nonlimiting conditions for variables that are not under investigation. Neutron probes will be used to measure soil water content, and soil samples will be analyzed for KCl-extractable ammonium and nitrate, and total N. Experimental and historical data will be collated in a format that conforms with the standard minimum data set as specified by the International Benchmark Sites Network for Agrotechnology Transfer project (IBSNAT 1988).

In the large agronomic plots (8 x 5 m), periodic soil and plant sampling to determine soil nitrate and ammonium status, moisture content, plant growth, and tissue nitrogen and nitrate content will be carried out. Below-ground harvest of roots will be carried out at least three times during the growing season for some selected experiments and treatments only. These data will be critical for gaining an understanding of root distribution under different water and nitrogen regimes and of nitrogen use efficiency.

The small research plots (4 x 4 m) will be used for the long-term study on volatilization, mineralization, and concomitant leaching of N from chemical fertilizers and organic sources over multiple seasons and crops. Some of the treatments will have microplots with 15_N applied as well.

Individual experiments will be designed from the following range of treatments: a) Soil types--sandy alluvial and clayey; b) Sources of nitrogen fertilizers--urea, control-release urea, nitrate, wheat straw, green manure, and farm yard manure; c) Rates of N--0, 75, 150, 225, and 300 kg N/ha; d) Timing--planting, 4th leaf stage (pre- and post-irrigation), and 1st node; e) Method--broadcast, incorporated, 10-32; and f) Irrigation--line source (5 points along a gradient), flood. Standard planting densities and common genotypes will be used in the experiments.

Ongoing Research

There is considerable complementarity between the project and ongoing activities at both IFDC and CIMMYT. IFDC is actively working with IBSNAT, Michigan State University, ICRISAT, IRRI, and The Universities of Florida and Guelph to improve the crop and nutrient simulation models. IFDC has field trials evaluating nitrogen dynamics in Malawi with maize, Uruguay with rainfed wheat and barley, ICRISAT with sorghum, and IRRI with rice. These trials will provide valuable information on nitrogen transformation processes.

It is anticipated that some of CIMMYT's wheat trials (Table 4.3) would provide relevant information on the fate of nitrogen, and in some instances may be used for validating the model and estimating genotype coefficients of durum and spring wheat varieties.

Table 4.3. 1990-91 CIMMYT wheat experiments.

Experiment	Type of Data	Possible Model Use
Yield potential	date--anthesis, maturity; harvest--anthesis, final	validation
N management	initial and intermediate soil nutrient and water content; date--anthesis, maturity; harvest--anthesis, final	validation
Maximum Yield	date--anthesis, maturity harvest--3 intermediate and final	validation
Efficiency of N use and quality	initial soil nutrient, water; date--anthesis, maturity harvest--2 intermediate and final	validation
Straw management	date--anthesis, maturity harvest--anthesis, final	validation
Line-source	initial, intermediate soil water content; and harvest--final	validation

Double line-source	initial, intermediate soil water content; and harvest--final	validation
Agronomic diagnosis in farmers' fields	initial soil water, nutrient; soil physical properties; harvest--2 intermediate and final; and tissue N concentration	validation

Modeling

Recent research at IFDC and at other institutions indicates that crop growth simulation models, combined with the basic information on reactions of different forms of nutrients in the soil, hold high potential for rapid assessment of fertilizer management decisions that are neither site- nor season-specific. The basic premise is that a nitrogen dynamics model that takes into account the key factors that influence N transformation should be able to simulate N reactions in any soil, in any season, and in any location.

CERES-Wheat is a simulation model that allows the quantitative determination of the growth and development of the wheat crop, and was developed under the auspices of the IBSNAT project (Godwin et al. 1989). The model simulates growth, phenology, water and nitrogen balance, and yield of wheat in any environment specified in terms of soil and climatic conditions. A phosphorus component for CERES-Wheat is currently under development at IFDC.

The model operates on a daily time step from sowing to maturity, on the basis of physiological processes as determined by the response of the plant to soil and aerial environmental conditions. Running the model requires a minimum of input data which are readily obtained from typical agronomic experiments (IBSNAT 1988). However, to validate the model for particular locations, additional data are needed, as specified in Table 4.2. In conjunction with the nitrogen recommendation expert system, the simulation model will be used for both tactical (real-time, or within-season) and strategic (long-term) decision-making.

In the nitrogen submodel, various processes are simulated: the turnover of organic matter with the associated mineralization and/or immobilization of nitrogen, nitrification, denitrification, hydrolysis of urea, and ammonia volatilization. Fluxes of nitrate and urea associated with water movement are also simulated. Nitrogen uptake is treated as a process that is sensitive to soil nitrogen concentrations, root length density, soil water availability, and plant nitrogen demand. Thus, the distribution of root growth among soil layers is simulated as a process which is very sensitive to the prevailing water and nitrogen conditions in each layer. In environments where timing and placement of fertilizer applications may be critical, the simulation of root distribution in this manner enables the model to show sensitivity to fertilizer management. The effects of nitrogen deficiency on photosynthesis, leaf area development, tillering, senescence, and remobilization during grain filling are included. The model does not simulate the effect of N stress on phenological development, however. Trials data will be used to incorporate this effect into the model. Nitrogen transformations associated with chemical fertilizers and organic sources can also be simulated.

CERES-Wheat and the nitrogen submodel have been validated and applied in many locations world-wide (Otter-Nacke et al., 1986). However, refinements and modifications may be needed for the following processes:

- Leaching.

- Ammonium volatilization,

- Mineralization and immobilization as affected by different forms of N.

- Salt accumulation.

With respect to leaching, nitrate and urea movement in the model are dependent upon water movement. This procedure has worked well in many soils. However, recent tests have indicated that in spite of accurate water balance predictions the model tends to overpredict leaching in variably charged soils, particularly positively charged soils with nitrate retention capability (Bowen et al. 1990). Mineralization and immobilization processes in the CERES model as influenced by differences in soil properties, C:N ratio of organic residue, and composition of fresh organic residues (in terms of carbohydrate, cellulose and lignin), need to be tested under long-term cultivation conditions. The relationships in the model that deal with volatilization losses following top-dress applications of urea and ammonium fertilizers also need to be validated and refined under various irrigation management options.

A diagnostic N recommendation expert system will be developed based on tissue nitrogen and nitrate concentration. The expert system linked with the crop model will enhance the model's capability to provide within-season management decisions. A model run can be halted at any time during crop growth to provide information on the status of the crop. Based on the current tissue nutrient concentration, management decisions could be made pertaining to fertilizer application and amount, for example.

The field experiments described above have been designed to enable CERES-Wheat to be refined for ME1. Once this has been done, validation can then be carried out using existing experimental data sets. After validation, simulation experiments can be carried out using historical or synthetically generated weather sequences over many seasons. Fifty fertilizer strategies can be simulated in several minutes on a personal computer, facilitating the rapid evaluation of strategies in terms of the distribution of outcomes that can arise over time. The risks arising from weather variability and input-output cost uncertainty that are associated with particular treatments can thus be exposed and quantified. For example, based on the long- term weather and soils data as well as wheat and fertilizer prices, recommendations can be made regarding the N rates and management required to achieve maximum economic yields. Crop simulation models are therefore valuable tools for helping to achieve high yields without the wastage of valuable input resources.

Such ex-ante assessments of alternative management practices can provide information for use by researchers, farmers and policy makers that is tailored to particular bio-physical and socio-economic circumstances. Through the use of simulation modeling, the applicability of field trial results can be increased radically, by extrapolation through space and time.

International Collaboration

For a number of years IFDC has been an active member of the IBSNAT project. Staff at IFDC have assisted in model development and testing activities of IBSNAT, and have worked closely on the development of the Decision Support System for Agrotechnology Transfer (DSSAT), a piece of computer software that integrates crop models and natural resource databases. There has also been close liaison in training activities.

CIMMYT scientists have been using the DSSAT and have future plans to use the DSSAT and a geographic information system (GIS) in wheat-growing environments. It is envisaged that with the proposed project the linkage with IBSNAT will continue and also provide backup to the project. Both CIMMYT and IFDC have also expressed their desire to work with IBSNAT on a proposed sustainable agriculture project over the next five to ten years.

Both IFDC and CIMMYT have long experience in working with national programs in countries in the tropics and subtropics. The work proposed here will involve a number of national programs in ME 1 through the setting up and running of satellite experiments to complement the field work carried out in the Yaqui Valley of Mexico.

Project Execution

A 5-year collaborative project is envisaged. The research will be conducted jointly by IFDC and CIMMYT and will involve personnel and facilities of both institutions. An IFDC post-doctoral fellow will be stationed at CIMMYT on a full-time basis for the duration of the project to conduct the field experimentation on the fate and efficiency of N, and to communicate results to the crop modeler.

Some travel will be necessary between CIMMYT and IFDC. The post-doctoral fellow stationed at CIMMYT will be named with the mutual approval of IFDC and CIMMYT. The 15N tracing material needed for the project will be produced at IFDC. The soil N and plant N analysis for the labelled treatments will also be carried out at IFDC. Staff at IFDC will be responsible for adaptation of the models to ME 1. In collaboration with the post-doctoral fellow and CIMMYT scientists, IFDC modeling staff will work to sharpen the focus of the CERES-Wheat model and the N recommendation expert system to ME1. An economist/modeler from IFDC will also work closely with CIMMYT staff to incorporate appropriate economic components. Risk analyses will be carried out for differing nutrient management strategies that could be employed across ME 1. Based on the pricing structure of wheat and inputs, optimal economic fertilization strategies will be developed.

By the end of year 3, most of the experimental and modeling work should have been completed, allowing two years for model validation trials, model experimentation programs, and model applications to be developed.

Training

Training will form an integral part of the project. It is anticipated that training of key collaborators will be provided within the existing extensive training programs of IBSNAT, IFDC, and CIMMYT. The scientists participating in model validation trials from other locations in the ME1 network will be trained in data collection procedures and use of crop models. Eventually the skills needed to use the models will be transferred to national programs in ME1, so that they themselves can make relevant agricultural and natural resource decisions on input-use efficiency and sustainable production.

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4.2. Sustainability of Major Wheat Cropping Systems

Major developing world wheat cropping systems include rice-wheat, soybean-wheat, cotton-wheat, and maize-wheat. Each of these occupy relatively well defined geographical niches and have specific characteristics and problems. CMP is presently studying three of these systems aiming at identifying the production problems as well as medium- to long-term sustainability problems such that the resource base is maintained and improved along with systems yields.

The rice-wheat work is being done in South Asia, the soybean-wheat studies are being performed in Latin America (Southern Cone) and the wheat-maize work is being started in Mexico. In what follows, reports on the South Asia and Southern Cone activities and the wheat-maize project in Mexico are presented.

4.2.1 Pakistan: A Foundation for Strategic Research

Research results obtained by CIMMYT staff posted in Pakistan prior to 1988 are presented here since they laid down the foundation for the strategic rice-wheat and other systems work now being conducted in South Asia and elsewhere.

CIMMYT wheat involvement in Pakistan dates back to the early 1960s with vigorous germplasm development and exchange with local wheat breeders. This emphasis on germplasm development and disease resistance has led to a strong wheat breeding program and a succession of improved wheat varieties in the country. Most of the Pakistani alumni of CIMMYT germplasm improvement training are active and meet the demands for improved, disease resistant wheats for the country.

In 1977, CIMMYT posted Dr. Homer Hepworth to Pakistan under the auspices of the Pakistan Agricultural Research Council (PARC) and with USAID funding. He paid more attention to agronomy research, especially in the barani (rainfed) areas and emphasized tillage and weed control. Dr. Peter Hobbs was posted to Pakistan in 1982 to replace Dr. Hepworth and he continued the agronomy focus, but with more concentration on conducting on-farm research with a farming systems perspective. This work was further strengthened and facilitated by the presence in Pakistan of CIMMYT economists (Drs. Derek Byerlee, Paul Heisey, and Jim Longmire).

Much of the work was done in collaboration with the national wheat scientists at National Agricultural Research Centre (NARC) and some collaboration with the provincial scientists of North West Frontier Province (NWFP) and Punjab. It was important to demonstrate on-farm research with a farming systems perspective (OFRFSP).

From 1982 to 1988, CIMMYT's agronomist concentrated on three major wheat systems; barani wheat in northern Punjab, wheat after rice in Punjab, and wheat after maize in NWFP. Some diagnostic work was also done for wheat after cotton in Punjab. In addition to this research, a traveling seminar initiated by Hepworth was continued from 1982-88 with the objective of taking a group of multidisciplinary wheat scientists from South to North Pakistan to view research work and assess farmer wheat production. This enabled researchers from different provinces to see the agronomic on-farm research.

Rice-wheat systems in Punjab

There are about 1 million hectares of rice-wheat in Pakistan's Punjab. Yields of wheat are below 2 t/ha, well below the potential of the farmer improved varieties. The following are a few of the major problems, for wheat production in this area.

Late planting of wheat--More than 80% of the Punjab is planted to late-maturing, high quality Basmati rice. This together with the long turnaround time needed to convert the puddled rice soil into a suitable wheat seedbed, delays wheat planting into December and even into January. There is a 1% reduction in wheat yield potential for every day delay after November 20.

One solution is zero-tillage establishment of wheat. This has been tested and shown to be a good technology for this problem resulting in more optimal planting, better plant stands, higher yield, better use of residual moisture and less weeds. Rice stemborer was also studied and found not to be an issue in this new technical system. The exercise of growing wheat after rice with irrigation and fertilizer resulted in rice stubble breakdown and mortality over wintering larvae of the overwintering larvae before they could finish their metamorphosis.

Phalaris minor weed problem--This grassy weed proliferates in the rice-wheat areas of Pakistan. Complete yield loss is found in seriously infested fields and an average loss of 25% can occur in many fields. Herbicides, like the substituted ureas, were tested and found successful in controlling *Phalaris minor* and other weeds. However, it was management sensitive and required a 500 kg of wheat return before it was profitable to use. Rotation with fodder legumes and sunflower may be a better solution and needs more research.

Poor water management--Most farmers irrigated wheat like rice. Water was put into one corner of the field and continued to the next field at the end of the plot. Wheat is sensitive to waterlogging at the early vegetative stages of growth and the above practice reduced yield potential. In-field drainage, improved water distribution management and delaying the first irrigation are all possible solutions.

Fertilizer management--Nitrogen response of wheat was very steep following rice. Phosphorus and K responses were much less. Fertilizer trials in farmer fields using incomplete designs showed that farmers should spend more on nitrogen, and less on Phosphorus. In fact, the phosphorus could be applied on the previous rice crop.

The maize-wheat system in NWFB

This system had fewer problems than the previous system because the soil condition after maize was better than after rice and wheat planting was not delayed by maize. However, sugarcane-wheat was a second important system in this area where the sugarcane harvest often delayed wheat planting. The average wheat yields in this area were close to 3 t/ha.

The major problems were :

- Low use of phosphorus fertilizer. Farmers mostly used just nitrogen but fertilizer experiments showed that P was also necessary.
- Compaction caused by excessive tillage for maize and wheat was restricting rooting. Moldboard plowing did increase yields by 10%.
- Weeds, both grassy and broadleaf, were substantially reducing yields. Several phenoxyacetic and substituted urea herbicides were available to economically control these weeds although farmer knowledge on their proper use was minimal.
- Karnal bunt was a serious disease in the area in certain climatically favorable years.

On-farm yields were close to 5 t/ha in this area when some of the above factors were controlled.

The cotton-wheat system of Punjab

This is the most important cropping system in Pakistan. More than 2.2 million ha of wheat are grown following cotton in Punjab. The major problem for wheat in this system is late planting. Economic studies at existing cotton prices showed that the loss due to delayed wheat planting was less than that obtained from the cotton left to mature later. It may be possible to introduce earlier maturing cotton varieties and in fact NIAB-78, an earlier maturing variety, was having an impact in the Province. The other route is to develop zero or reduced tillage wheat establishment methods for this pattern. Other problems were:

- Low efficiency of fertilizer use, probably caused by late planting. Data suggest that fertilizer responses flatten out at late planting.

- Weed problems, particularly *Chenopodium album* and *Convolvulus arvensis*. No satisfactory herbicide was available for the last weed. Rotation may be a better solution.

- Farmers were using rust susceptible wheat varieties. This has been improved through the introduction of Pak 81, a variety that not only has good rust resistance, but is also less seeding date-sensitive and does well at normal and later planting.

Conclusion on Pakistan Agronomy Activities

Most of the work was done by the Federal NARC wheat agronomists. Discipline specialists were not well integrated into the work. The fine work of the NARC entomologist in studying the problem of stemborers in zero tillage is an example of the benefits of integrating relevant expertise in problem definition and solution.

Agronomy work in Pakistan is not given the same status or attention as that of breeding, and because of the complex nature of the post-Green Revolution problems and poor training in the principles of agronomy, the national agronomist is not able to develop suitable solutions for increased productivity. Until this defect is corrected and more incentives are given to solve farmer problems in an integrated team approach, Pakistan wheat yields will not keep pace with population demands. Sustainability problems are even more complex and require even more this change in management. These longer term problems were not addressed during the 1980s in Pakistan, but will increasingly become important in the future. There is some evidence of declining yields in the Punjab, which could be linked to suboptimal levels of salinity in tube well irrigation water.

4.2.2 Rice-Wheat System: The CIMMYT CMP Wheat Program in South Asia

Peter R. Hobbs

Background

The South Asian Region includes India, Pakistan, Nepal, Bangladesh, and Bhutan where the semidwarf Mexican spring wheats are well adapted and grown as a winter crop. Planting occurs from late September (hilly areas) to January, with the optimum time being the last week of November. Yield declines of 1% per ha/day occur after this date.

Harvest starts in the warmer areas in mid-March and lasts up to early June in the hills. The region does not include the warmer areas of S.E. Asia (Thailand, Philippines, Indonesia) or Myanmar.

Wheat is a major staple crop in the region and competes with rice as the number one cereal in terms of area and production (Table 4.4). Both crops are generally grown in a rice-wheat rotation system. In Pakistan, and parts of NW India, wheat is the preferred staple and surpasses rice in area. In eastern India, Nepal, Bhutan, and Bangladesh, rice is the preferred staple. The 33.5 million hectares of wheat in the region is mostly (90%+) Mexican-type germplasm and is therefore the most important wheat region for CIMMYT in terms of area.

Table 4.4. Area (000 ha) and production (000 tons) of rice, wheat and maize in the South Asian countries.

	Wheat		Rice		Maize	
	Area	Prod	Area	Prod	Area	Prod
India (89)	24,092	53,995	41,855	70,667	5,946	8,331
Pakistan (89)	7,585	15,703	2,000	3,315	809	1,028
Nepal (89)	599	830	1,450	3,283	722	1,072
Bangladesh(88)	1,476	1,048	25,507	15,991	8	3
Bhutan (87)*	16	22	37	84	52	85
Total	33,468	71,598	70,849	93,340	7,537	10,519
Av. yield (t/ha)	2.02		1.32		1.40	

* Targeted figures.

South Asia has more than 1 billion people (Table 4.5) with an average official population growth rate of 2% that is as high as 3.1% in Pakistan. This region also has some of the poorest people in the World.

Much of the wheat in India (75%) and Pakistan (80%) is irrigated and farmers use the new improved varieties of wheat with moderate levels of fertilizer. Despite this, average yields are low (2.09 t/ha). Similarly in Bangladesh, Bhutan, and Nepal much of the wheat receives at least one irrigation and improved seed and fertilizer are commonly used. Yields in these three countries are also low (1.1 t/ha). In addition there is evidence from the region that yields are stagnating or even declining. This will be discussed later, but it has alarming implications in terms of feeding the large, growing population in the region for the decade to come.

Table 4.5. Population and population growth rate for the 5 south Asian countries.

	Population (million)	Population Growth Rate %
India	836.3	1.8
Pakistan	113.8	3.1
Nepal	19.1	2.5
Bangladesh	110.4	2.4
Bhutan	1.5	2.4
Total	1081.1	2.0

All of the national wheat programs in the region have high yield potential, disease-resistant germplasm available for farmers. There are seed multiplication and distribution problems that delay the availability of this improved seed at the farm level. There are also socio-economic problems of credit, marketing, and availability of inputs that are lowering the wheat production potential in the area. However, most of the problems of low productivity and possibly sustainability are crop management related. These CMP problems are complex, and they require an integrated multidisciplinary, in-depth assessment at specific sites in order to develop suitable solutions. Here, some of the research conducted by the CIMMYT regional agronomist in collaboration with the national programs to address these post-Green Revolution production problems is outlined. Some suggestions on how to strengthen the linkages of the regional program with CIMMYT headquarters for stronger regional activities are also presented.

Methodology

Agronomy research, especially in the post-Green Revolution era in South Asia, is more complex and requires much more association and integration of disciplines and commodities. A rice-wheat (R-W) program has been created. The main objective of the R-W program is to develop a favorable environment for a team approach to studying farmer production problems through natural trust and assignment of specific responsibilities to the appropriate expertise. This approach attempts to use existing expertise rather than developing new institutions or divisions.

The methodology follows a logical sequence of activities that begins with diagnosis, continues through planning, experimentation, further studies and verification, with suitable feedback at each level. The following is a brief description of the activities:

- The diagnosis of farmer production problems is considered essential before developing a research agenda. This is done by assembling a multidisciplinary and across-commodity team of researchers and, if possible, extension personnel to conduct informal surveys in selected sites. Sites are selected that represent larger areas so that results can be extrapolated. This informal activity has helped to describe and understand the agro-climatic and socio-economic conditions under which farmers in a given location make decisions. It also provides clues to production problems.

- The various short- and longer-term (sustainability) problems identified by the diagnostic surveys are discussed by the group of scientists to hypothesize and prioritize the main causes of low yields and to develop a future research agenda for solutions to the problems identified. Responsibilities are then assigned to participating experts to conduct further research. Important in this assignment of responsibilities has been the provision of resources and incentives to promote cooperation.

- Based on the above diagnosis and planning, research can take the form of experimentation or further more formal, focused surveys to better define the problem or to seek solutions for the problem. Research is conducted on-farm or on-station, depending on relevance or degree of control needed.

- For longer term issues several approaches are used:
    1) Review of past data sets to determine if there are any long-term trends. Data sets could include past breeder evaluation yield trials, district statistics, or existing long-term trial data.
    2) Development of new long-term trials, carefully designed to address key issues.
    3) Initiation of monitoring research of farms and fields in the command area to allow present and future evaluation of farmer practices, land quality, and productivity.
    4) A verification of technical solutions through farmers' field trials is done where extensionists and farmers are actively involved.

The CIMMYT-IRRI-National Program Regional Project on Rice-Wheat

Discussions were initiated in December 1989 between CIMMYT, The International Rice Research Institute (IRRI) and national programs in India, Pakistan, Nepal, and Bangladesh to develop a proposal for integrated CMP on the rice-wheat systems of South Asia. The objective of this project is to evaluate the productivity, profitability, and sustainability of the rice-wheat systems in the region and identify possible solutions (practices or techniques) for near-term productivity issues and longer-term sustainability problems. The proposal was prepared and funding sought from Asia Development Bank (ADB) and USAID to supplement the core support from CIMMYT and IRRI and national program contributions. At the moment, ADB funds have been released to IRRI for this initiative and CIMMYT is pursuing funds from USAID for local support costs in Nepal and India.

Nine sites were selected in the four participating countries to represent the different physical, biological, and socioeconomic R-W systems in the region. The nine sites are:

- Bhairahawa, Nepal. Tarai soils, small farm, animal power, rainfed and irrigated.

- Pantnagar, India. Tarai soils, large and small farm, tractor power, partially irrigated sugarcane-R-W and R-W systems.

- Faizabad, India. Loam and clay-loam soils, small farm, tractor and animal power, irrigated R-W.

- Punjab, Pakistan. Loam and clay soils, small and large farms, tractor powered, Basmati rice-wheat system.

- Sind, Pakistan. Clay-loam soils, tractor powered, small and large farms, IRRI rice-wheat system.

- Karnal, India. Medium to heavy soils, mechanized, small and large farm, rice-wheat system.

- Nashipur, Bangladesh. Loam soils, animal powered, small farm, irrigated and rainfed R-W.

- Jessore, Bangladesh. Medium soils, animal power, small farm, irrigated and rainfed R-W.

- A hill site to be identified in Nepal. Medium soils, small farm, animal and human power, irrigated and rainfed system.

At each site the project will initiate the program by conducting diagnostic surveys in the wheat and rice seasons.

Surveys in Punjab and Sind, Pakistan, were completed before 1988. Those at Bhariahawa and Pantnagar for both rice and wheat and at Faizabad for wheat have been completed. Reports of their findings are available (Appendix 4.2.2). The last three surveys were very successful in integrating expertise and developing a congenial atmosphere for future research planning.

At each site, several problems were identified and discussed by developing problem-cause diagrams. These helped the scientists to fully understand the complexity of the problems and to identify a future research agenda where different expertise could collaborate. The problems and causes were also prioritized using simple criteria on extent of area and yield loss, to help highlight the more important issues.

Several broad topics were identified as common throughout the region whereas others were more site-specific. Late planting of wheat is an issue at all sites, however, the causes of late planting are different and are given different rankings at each site. The following were the major near-term and longer-term problems encountered:

- Near-term issues:

    1) Delayed and suboptimal wheat establishment.
    2) Inadequate soil and water management.
    3) Losses due to pests, diseases and weeds.
    4) Reduced input use and high costs for rice and wheat.

- Longer-term issues:

    1) Soil nutrient imbalance.
    2) Carryover and buildup of rice and wheat pests and pathogens.
    3) Environmental changes. Delayed and suboptimal wheat establishment

Near-term issues

The late planting problem will be used as an example of a near-term issue and the process used in the diagnostic survey. The analysis of the problem shows that it can be divided into two main causes:

- Delays caused by the previous crop.

- Delays caused by the problems of preparing land after rice for planting wheat.

In Pakistan, photosensitive, long-maturing varieties of Basmati rice are harvested in November and delay wheat planting. In Bhairahawa , the previous rice crop does not delay wheat planting, but problems of long turnaround are very important. At Pantnagar, the harvest of the rice crop does not delay wheat planting, but the previous sugarcane crop or a crop of oilseeds or potato taken after an early maturing rice crop do. In Faizabad, labor constraints for rice planting and rice harvest delay wheat planting.

In Pakistan, Bhairahawa, and Pantnagar, excessive tillage delays wheat planting. Farmers in these areas plow many times to try to obtain the desired seedbed tilth for wheat. In some of these places, excessive moisture, because of rains or lower, poorer drainage land delay wheat planting. In others, the soil is too dry and required irrigation before tillage for wheat can proceed.

The result of all these causes is wheat planted in December or even early January. With secondary data showing a 1% loss per day for wheat planted after November 20, substantial yield potential is lost in this system by late planting. In addition, secondary data from Bangladesh and Nepal show that nitrogen fertilizer response is reduced at late planting. In other words one cannot make up for late planting by increasing fertilizer rates.

Several solutions to this problem were discussed depending on the cause:

- Development of earlier rice varieties with high yield potential. Farmers are not willing to sacrifice yield for earliness. The development of Basmati 385 in Pakistan, a variety that is higher yielding and 2 weeks earlier than the popular Basmati 370, is an example of a solution to this problem.

- Earlier planting of rice is a solution adopted by farmers in the Indian Punjab and China. This requires assured irrigation at the hottest time of the year. Development of dry seeding techniques, direct seeding on puddled soils or a mechanical transplanter are other solutions to explore.

- Where sugarcane or another crop after rice delays wheat harvest, we may have to accept the lower yield potential or look for wheat varieties that do best at late planting--good grain filling at higher temperatures.

- Long turnaround can be addressed by exploring zero or reduced tillage systems. The use of zero tillage has been successfully demonstrated in Pakistan. The goal now is to provide appropriate seed drills to farmers for wider testing and to overcome the doubts of station and office bound scientists and extension officers presently delaying this demonstration of technology to farmers. In Nepal, reduced tillage, using a tillage system from China, may be more appropriate because of the heavier soils and higher temperature induced rice season weed interactions and carryover. Zero and reduced tillage are also solutions for poor plant stand. Fertilizer management and long term pest problems need to be studied and accounted for in this new system.

- Where excess moisture delays planting, other alternative crops, less sensitive to planting date, should be evaluated. Sunflower in Pakistan is an example.

- Where soils are too dry for planting, water management and timing of the last irrigation for the previous rice crop could offer a solution.

- Relay planting of wheat into a standing rice crop has been successful in Bangladesh.

Other issues have been discussed and evaluated for future research in a similar way as late planting. Many of these problems require more in-depth study to better understand the causes and develop solutions.

Longer-term sustainability issues
These issues require even more interdisciplinary and intercommodity cooperation. At present, there is still debate about whether these long-term production problems even exist. Some farmers say their yields are increasing. However, on more critical examination, we usually find this is at the expense of more input use (more available water and higher fertilizer doses). Productivity is therefore declining, but how long before production declines or stagnates needs to be determined.

The only real source of reliable data on these longer-term issues comes from data sets of long-term trials conducted on-station in various parts of India and Nepal. These trials have not been well managed and the data are affected by year-to-year variation in climate and researcher management. Many experiments have been conducted over the last 10 to 15 years, but many have not been critically analyzed to obtain useful information on yield trends.

As part of the R-W work, attempts have been made to obtain long-term data from the selected sites, and to do some analysis. Figure 4.6 is an example of the data from Pantnagar for a rice crop in a rice-wheat rotation. Figure 4.7 shows data for the first rice crop in a rice-rice-wheat rotation in Bhairahawa, which is more sensitive to low P levels than wheat. The data from Bhairahawa show an obvious decline in yield where phosphorus is not used, but also show a decline in other treatments including those with N-P-K and those with farm yard manure. The Pantnagar data show a decline in all treatments. Interestingly, at Pantnagar, there are no declines in wheat yield.

Soil tests from the Bhairahawa plots showed low levels of zinc and boron but when the plots were split last year with one half getting zinc and the other half no-zinc, there was no response. In fact, the yields of some treatments, where P was not applied, were lower with zinc than those without. A zinc induced P interaction can probably explain this result. Also last year, there was an obvious potassium deficiency problem in the second rice and wheat crops. This is being explored in more depth but it looks like K-deficiency shows up after 12 years. Sulfur and boron are two other elements that need further study and could account for the decline in the treatments with balanced doses of NPK.

Two other factors that need further study in this experiment that could also explain the declines are :

- The possible build-up of soilborne pathogens or nematodes in this intensive three-cereal crop system. Evidence from separate soil solarization experiments and of symptomatology on roots suggests that biotic factors are responsible for some damage in rice-wheat rotations. The data presented in Table 4.6 might be partially explained by levels of the rice root nematode (*Hirschmaniella oryzae*), which were 11 times higher in the nonsolarized than the solarized treatments. However, pathologists can find the nematode only in the soil and in rice roots--not in wheat roots. Therefore, soilborne fungi may be responsible for the

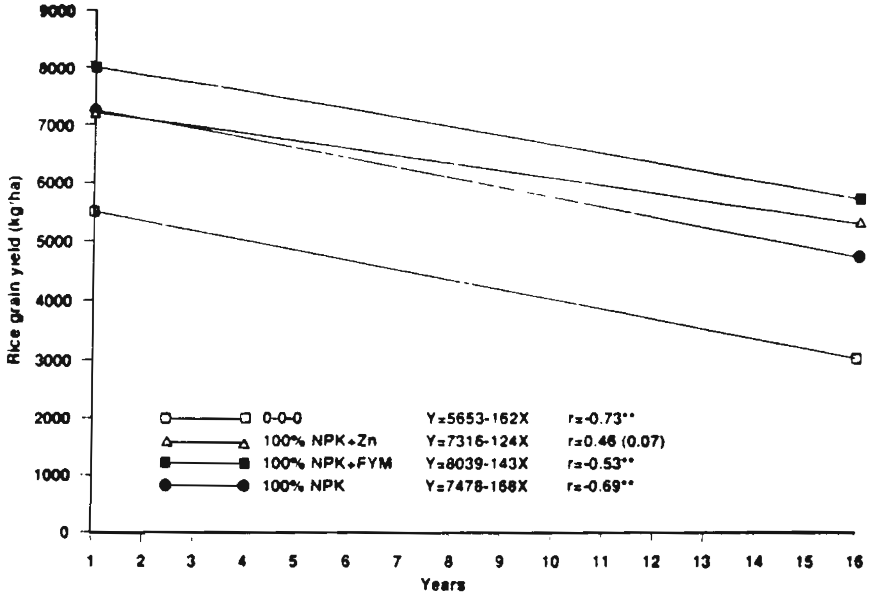
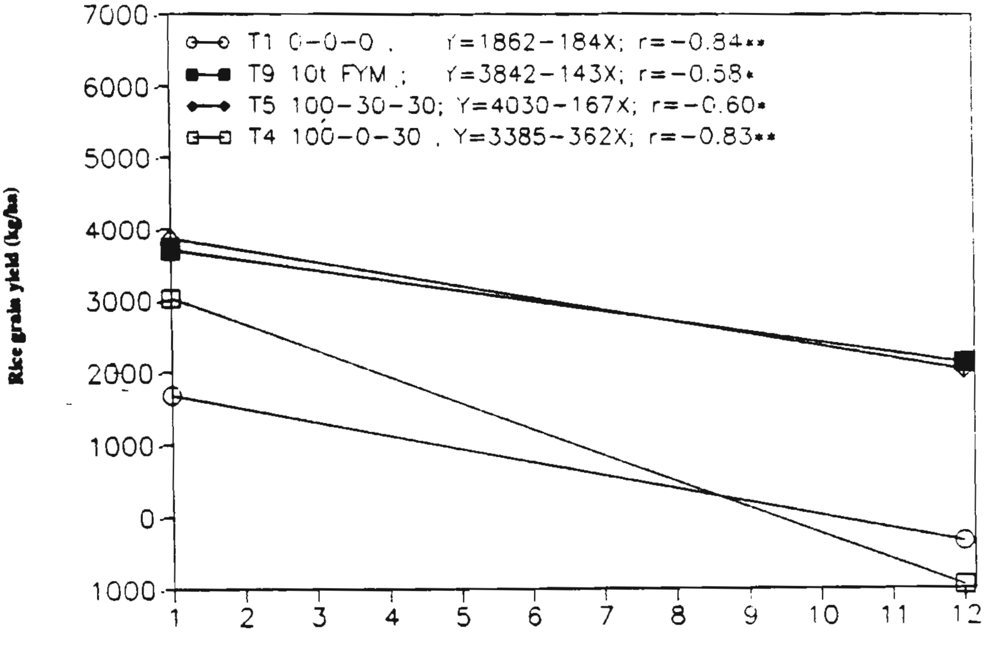


Figure 4.6. Trends in rice yield for a rice-wheat long-term trial at Pantnagar University for selected fertilizer treatments. Source: V. Bhardwaj, N. Ram, and R.P. Tripathi.



Year 1 = 1977; 12 = 1990

Figure 4.7. The effect of various fertilizer levels on the yield of early rice in rice-rice-wheat cropping pattern at Bhairahawa, Nepal, over the past 12 years.

Table 4.6. Effects of soil solarization and fungicide on wheat yields (kg/acre) NWDP, Bhairahawa, 1987-88.

Solarization	Fungicide +	Fungicide -	Solarization Means
+	3152	2932	3038
-	2855	2308	2582
Fungicide means	3004	2616	2810

P = 0.01 Main (Solar), CV = 2.7%
P = 0.02 Sub (Fungicide), CV = 9.0%

LSD = 0.05

1. Solarization means = 71 kg/ha
2. Fungicide means = 186 kg/ha
3. Fungicide means within solarized or nonsolarized = 262 kg/ha
4. Fungicide means between solarized and nonsolarized = 222 kg/ha

difference in treatments. Work has been initiated on this problem and *Fusarium*, *Helminthosporium*, and *Pythium* spp. have been isolated from infected roots.

- Soil physical problems of compaction, plow pan formation and poor rooting may have developed in this system. More soil physical measurements are required in this area.

In other words, it is important to involve other discipline scientists in these established long-term trials to help explore the causes of any yield declines. Other long-term trials should also be initiated to help explore knowledge gaps that existing experiments cannot answer.

Data from breeders' yield trials
There are numerous data sets of breeders' yield trials in the region that could also be used for looking at sustainability issues. Figure 4.7 is an example of advanced yield trial data from Bhairahawa that was aggregated for 10 years for the experimental mean and two local checks and exposed to regression analysis. Year-to-year variability is high, but the trends are obvious. Of course, these trials were not planted on the same field every year although they did receive the same recommended fertilizer, were well managed, and followed a rice-wheat rotation.

Monitoring research
Another approach being tried at Bhairahawa is monitoring research. The involvement of the social sciences in this activity is crucial. The objective in this approach is to evaluate farmer management practices, land quality, and productivity--now and in the future

through monitoring the same fields and farms over time. A random sample of farmers was selected and a benchmark survey conducted about their farms and one of their typical rice-wheat fields. The same field will be sampled over time to ascertain how farmers' practices, land and resource quality, yield levels, and system productivity change over time.

Soil samples have been taken from the 170 selected fields in Bhairahawa and next year, pest, diseases, and weed data will be collected by the appropriate discipline at the correct time. Crop cuts will be taken for rice and wheat yield at each harvest. The project will help involve scientists from several disciplines and commodities. Also, in Bhairahawa, involvement of the extension service in the collection of routine data and contact with the selected farmers are being encouraged.

The resulting large database has been computerized and training has been given to local scientists to allow them to access and use the data. The monitoring will also allow scientists to evaluate the carryover and build-up of rice and wheat pests and pathogens and to measure environmental changes.

Support needed from CIMMYT base

The job of catalyzing CMP activities in a region as large as South Asia is difficult. It is made even more so by the fragmentation of the research disciplines that are involved in CMP and the separation of commodity programs, like rice and wheat, into distinct institutes. The quality of training given to graduates in agriculture in the region is weak and many of the brighter students are opting for careers in fields other than agriculture. The practical experience of students in conducting research, even on-station, but especially in farmers' fields, is very poor. Add to this the system of management, where decisions are centralized and come from the top--and progress becomes very slow.

The question that should be posed is whether a regional agronomy program in a region like South Asia is really feasible. A better approach may be a series of bilateral efforts to first attune the scientists to the more complex issues facing the country and then move to a more regional mode as research systems become more functional and focused. The development of a good CMP program in the region will take time because of the present system and the cultural problems. We have to demonstrate the benefits of changing the old system to a system that requires provision of incentives to facilitate cooperation.

The following are a few issues that need to be discussed on the support role of CIMMYT base for regional agronomists:

- **Training (short-term, 5-7 months)**

It is important that CIMMYT continues to provide the CMP course for young scientists from the region. The agronomists at CIMMYT had developed an integrated training by doing a course that is not available anywhere else. It was just the type of training needed for young scientists beginning their careers. I do not believe that a course of this nature can be run in the region or that the participants would be interested in attending even if it were organized. Part of the benefit of the training in Mexico is the chance to observe and participate in research at a good organization like CIMMYT and interact with the many foreign scientists. A huge investment of time would be required by the regional agronomist if the course were held in the region--this would detract from the other activities involved in our already busy schedule.

In breeding, and to a lesser extent in pathology, there is a core of well trained scientists in the region. In CMP, this is not the case. This is partly because of poor selection of candidates (we don't always have a say in selection), partly due to lack of follow-up on their return, and the integration of their new expertise into a good CMP program, and partly due to attrition and transfer of scientists out of the program.

Now that we are developing good programs at specific sites, we will need more appropriate young scientists identified and trained in CMP in Mexico.

- **Visiting scientists**

Although we are recommending more integration of disciplines, we also will require more specialist expertise to address some of the complex issues in CMP. This can best be done by inviting scientists from national programs to CIMMYT, IRRI, or wherever the expertise exists, to upgrade their skills. I believe the past visiting scientist program in CMP from South Asia has not fulfilled this need. Most of the blame can be put on poor selection of candidates and the lack of defined programs before the scientists reached Mexico. India is an example of where few agronomists are selected (breeders predominate) and those that are selected are sent without any prior planning as to what they will do in Mexico. I think with the new site-specific programs that are being developing for R-W, this situation should change and we should insist on a program of study before they are accepted. The Chinese have experience with rice-wheat and can boast some of the highest yields for this system in the region. CIMMYT base could help us tap into this information by inviting more Chinese visiting scientists to work at CIMMYT or even in the region.

- **Regional workshops**

The development of regional workshops to highlight a special need of the region would allow more scientists to be trained. This could be done by using IRRI or CIMMYT staff or hiring consultants to do the job. Computer training and statistical analysis is one topic that could be held in the region over a short time period and be very useful for the national scientists.

- **Post-doctoral fellows**

It may be useful to consider placing post-docs in the region to work on specific topics. The main problem will be to convince the national programs that a foreign post-doc would be better than a local scientist. This will involve getting approval for the student to work in the national program. If this hurdle can be overcome, I believe that many topics could be studied in more detail for the benefit of the national program, the student, and the IARCs.

Other support

We need more support in computer use, statistical analysis, and editing. Luckily, we are getting this support at present, but usually the staff at base are doing this in their extra time in addition to their base duties. It is very difficult to get this support in the region.

It seems that one of the most limiting factors to accomplishing any of the above is funding. This last year, a lot of time was taken away from technical issues because of the need to prepare funding proposals. It would be useful to get more support from base on this issue so that we can devote more of our time to solving the issues we are trained to address. It is particularly important that we have a stable, flexible funding source if we are going to do justice to the complex long-term problems described in this report and develop a partnership relationship with our national colleagues. We are making progress, although slow, and will require long-term funding for success.

Future Directions

The rice-wheat work in South Asia needs a long-term time perspective, especially if we are to be successful in studying and resolving the long-term issues. The work outlined in this report will form a basis for the work in the future. However, the comparative advantage of the IARCs comes in addressing the more complex sustainability issues and this area of research will be given more attention as the shorter-term problems are tackled by the national programs. The IARC advantages in sustainability work will come through their ability to develop suitable methodologies for addressing this issue, acting as catalysts in national programs to promote the integration of the necessary expertise and development of techniques to quantify the research results for better extrapolation.

Specifically the future work will involve:

- Completing the diagnostic surveys and development of prioritized research agendas for the selected sites where this has not already been done.

- Developing integrated experimental programs on key issues at the selected sites where there is a group of capable scientists available to address the issue and where the issue is of key importance to raising the productively of the rice-wheat system.

- Reviewing past results from relevant short- and long-term experiments and the initiation of new long-term trials where needed.

- Developing a long-term monitoring program of farmers' fields at key sites to allow the production of a database for use in sustainability measurements. This would enable us to answer the question about whether sustainability issues occur and in what form they take. It would also give us a key as to how farmers react to these problems.

- Developing a more systematic scientific way of handling the various outputs to allow more efficient extrapolation of results within the region. The use of modelling would play an important role in this activity.

The key to the whole project will be the involvement of the national program staff. It will take time to develop the trust and rapport needed to convince the national programs to reorganize their existing research systems into a more efficient, focused effort to address the more complex productivity issues of today. Long-term funding that is flexible and available on request to national scientists is essential to get this program moving.

Appendix 4.2.2.
Miscellaneous Publications on CMP Research in South Asia

Akhtar, M.R., D. Byerlee, A. Qayyum, A. Majid, and P.R. Hobbs. 1986. Wheat in the cotton-wheat farming systems of the Punjab: Implications for research and extension. 64 pages.

Aslam, M., A. Majid, P.R. Hobbs, N.I. Hashmi, and D. Byerlee. 1989. Wheat in the rice-based cropping system of the Punjab : A synthesis of On-farm research results, 1984-1988. 58 pages.

Byerlee, D., A.D. Sheikh, M. Aslam, and P.R. Hobbs. 1984. Wheat in the rice-based farming system of the Punjab: Implications for research and extension. 49 pages.

Byerlee, D., P.R. Hobbs, B.R. Khan, A. Majid, M.R. Akhtar and N.I. Hashmi. 1986.

Increasing wheat productivity in the context of Pakistan's irrigated cropping systems : A view from the farmers' field. 56 pages.

Byerlee, D., M.R. Akhtar, and P.R. Hobbs. 1987. Reconciling conflicts in sequential cropping patterns through plant breeding: The example of cotton and wheat in Pakistan's Punjab. Agricultural Systems 24:291-304

Byerlee, D., P. Heisey, and P.R. Hobbs. 1989. Diagnosing research priorities for small farmers: experiences from on-farm research in Pakistan. Quarterly J. of Intl. Agriculture 28:254-266.

CIMMYT. 1989. Wheat research and development in Pakistan. Mexico, D.F.

CIMMYT. 1989. Rice research needs for the rice-wheat system in Nepal's Tarai: A farmer oriented assessment. Diagnostic survey participants.

Fujisaka, S., and L. Harrington. 1989. The rice-wheat cropping pattern in the Nepal Tarai: Farmers' practices and problems and needs for future research.

Harrington, L., P. Hobbs, S. Fujisaka, C. Adhikary, G.S. Giri, and K. Cassaday. 1993. Rice-wheat Cropping Systems in Rupandehi District of the Nepal Tarai: Diagnostic Surveys of Farmers' Practices and Problems, and Needs for Further Research. Mexico, D.F.: CIMMYT.

Hobbs, P.R. 1985. Agronomic practices and problems for wheat following cotton and rice in Pakistan. Wheats for more tropical environments. In: A proceedings of the International Symposium. CIMMYT, pages 272-277.

Hobbs, P.R., G.P. Hettel, R.P. Singh, Y. Singh, L. Harrington, and S. Fujisaka, eds. 1991. Rice-wheat cropping systems in the Tarai areas of Nainital, Rampur and Pilibhit Districts in Uttar Pradesh, India.

Hobbs, P.R., G.P. Hettel, R.K. Singh, P. Singh, R.P. Singh, and K.G. Pillai, eds. 1992. Rice-wheat cropping systems in Faizabad District in Uttar Pradesh, India: Preliminary report of an exploratory survey of farmers' practices and problems and needs for future research.

Hobbs, P.R., B.R. Khan, M. Nasir, M. Munir, N.I. Hashmi. 1983. Yield assessments of wheat in a barani area of Rawalpindi District in 1983. 11 pages.

Hobbs, P.R., B.R. Khan, M. Munir, A. Razzaq, and N.I. Hashmi. 1983. Agronomic results for wheat in a rainfed area of Northern Punjab. 31 pages.

Hobbs, P.R., B.R. Khan, A. Razzaq, B.M. Khan, M. Aslam, N.I. Hashmi, and A. Majid. 1986. Results from agronomic on-farm trials on barani wheat in the high and medium rainfall areas of Northern Punjab from 1983 to 1985. 34 pages.

Hobbs, P.R., C.E. Mann, and L. Butler. 1988. A perspective on research needs for the rice-wheat rotation. In: Klatt, A.R., ed., Wheat Production Constraints in Tropical Environments. Mexico D.F.: CIMMYT, pages 197-211.

Hobbs, P.R., A. Razzaq, N.I. Hashmi, B.R. Khan, and B.M. Khan. 1989. Wheat production and yields in Rawalpindi District of the Punjab from 1983 to 1986. 36 pages.

Hobbs, P.R., A. Razzaq, N.I. Hashmi, M. Munir and B.R. Khan 1985. Effect of mustard grown as a mixed or intercrop on the yield of wheat. Pakistan J. Agric. Res. 6:4: 241-247.

Hussain, S.S., D. Byerlee, B.R. Khan, B.M. Khan, and P.R. Hobbs. 1985. Wheat in the irrigated farming systems of Mardan District : Implications for research and extension. 35 pages.

Inayatullah, C., E. Haq, A. Mohsin, A. Rehman, and P.R. Hobbs. 1989. Management of Rice Stem Borers and the feasibility of adopting no-tillage in wheat. 64 pages.

Khan, R.A., N.I. Hashmi, M. Nasir, M. Munir, and P.R. Hobbs. 1983. Farming Systems Research : An exploratory survey of rainfed agriculture in Northern Punjab. 12 pages.

Khan, B.R., B.M. Khan, A. Razzaq, M. Munir, M. Aslam, S. Ahmed, N.I. Hashmi, and P.R. Hobbs. 1986. Effect of different tillage implements on the yield of wheat. Pakistan J. Agric. Res. 7:3: 141-147

Majid, A., M. Aslam, and N.I. Hashmi. 1988. Potential use of minimum tillage in wheat after rice. In: Klatt, A.R. ed., Wheat Production Constraints in Tropical Environments. Mexico D.F.: CIMMYT, pages 71-78.

Razzaq, A., B.R. Khan, B.M. Khan, P.R. Hobbs, N.I. Hashmi and P. Hessey. 1990. Irrigated wheat in North-West Frontier Province: A synthesis of On-farm research results, 1983-86. 43 pages

Razzaq, A., N.I. Hashmi, B.R. Khan, and P.R. Hobbs. 1990. Wheat in Barani Areas of Northern Punjab : A synthesis of On-farm research results, 1982-1988. 69 pages.

Razzaq, A., B.R. Khan, B.M. Khan, P.R. Hobbs, and N.I. Hashmi 1986. Comparison of morphological and physiological parameters of wheat cultivars under rainfed conditions. Pakistan J. Agric. Res. 7:3: 148-151

Supple, K.R., A. Razzaq, I. Saced and A.D. Sheikh 1985. Barani Farming systems of the Punjab: Constraints and opportunities for increasing productivity. 67 pages.

4.2.3. Soybean-Wheat System: Southern Cone

P.C. Wall

The Southern Cone Regional agronomist position, funded by the UNDP project for Wheat for the Marginal Areas, was first staffed in early 1988 during the second phase of the project. As the thrust of this project continues to be the warmer areas, the region is defined as Paraguay, Brazil, lowland Bolivia and northern Argentina. Over time there has been a slight shift in emphasis towards the soybean-wheat areas, and therefore the region also comprises central Argentina. Northern Argentina because of its atypical rotations and relative lack of wheat has not received any attention. Although neither nontraditional warm areas nor soybean-wheat systems are represented in Chile or Uruguay, occasional visits and consultancies have been undertaken in those countries, largely because of geographical proximity.

The six countries of the Southern Cone have very different growing conditions, production statistics, wheat trade balances, and research resources and infrastructure. Wheat areas, yields, total production, and net trade figures are shown in Table 4.7, population and wheat consumption in Table 4.8.

Country Sketches

On the basis of these tables, the following sections provide sketches of wheat production areas, problems, and potential in Argentina, Bolivia, Brazil, and Paraguay. Comments on research infrastructure are also included.

Argentina
As a major wheat exporter, most of the politics of wheat production in Argentina are governed by world markets and prices. Argentina sells wheat on the world market for approximately US$20/t FOB below the Gulf Port prices because of extra transport costs to most markets. To sell below the discount prices for most developing countries offered by the US and EEC, Argentina currently offers a FOB price of about US$75/t. The farmer pays a 15% export tax and various other charges, which results in a farm-gate price of about US$60/ton. This largely explains the lack of input use in wheat production in Argentina.

Over 60% of Argentina's wheat area is in the province of Buenos Aires, with considerable areas also in Santa Fe, Cordoba, and La Pampa. These four provinces account for 97% of the wheat area of the country. In the northern part of this area, the major rotation involves wheat, soybeans and maize in different combinations, but often with three crops in 2 years. In the more southern areas, where spring rainfall is lower, the wheat-soybean relay is replaced by wheat alone and maize is replaced by sorghum or sunflower.

The major problems in the "Rolling Pampa", the area where the wheat-soybean relay is common, are associated with soil degradation. As the surface soil of these typic and vertic argiudolls has up to 70% of silt and fine sand, crusting and surface sealing are a problem, especially when aggressive land preparation practices are undertaken twice a year. Plow pans are also common. Due to the sealing of the surface, runoff has become a

Table 4.7. Wheat production statistics yields and net wheat trade of the countries of the southern cone of South America. Data for 1989. Source: CIMMYT Economics Program.

	Wheat Area 1000 ha	Wheat Prod. 1000 t	Average Wheat Yield t/ha	Net Wheat Imports[a] 1000 t
Argentina	5,415	10,000	1.85	-4,375
Bolivia--Total	86	60	0.70	168
Bolivia--Lowland	13	11	0.81	50
Brazil	3,317	5,408	1.63	1,322
Chile	540	1,766	3.27	42
Paraguay	230	511	2.22	0
Uruguay	227	473	2.09	150

[a] Exports shown as negative figures.

Table 4.8. Population and per capita wheat consumption in the Southern Cone of South America, 1989.

	Population `000	Wheat Consumption kg/capita/yr
Argentina	31,920	138
Bolivia	7,112	58
Brazil	147,404	53
Chile	12,961	138
Paraguay	4,157	59
Uruguay	3,105	86

major problem leading to problems of erosion and flooding. The limiting factor to yields in the wheat-soybean-maize system is moisture.

As soil degradation progresses, marked especially by lower infiltration rates and, therefore, reductions in available moisture to the crop, maize is the first crop to disappear from the system based on its drought susceptibility and price, followed by wheat. A soybean monoculture is extremely damaging as very little organic matter is returned to the system.

Most research in Argentina is conducted by the government institute, INTA. Research into soil and crop management in the soybean-wheat system is well under way and fairly well staffed. Approximately 15 researchers are involved in conservation tillage systems for wheat-soybean-maize around the Rolling Pampa. Little research is being conducted on management of the wheat crop per se (i.e., fertilizer, seed rates, weed control, etc.) for two reasons:

- Reasonable technologies are available.
- Given the comparative prices of grain and inputs, there is little use of inputs on the wheat crop and little demand for this research.

On-farm research (with a farming systems perspective) (OFR-FSP) or Integrated Applied Agronomic Research (IAAR) is not widely spread in Argentina. Most research is disciplinary, with some agronomists identifying a need for an integrated approach, and some work is carried out under representative farmer conditions. Much of this work does, however, appear to be "on-station research conducted on farmers' fields."

Since 1991, the CIMMYT Wheat Crop Management Training Course has been conducted only in English in Mexico, while the Spanish course is being run by INTA personnel in Pergamino, Argentina (the center of the Rolling Pampa), with support from CIMMYT staff.

Bolivia

Until recently, most wheat production in Bolivia was in the inter-mountain valleys, where it is grown during the short summer rainy-season. This ecological area is part of the Andean Region.

Winter-sown wheat does, however, fit well into the summer soybean areas of lowlands around Santa Cruz. This is a high rainfall area (1200-1400 mm/yr), but with most rain falling in summer. Winter rainfall varies from 200-400 mm, with most of the wheat area receiving 200-300 mm. Winter soybean crops for grain and seed production are grown in much of the wetter areas (300-400 mm).

The summer soybean crop covers almost 100,000 ha and this is potential wheat area. Further expansion is taking place at present, and new land is being opened up. In 1990, a new wheat area expansion plan in lowland Santa Cruz was started by ANAPO (The Oil Seed Growers Association) with PL480 funds from USAID. This is a 5-year project and includes money for seed production, credit (for both producers and millers--so that the latter can pay on the nail), and also includes money for research and extension. In the first year of this program, 1990, they surpassed their goals with 32,000 ha of wheat seeded with a total production of almost 50,000 t. This is about 60% of the annual consumption of Santa Cruz.

Wheat is grown by large farmers of three ethnic groups (Bolivia, Japanese, and Mennonites)-all of whom have different socioecological traits. Most of the expansion last year was on the farms of Bolivian businessmen/farmers, many of them growing wheat for the first time.

Major problems in the wheat areas are:

- *Schizaphis graminum*--green bug.
- Soil compaction and plow-pan formation.
- Soil crusting.
- Diseases--leaf rust and *Helminthosporium sativum.*

Efficient use of moisture is of prime importance due to the low rainfall during the crop season.

Research is carried out by the Centro de Investigación de Agricultura Tropical (CIAT). Until 1990, they had no research agronomists in their Wheat Program, but did have agronomists working in the FAO national soil fertility projects and together with the British Technical Aid Mission on soil physics and tillage. At present, there are two new agronomists in the Wheat Program--funded with PL480 money.

Brazil

Brazil is the second largest wheat producer in Latin America. Both area seeded and mean yields doubled during the decade of the 1970s due to government subsidy programs, liming, fertilizer use, and new varieties. As of 1990 wheat production is no longer subsidized and a decrease in area seeded is expected in 1991, due largely to the relatively high cost of production per ton of wheat in Brazil, and the artificially low price of wheat on the world market. If world price were around US$150/ton, it is probable that expansion in wheat area would continue in Brazil.

Most of the wheat area in Brazil is relay cropped with soybeans and/or maize. Approximately 75% of this area does not include other crops in the rotation, while in the remaining 25%, oats, barley, and green manures enter the system. In the wheat-soybean and wheat-maize areas, wheat is often not seeded every year, so that considerable areas of fallow are encountered.

Wheat is produced mostly in the southern region of Brazil, comprising the states of Rio Grande do Sul (22% of total wheat production) Santa Catarina (3%), Paraná (53%), Minas Gerais (1%), São Paulo (5%), and Mato Grosso do Sul (15%). The soils of this region are largely Oxisols, with smaller areas of Alfisols and Ultisols. Although all the soils are acidic, allic soils only account for about 25-40% of the area. Rainfall ranges from 1200-1800 mm/year. In Rio Grande do Sul, this is more or less evenly distributed over the year, resulting in the summer months being the driest, (potential evapotranspiration exceeds precipitation) whereas in Paraná and Mato Grosso do Sul, there is a peak of rainfall in the summer months. In these states, precipitation is generally lower than potential evapotranspiration in the winter, with August (flowering time) being the driest month.

Obviously, the problems associated with wheat production in such a large area are varied. However, among those most often quoted are:

- Soil erosion (often necessitating reseeding).
- Drought--mid-season.
- Soil compaction.
- Diseases--*Helminthosporium sativum* (root disease in the south; foliar disease in the warmer areas), *Helminthosporium tritici repentis* on zero-till land, and leaf rust.

Practically all of Brazil's wheat is grown on relatively large mechanized farms. (Small farms are classified as those of 50 ha or less).

Research in Brazil is organized in five overlapping sectors:

- EMBRAPA, the Federal research organization, has national commodity research centers such as the National Center for Wheat Research (CNPT) based in Passo Fundo, Rio Grande do Sul. Until recently, these centers had a national mandate for research coordination. However, in March 1991 this was changed to a local mandate, but at time of writing nobody is quite sure how this is to work.

- EMBRAPA also has a few regional development centers such as the UEPAE in Dourados, Mato Grosso do Sul and CPAC outside Brasilia for the Cerrados. These centers have a local mandate, normally in areas of expansion of the agricultural frontier.

- States may have their own state government-funded research centers, such as IAPAR--a relatively strong research center in the state of Paraná. Other state organizations have resulted in relatively weak research-extension organization such as EPAMIG (Minas Gerais) and IPAGRO (Rio Grande do Sul).

- Research institutes run by the organizations of cooperatives. These are especially strong in Paraná (OCEPAR) and Rio Grande do Sul (FUNDACEP/FECOTRIGO).

- There are several strong agricultural universities that carry out research, especially those of Piracicaba, Joboticabal, Instituto Agricola Campinas, Porto Alegre, Santa Maria, Pelotas. As often happens, much of their research is fairly basic and esoteric, but some people are involved in applied research.

Brazil borrowed much money in the 1970s, which they put into training personnel. They now have a vast number of highly trained people. Among EMBRAPA-CNPT, EMBRAPA-CPAC, EMBRAPA-Dourados, IAPAR, OCEPAR, and FECOTRIGO, there are at least 12 Ph.Ds, 17 M.Scs, and 10 B.Scs agronomists working on wheat or the wheat-soybean centered system. The weakest point of the system appears to be a relative lack of integrated applied agronomic research. However, this is partly due to the complexity of the factors they are addressing.

Paraguay

The rapid expansion of wheat production in the 1980s in Paraguay can be attributed to:

- New varieties.
- Effective fungicides.
- Subsidized credit and inputs.

Since 1990, there have been no apparent subsidies on wheat production, and wheat area in 1991 is expected to be 10-15% lower than 1990 due to poor prices and problems selling the crop. With a return (hopefully) to more realistic prices, it is probable that Paraguay's production will stabilize around 350-400,000 t/year, which would cover consumption and leave a slight excess for export--possibly to Bolivia. Paraguay probably cannot compete with Argentina on the export market, except possibly for lowland Bolivia and some small areas of Brazil.

Practically all wheat in Paraguay is grown on the Alfisols and Ultisols in the southeastern crescent of the country along the borders with Argentina and Brazil. This accounts for >95% of the countries wheat production. It is produced on the relatively large recently colonized mechanized farms and farmed by colonists of varied national origins.

Rainfall during the wheat season ranges from approximately. 300-500 mm. in this area. Frost may be a problem, and seeding dates are decided largely on a balance between moisture and frost considerations.

Apart from this area, there are small pockets of wheat production on the sandier soils of the central region of Paraguay, mostly produced by Mennonite farmers. Rainfall in these areas is lower.

All of the wheat in Paraguay is seeded after soybeans, but wheat area is only one third (officially) of the soybean area. There are no other viable winter crops at the moment, so approximately two-thirds of the soybean land is left idle in the winter.

Major technical problems of wheat production are:

- Soil compaction (and degradation).
- Soil erosion.
- Diseases--leaf rust, *Helminthosporium sativum*, and *Helminthosporium tritici repentis*.
- Soil fertility.

Research is under the Ministry of Agriculture; wheat research is centered at two stations, one near Asuncion (IAN) and one near Encarnacion (CRIA). Breeding has traditionally been the emphasis of the wheat program. At the moment, there are two wheat program agronomists (one away studying for an M.Sc.), both based in IAN, and two agronomists working part-time with wheat (one on weeds and one the JICA counterpart) at the CRIA station near Encarnacion. Dates of seeding trials are also conducted at three Ministry substations and the JICA experiment station.

Funding of research has been very limited. The site of the IAN station, the wheat agronomists' base, is >250 km from the commercial wheat growing areas and transport and travel funds are extremely limited. The soils of the IAN station are some of the most degraded in the country, and are representative of little, if any, of the wheat production area.

Summary of the Regional Agronomist's Activities to Date

Argentina

- Consultancy visits in the soybean-wheat area. After an initial visit to the Saenz Peña region, it was decided that neither this nor the Salta region fall within the two priority thrusts of the program.

- Help in setting up the Crop Management course that will start in 1991.

Bolivia

- Presently the major effort is in helping new CIAT agronomists define priorities and design a coherent research program and conduct the trials (Trials include date of seeding, spacing x seedrate, deep ripping x chemical fertilizer, weed control, etc.).

- Assistance in training of CIAT and ANAPO agronomists.

- Maintain close contact with both the FAO soil chemical fertility project and the British Aid soil physical fertility project in an effort to amplify their vision. Help them to coordinate work with the wheat programme agronomists.

Brazil

- Get to know research programs and act as an informal data exchange channel.

- Help organize workshops on planning and design of long term trials and evaluation of soil physical characteristics in management trials.

Paraguay

- Reformulation of priorities of agronomic research. Done by limited survey work and observation. This resulted in a shift in the top priority of the agronomic effort from NPK trials to soil tillage and management work.
- Assistance in trial planning, management, and intensification of data acquisition.
- Installation of a few trials designed to get data on crop development and yield potential.
- Work on demonstrating the level of soil degradation and erosion on the IAN station, and help in improving management to overcome this.

Future Activities

- Help plan and analyze trials and compile data on yield potential and yield limitations, especially those where data are sufficient for crop model validation.
- Organize a network of researchers working on soil conservation and management in the Southern Cone. Help look for a donor to fund this project within PROCISUR.
- Continue to provide help and training in an effort to strengthen the agronomic research on wheat in Paraguay.
- Increasingly provide training to CIAT, Bolivia in an effort to strengthen the agronomic research on wheat in lowland Bolivia.
- Compile data from well conducted and data rich agronomic trials in the warmer areas, in an effort to unearth "universal" management guidelines.

Links between Base and Regional Program

Links up until now have been extremely tenuous. There is a possibility of increasing these links somewhat with the incorporation of a physiologist into the UNDP project for the warmer areas based in Mexico and some joint work in this field in the region is envisaged.

However, as long as regional activities are based on regional priorities and not CIMMYT-designed global priorities, it is unlikely that many links will be established except those for information sharing.

The regional program receives variable help and support from the base "support" programs. This ranges from excellent to extremely poor depending on the particular section.

On-farm research

As is evident from the previous sections, wheat farmers in the warmer areas and soybean-wheat areas of the Southern Cone are practically all large farmers--at least by Andean or Asian standards.

The socio-economic aspects of on-farm research are especially designed for the risk-averse farmers. For these farmers, normally those who have little access to capital, it is important for research to "fine" tune technologies as much as possible before recommending them. However, with large, capital-intensive farmers, risk is not normally as important a factor as it is to the small farmer, while profit-maximization becomes more important. Once the crop is seeded, the large-scale farmer also tends to be more prepared to spend time, effort, and money insuring his investment in the crop, (e.g., with fungicide sprays) rather than risking a loss. The small farmer possibly also thinks this way, but does not normally have the ready capital to be able to make input decisions rapidly.

Although the basic concepts of on-farm research with a farming system perspective still have the same validity for large farmers as small farmers, the large farmer often does much of the research himself and often only exploratory work to show the limiting factors and priorities between them is enough for considerable adoption. For these reasons, I have paid little attention to the detail of OFR methodology in the Southern Cone, although I do feel I have adhered to the basic principles.

Training in the Southern Cone Regional Program

As the regional agronomist position has been filled for just 3 years in the Southern Cone, the training activities have obviously been limited. There are, however, three types of activities that have been undertaken.

- Informal intensive training. Working alongside national program scientists, showing and trying to convince them of new priorities, methodologies and techniques. This has been undertaken especially in Paraguay, but also to some extent in lowland Bolivia. Because of its intensity, this is also the most time consuming of all training activities, but also, undoubtedly, the most effective.

- In country courses and seminars. A course for agronomists was conducted in Santa Cruz, Bolivia, at the request of CIAT at the outset of the AID/ANAPO project. This was a 1-week course designed to make people aware of general wheat physiology and agronomy, the available wheat technology, and/or the gap in this technology. In fact, the course was over-weighted towards chemical pest (disease) control, and therefore lost some of its effectiveness. Unless course participants are picked for their interest, one can spend an awful amount of time following theoretical red herrings.

  In-country travelling seminars in Paraguay have had very little success. These were started as a breeders' activity, and the agronomists incorporated into it. However, I now feel that the time and money can be more effectively spent in other activities, such as farmer surveys. Very little important information or discussion has been obtained on the travelling seminars.

- Regional courses. Two courses or workshops have been organized in conjunction with PROCISUR, and both held in Brazil, with a preponderance of Brazilian participants, but including participants from the other countries of the region. The first of these was a workshop on the design and methodology in long-term trials, conducted by Dr. Carlos Gonzalez, at my invitation. His participation was paid by PROCISUR. This course was conducted at OCEPAR/Cascavel and although, it was most interesting, it attracted very few participants. This may have been due to shortages of funds, or due to inter-institutional rivalries. The second workshop, also in conjunction with PROCISUR, was conducted with EMBRAPA-CNT in Passo

Fundo in December 1990. This workshop was on methodologies in soil tillage and conservation trials, and brought together, probably for the first time, many people involved in soil tillage trials, to discuss the importance and relevance of the data they are taking. One weak point of the workshop was inviting too many people from Universities whose outlook was far too theoretical to be useful in this forum. A summary of the proceedings of this meeting is currently being prepared.

- Conferences and Seminars. I have presented five papers at conferences and workshops in the region. Three on soil degradation and physical fertility, one on general wheat physiology and one on use efficiency with special reference to wheat.

4.2.3.1 Soil Degradation in the Soybean-Wheat Rotation in South America

P.C. Wall

Soybeans were introduced into the farming systems of Argentina, Brazil, Paraguay and southeastern Bolivia in the late 1960s and early 1970s, and since then the area seeded has increased to nearly 13.5 million hectares and total production of the four countries to over 25 million tons (FAO 1988). One of the significant benefits of this crop to the farmer is that it combines well with a winter wheat crop, so that two crops per year may be produced on the same land. This is turn has led to an intensification of agriculture in the region, a rapid advance of the agricultural frontier in Paraguay, southern Brazil, and Bolivia, and a move away from the traditional wheat-pasture rotation in Argentina. This double-crop system has been the most common production system in the region in recent years. However, there is growing concern that the productivity of the system is declining.

Annual rainfall in this "soybean-wheat" region varies from 900 to 1700 mm per year, of which generally only 100 to 500 mm fall in the winter. Rainfall intensity can be high, and in few places are intensities of greater than 60 mm/hr not experienced. Topography is obviously variable, with large areas of almost flat land in the Argentine "Pampa" and southeastern Bolivia, contrasting with the rolling topography of much of the soybean-wheat areas of southern Brazil and southeastern Paraguay.

It is difficult to obtain coherent data showing long-term trends in productivity compared to input use in order to substantiate impression of overall productivity decline. For farmers who have passed the critical stage of decline, the effects are very noticeable, but on a regional, or even subregional basis, it is difficult to provide unequivocal proof. Data of crop areas and fertilizer use taken from the FAO statistics suggest a decline in fertilizer efficiency in most countries of Latin America, especially in Brazil, Mexico, Colombia, and Venezuela (in order of decreasing production increments per extra-unit of fertilizer applied) (FAO 1988a,b).

The data shown in Table 4.9 is taken from the state of Paraná, Brazil, and compares yields of the four major crops and input use over the 10-year period from 1970 to 1980. Data on input use on individual crops are not available, and so total consumption was divided by the total area of crops and improved pastures in the state to obtain an average. In terms of the major annual crops (maize, soybeans, wheat and beans), this is no doubt a very conservative estimate of input use as fertilizer, herbicide, fungicide, and insecticide use on these crops is proportionality greater than on the remaining area which includes improved pastures. Yields shown are calculated from 15-year yield trends, in order to overcome the effects of seasonal variation.

Table 4.9. Changes in Input Use and Yields of the Four Major Crops Over a 10-Year Period in Paraná, Brazil.

	1970	1980	% Change
Nitrogen (N) (kg/ha)	5.21	13.31	155
Phosphorus (P_2O_5) (kg/ha)	4.70	30.52	549
Potassium (K_2O) (kg/ha)	4.92	15.68	219
Insecticide (kg/ha)	1.62	7.02	333
Fungicide (kg/ha)	0.51	1.12	120
Herbicide (kg/ha)	0.05	0.57	1040
Maize Yield (t/ha)	1.72	2.14	24
Soybean Yield (t/ha)	1.45	1.99	37
Wheat Yield (t/ha)	0.80	1.00	25
Bean Yield (t/ha)	0.90	0.66	-27
Area Crop + Imp. Pasture (1000 ha)	7419	10071	

Adapted from Montoya (1982) and Sorrenson and Montoya (1984).

In the 10-year period, there were large increases in per hectare usage of all inputs--all registered at least 100% increases, and some very much higher. Yield levels, however, registered very modest increases, or in the case of beans, fell. Also, this table does not include the effects of liming and new varieties, which must claim at least part of the yield increases over the decade. Obviously, the cost of each kilogram of grain produced of these crops rose dramatically in the 10-year period.

The next piece of evidence of degradation use comes from fertilizer trial results from the "pampa humeda" of Argentina. The data in Figure 4.8 show the decline in yields of both fertilized and unfertilized crops as the numbers of years in annual cropping of a field increases. Not only was the yield of an unfertilized maize crop reduced from 7.7 t/ha to 3.7 t/ha by 30 years of cropping, but this reduction could not be overcome by applying abundant fertilizer. After 30 years of agriculture, the maximum yield of 5.9 t/ha was obtained with a fertilizer dressing of 120-60-0 (N-P_2O_5-K_2O), but this was still 1.8 t/ha below the yield of unfertilized crops in the first year after pasture. This same trend has been found for wheat (Figure 4.9) and soybeans, the other two main crops of the "Pampa". Due to this decline in yields, in time the area seeded to maize in central Argentina has decreased from 4 million ha 10 years ago to only 1.5 million ha today, which, as I shall suggest later, may increase the rate of degradation. There are, of course, those who argue that the reduction in maize area in Argentina is due to economics, and not to soil degradation. To be competitive with soybeans, maize must generally yield at least three times the soybean yield, which it does when the land is fresh out of pasture, but not after many years of continuous agriculture. Thus, maize is an economically viable crop in undegraded land, but not in degraded land.

If, as in the previous example, yield reductions are not due to depletion of the major nutrients, what is causing the yield decline?. It would appear that in this area of Latin

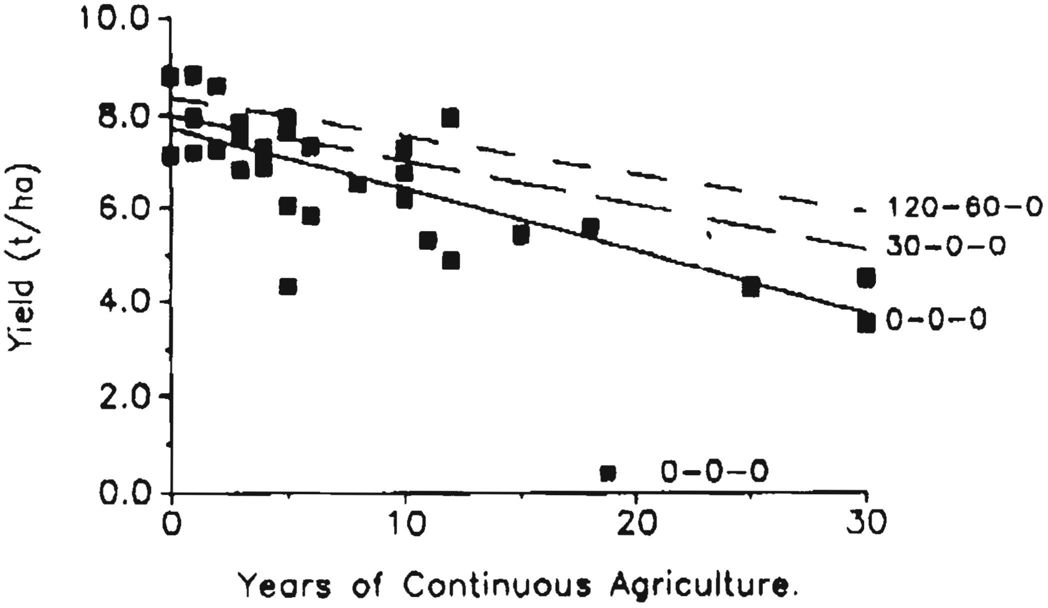


Figure 4.8. The effect of number of years of continuous cropping on maize yield at the three fertilizer levels in the rolling Pampa of Argentina. Adapted from Senigagliesi et al. (1984).

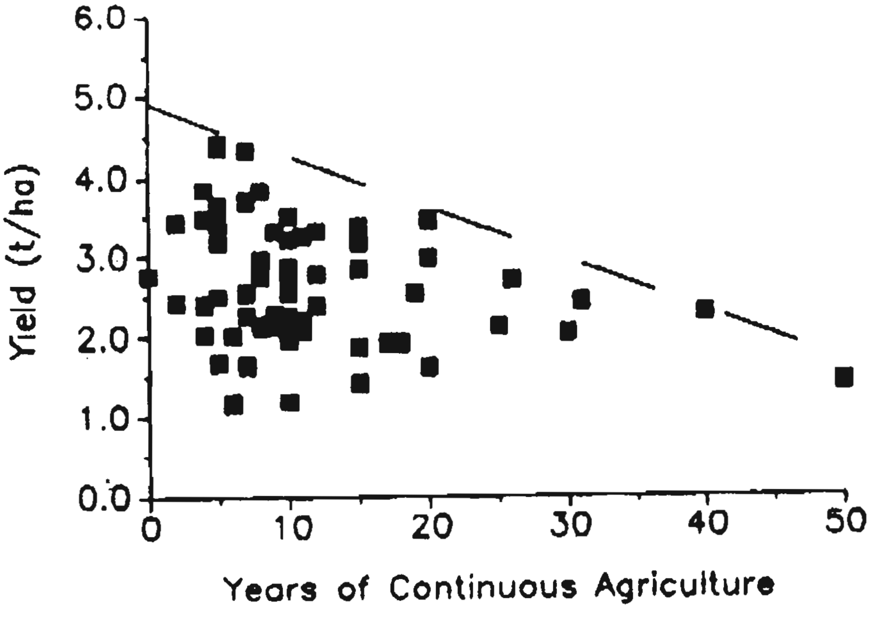


Figure 4.9. The effect of number of years of continuous cropping on wheat yields at without applied fertilizer in the rolling pampa of Argentina. Adapted from Senigagliesi et al. (1983).

America, most of the degradation is due to soil physical degradation, as opposed to soil chemical degradation, although more and more cases of secondary and micronutrient deficiencies are being identified. The four major factors involved in the soil physical degradation appear to be loss of organic matter, reductions in water infiltration rate, soil compaction, and soil erosion, all of which are, to a large degree, interdependent.

In the Pampa of Argentina, a comparison of "virgin" soil (under fence-lines) with average fields in annual crops showed organic matter contents of 4.4 and 2.8%, respectively (Michelena et al., no date), even though very degraded fields were not included in this study. Similarly, in the Argentine Chaco, natural organic matter levels of slightly above 3% were found to be reduced to 1.6% after many years of cotton cultivation (Inalban and Galetto, no date), and data from an oxisol in Paraná show reductions of nearly 60% in soil organic matter content (4.95 to 2.03%) in cropped land compared to the soil of the virgin forest (Kemper and Derpsch 1981). Obviously, these reductions in soil organic matter represent reductions in soil structural stability. As soil organic matter content is also closely linked to chemical fertility, these reductions in organic matter content also represent possible declines in soil chemical fertility.

As would be expected in the light of these reductions in organic matter content (coupled with increasing soil compaction referred to later in this chapter), water infiltration rates have fallen, often dramatically. In an oxisol in Rio Grande do Sul, Brazil, infiltration rates of 136 mm/hr were found in natural forest, while after 7 years of tillage and cropping this value was reduced to 31.3 mm/hr and after 20 years of cropping to an almost impermeable 0.2 mm/hr. This decline in infiltration rate effectively reduces the amount of water available to the crop, increasing the risk and incidence of drought. In studies in the Argentine "Pampa" wheat yields increased by 30.9 kg/ha for each extra 1 mm of water in the top 20 cm of soil at seeding and by 21 kg/ha for each extra mm of rain above the average of 86 mm in the period from seeding to the end of tillering (Garcia and Senigagliesi 1988). Since only rain that enters the soil is of any use to the crop, any increase in total infiltration either before or during the early part of the season will give sizeable yield benefits. Also, water that does not enter the soil runs off across the surface and increases the risk of erosion.

Soil compaction and the formation of compacted plow-layers, primarily due to the use of heavy disc implements for land preparation, is widespread in southern Brazil, Paraguay, and lowland Bolivia, and to some degree in Argentina. Heavy disc harrows are the most common land preparation implement as they can be used in fairly wet soil, they give a fine seedbed, and they are fast--many hectares can be covered quickly. However, it is just these characteristics that make them very dangerous implements. Not only do discs compact the soil at the base of the disc, especially in wet soil and when used at high speed, but they also pulverize the soil, breaking down the aggregates and reducing surface infiltration. For this reason, these implements are commonly used to prepare the foundations for highways. As well as restricting infiltration of water, plough layers restrict root growth, thus making crops more susceptible to climatic drought. On sloping land, they also increase the erosion hazard as the soil above the compacted layer becomes saturated and susceptible to sliding.

Water erosion is extremely serious in southern Brazil and serious in Paraguay and Argentina. Erosion studies in the state of Paraná, Brazil, extrapolated to a constant 6% slope, have shown that when tillage is performed up and down the slope, soil losses can be as high as 700 t/ha/year, equivalent to a 7-cm layer of soil. This can be reduced to 400 t/ha/year by contour tillage, and to 100 t/ha/year with contour bunds and tillage (Kemper and Derpsch 1981). For the whole state of Paraná, average annual soil losses appear to be approximately 30 t/ha/year (Sorrenson and Montoya 1984), still well above the calculated tolerable losses of 12-13 t/ha/year (Bertoni et al. 1975). Peak erosion is associated with heavy rainfall--up to 160 mm/hr (Kemper and Derpsch 1981)--when the soil has been recently disturbed, as shown by the coincidence of the peaks of suspended solids entering Lake Itaipu with periods of soil preparation. Apart from this silting problem, which affects lakes and ports, losses of nutrients are high. Estimated erosion for the whole state of Rio Grande do Sul, Brazil, is 41.8 t/ha, representing a soil loss of 242.4 million t/year. To replace the nutrients lost in this soil would require 485,000 t lime, 661,000 t N, 91,000 t P_2O_5, and 46,000 t K_2O (Denardin and Kochhann 1986).

This scenario may look rather grim. However, considerable research is underway in Brazil and Argentina on methods to stem soil degradation and erosion. Much of this work is applicable to Paraguay and lowland Bolivia as well. Methods of stabilizing soil conditions and regenerating at least part of their natural fertility include a reduction of tillage operations, a change of tillage implements, maintenance of crop residues on the soil surface and crop rotation, including the use of cover crops and green manures. Data on the benefits of these practices are generally positive, but not always so, mainly because it is impossible to restore fertility to a degraded field in one or two seasons. Full benefits will only be accrued after considerable time. For example, Phillips (as quoted in Kemper and Derpsch 1981) suggests that it takes at least 12 years of no-till cropping to attain a natural soil structure approximating that of a permanent pasture.

The effect of mulch on infiltration rate of an Oxisol near Londrina, Paraná, Brazil, is evident in Figure 4.10, which shows measurements taken from plots treated with a rainfall simulator. As the amount of mulch (degree of soil cover) increases, so does total infiltration. In the trials shown in Figure 4.10, it was necessary to have approximately 4 t/ha of wheat residues or 6 t/ha of soybean residues to obtain complete ground cover (Roth et al. 1988). This agrees well with necessary mulch rates proposed by researchers elsewhere (Lal 1982, Mannering and Meyer 1963).

However, in Brazil, Paraguay, Argentina, and lowland Bolivia the amount of residue left by normal wheat and soybean crops is considerably less than this, suggesting that it is necessary to incorporate other crops that produce more residues into the rotation, e.g., maize and cover crops. Also with the relatively high temperatures, residues with low C:N rations such as the legumes (approx 20:1) break down very fast, whereas straw with much higher C:N ratios such as maize or wheat (approx. 80:1) break down much slower and therefore provide a much more durable mulch.

In order to keep more crop residues on the soil surface, less turning of the soil by plows and barrows is necessary. This involves a move towards tined implements, such as chisel plows and tines cultivators. A chisel plow passed through wheat stubble will bury between 30 and 50% of the stubble depending on the tines used, whereas a disc-plow will often bury over 90% of the stubble (Hoogmoed 1982). Most crop residue is maintained on the surface by zero-tillage or direct seeding, which therefore, often has spectacular effects on infiltration rate, and thus on crop yields, as evident in Figure 4.11. However, it is not a recommended practice for poorly drained areas, and gives its major benefits in drier season, when moisture is more limiting factor (Hansen et al. 1984).

In some soil types and conditions, zero-tillage can lead to compaction in the surface horizon, and this may limit the continuous use of the system in some areas. However, this compaction is more superficial, and therefore easier and less costly to overcome than the compaction at 10 to 25 cm and below caused by plows, heavy disc harrows, or tractor wheels riding in plow furrows. Again, soil with a low organic matter content is more susceptible to compaction and serious structural damage than is a "healthy" soil with a good organic matter level and high biological activity (Kemper and Derpsch 1981).

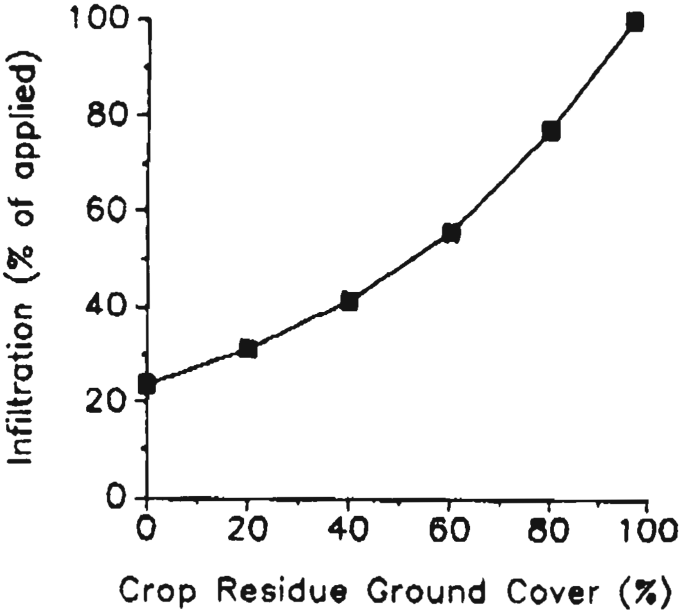


Figure 4.10. The effect of ground cover by crop residues on the infiltration rate of an Oxisol near Londrina, Parana, Brazil, during a simulated rainfall of 60 mm/hr. Source: Roth et al. (1988).

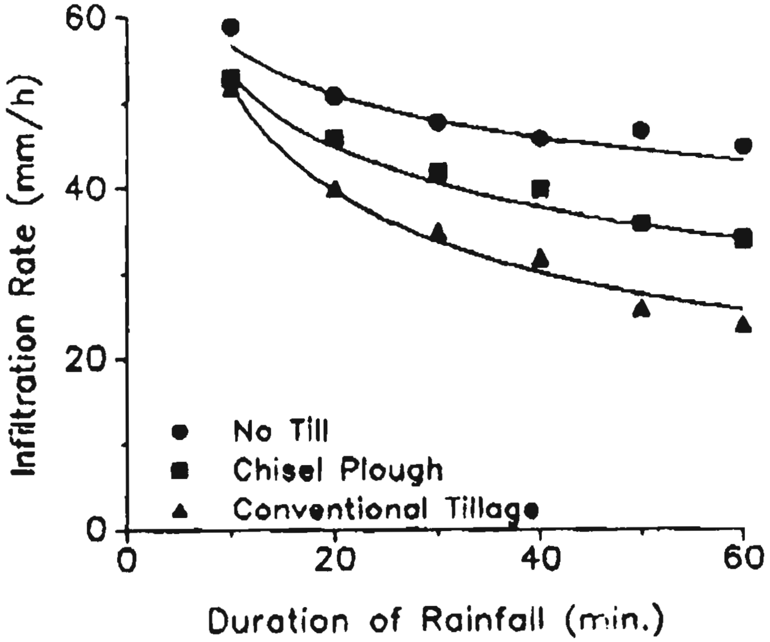


Figure 4.11. The effect of no-tillage (NT), chisel plowing (CP) and conventional tillage (CT) on average infiltration rate of a soybean crop. Source: Derpsch et al. (1986)

As a move is made towards more stubble retention, the need for crop rotation may be even more important than in conventionally tilled soils, due to the retention of crop diseases on the undecomposed stubble. Thus in Paraguay and Brazil, *Helminthosporium tritici-repentis* infects direct-seeded wheat as the spores on the previous year's stubble carry the disease. Secondary infection of conventionally tilled fields, free from early infection, is then a problem. Even when the soil is tilled, rotation may be necessary to overcome disease problems. In Rio Grande do Sul, farmers generally now seed wheat in the same field only once every three or four seasons even with other root diseases. Yields of wheat in continuous wheat rotation are only 60% of those where the rotation includes three winters without wheat (Santos et al. 1986). Neither fungicides nor rotation alone are enough to overcome the disease problem, and their effects are additive (Bougle 1981).

However, apart from sanitary considerations, important yield increases also may result from the right choice of rotation, including the incorporation of green manure crops. The large farmer cooperative of Batabo in eastern Paraná shows yield increases of soybeans in the order of 15% from a lupin-maize-wheat-soybean rotation compared to a continuous wheat-soybean rotation (Cooperativo Batabo 1988).

Green manure crops may also be important in reducing compaction, and increasing infiltration rate. In the data shown in Table 4.10, not only was infiltration rate increased by the cover crops during the season in which they were grown, but also in the soybeans the following season. While the roots of wheat, soybeans and crucifera become distorted and have difficulty in getting through a compacted layer, lupins and other cover crops penetrate the same compacted layers with no evident problem (Kemper and Derpsch 1981). This, of course, depends on the degree of compaction, as severe compaction will reduce or stop root penetration of these cover crops.

Table 4.10. Infiltration rates (mm/h) in wheat, two cover crops and the following soybean crop on an Oxisol, Paraná, Brazil.

	Wheat/ Soybean	Lupins/ Soybean	Horseradish/ Soybean
Sept. '78 (Winter crop)	44	125	79
April '79 (Summer crop)	67	112	90

Adapted from Kemper and Derpsch (1981).

Overall, therefore, it would appear that there is a widespread soil degradation problem in southeastern South America. However, there appear to be technologies available to reverse this situation and restore land fertility. One of the major problems with these technologies is that they require far more managerial competence from farmers than conventional technology, which allow farmers far more flexibility in land preparation and weed control--a factor that I have not touched on this section.

Adoption of these technologies are slow. Estimated areas under no-till in the countries of the Southern Cone are shown in Table 4.11. These estimates paint a rosier picture than warranted, as much of the area shown under no-till is not under a complete no-till system, but, rather, may be direct-seeded in one season and tilled the following season. Why is conservation tillage not spreading faster in the region? It appears that the main reasons are:

- Farmers, especially those on naturally fertile soils, are not aware they have a problem that warrants a change in production practices until they are well along the degradation path.
- Relatively little local adaptive research and demonstration.
- High initial cost of specialized seeders, and increased use of costly agricultural chemicals (mainly herbicides) in the first few years after establishing the system.
- Poor crop prices in recent years.

Table 4.11. Estimates of areas of direct-seeded crops in any one season in the Southern Cone of South America.

	`000 ha
Brazil	1,500
Argentina	300
Chile	10
Paraguay	10
Bolivia	1

In summary, data from the Southern Cone of South America suggest that a conventionally tilled wheat-soybean relay is not sustainable in the region. Technologies for improving this system are available, but their adoption is slow.

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4.2.4 Sustaining Wheat Cropping Systems of the Tropical Highlands: A Case Study of Wheat-Maize in Mexico

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Introduction

It can be argued that the CIMMYT Wheat Program has a comparative advantage in improving productivity of major wheat-based cropping systems of the Third World. This derives not only because part of the improvement involves germplasm improvement, in which CIMMYT has excelled, but also because only CIMMYT has a global view of wheat in the Third World and can draw on its experiences and that of national programs in many environments, few of which are represented in the developed world. In addition, CIMMYT has demonstrated the continuity in effort necessary for sustainability studies. Its work on the rice-wheat cropping system in South Asia now spans almost 10 years and has grown from a within-country effort to a regional project.

Rainfed wheat in the cool tropical highlands of the Third World (generally grown during the summer wet season) is part of what the CIMMYT Wheat Program classifies as wheat mega-environment 2 (ME2)--temperate, high rainfall, in which monthly mean temperatures are below 17.5^{o} but above 12.5^{o} and water supply to the crop is usually >500 mm. This combination of temperature and rainfall usually brings rust problems (YR often, also LR) and Septoria throughout. ME2 comprises some 9 million ha in the developing world, being 8.5% of the total wheat area and 10.5% of its total production. Nevertheless, tropical highlands are somewhat different from the two other major regions comprising ME2 (low altitude regions of high winter rainfall or high summer rainfall). Wheat growing tropical highlands are most widespread in eastern Africa (Ethiopia, Kenya), South America (Colombia, Ecuador, Peru, Bolivia) and Central America (Mexico and Guatemala). The total wheat area in tropical highlands is currently around 1.1 million ha.

The tropical highlands have several unique features such as frost and reducing photoperiod towards the end of the wheat crop cycle, but the features of more concern here are propensity for water erosion and many possibilities for crop rotation. The former is due to the nature of the rainfall (intense convective storms) combined with frequent cultivation and sloping topography (often volcanic), while the latter arises from a thermal and moisture regime permitting maize, barley, potatoes, and beans as competing crops with wheat (in the same cycle). Water erosion is a major problem in these highland regions and that monoculture predominates, despite the opportunities for rotation. In general, the areas are heavily populated by poor farmers and crop yields are poor. Experience elsewhere suggests that reduced tillage (Lal 1989), residue retention (Sanchez 1975), and crop rotation (Schultz 1988) offer much scope for improvement in productivity and amelioration of threats to sustainability from erosion and fertility decline. These possibilities provide the first reason for this project.

Mexico has 20% of its wheat area and 43% of its maize area in tropical highland ME2 (Table 4.12). It is proposing to produce more of these basic grains in this environment although the area has the same problems mentioned above. Since the CIMMYT Headquarters site of El Batan is in the middle of this ME and since the Mexican institutions have expressed their wish that CIMMYT become involved in research to increase production and sustainability of these highland cropping systems, CIMMYT is presented with an excellent opportunity to examine issues of sustainability in its own backyard. Added advantages are provided by access to maize scientists in CIMMYT, and to other disciplines in CIMMYT and nearby in Mexican Institutions, and the opportunity for in-house research on this wheat cropping system provides for broadening CIMMYT's resident training courses.

Table 4.12. Area of wheat and maize planted in high valley areas in 1988.

State	Area (ha) of	
	Wheat	Maize
Guanajuato*	116,400	311,000
Hidalgo	7,100	196,000
Jalisco	38,000	683,500
Mexico	35,500	394,700
Morelos	1,600	42,500
Puebla	18,000	537,000
Tlaxcala	30,700	72,800
Total area in Mexico**	912,000	9,127,300

Source: CIMMYT Economics Program.
* Includes irrigated area.
** Total area of wheat and maize in Mexico.

A Project in Central Mexico

Aim and objectives--The proposed project has as an overall aim the greater productivity and sustainability of wheat cropping systems in tropical highlands, currently threatened by serious water erosion and intensive monoculture. The specific objectives are to:

- Test crop management options in Central Mexico for improvement of local wheat cropping systems: in particular options for reduced erosion, principally through reduced tillage and retention of crop residue, and for breaking wheat monoculture with crop rotation.

- Feed back to wheat breeders information on changes needed to better fit wheat cultivars to the improved cropping systems.

- Use model validation in Mexico and modelling techniques in collaboration with relevant national programs to transfer the knowledge gained to wheat cropping systems in other tropical highlands (and other parts of ME2 in so far as possible).

- Strengthen the sustainability perspective of CIMMYT training by involving trainees in various aspects of the project. Likewise assist in strengthening this perspective in the Colegio de Postgraduados, to which Latin America sends many students, some with CIMMYT support. Provide opportunities for visiting scientists to CIMMYT from the Third World to participate in sustainability research.

- Provide opportunities for scientists/graduate students from the First World to link into crop management sustainability work in an important Third World situation, with CIMMYT Headquarters providing the logistic background and continuity needed to make involvement attractive.

Background in Mexico--The panorama presented by cropping in central Mexico is very similar to that of semi-arid tropical highlands of other developing countries. El Batan, the headquarters of CIMMYT, is centrally located with an altitude of 2,240 m and rainfall of 625 mm. Soils are Alfisols and Inceptisols, often developed on semi-consolidated volcanic ash: the topography is sloping. Land holdings are moderate to small in size, but not so small that tractor tillage does not dominate. The region is heavily urbanized and many farmers appear to be part-time, having off-farm jobs to supplement their incomes. The urban demand for water is competing severely for irrigation water supplies and irrigated cropping is not expected to expand. This fact plus price policy and distance from the sea favor increased rainfed production of basic grains such as maize, wheat, and beans in the region.

CIMMYT, Mexican Institutions (INIFAP, Colegio de Postgraduados, FIRA), and agri-chemical companies have been doing scattered research on cropping system issues in the region for the last 20 years, but most of the research has been on components of cropping systems. Thus, CIMMYT has conducted on-farm experiments in the region for the last 15 years as part of its annual crop management training in wheat: we have focused on the drier wheat/barley region of Tlaxcala, 50 km to east of El Batan, and more recently the higher and wetter wheat/maize areas of Chalco, some 50 km to the south. There have been noticeable improvements in wheat, barley, and maize cropping over this period (drill sowing, more fertilizer use, more herbicide use, use of improved varieties), but the tillage system (disc and disc harrow cultivation throughout the dry season) and crop rotation (monoculture, with occasional shifts in response to price or season) seem unchanged, and water erosion in the wet season and wind erosion in the dry one is widespread. Livestock in particular sheep seem to becoming more common in the areas; this, stall-fed cattle, and industrial uses provide heavy demand for crop residues.

Research strategy--Simple on-farm experiments with zero tillage as part of the CM training program were commenced by CIMMYT in 1987. A complex long-term tillage x rotation experiment was begun at El Batan in 1991 using existing resources. However, these efforts while useful are minor relative to the type of balanced research project needed to examine the central issues of productivity and sustainability. The following activities are envisaged in such a project:

- On-farm multidisciplinary surveys to locate the most appropriate situations for experimental work and to identify socioeconomic constraints especially as the relate to changes in tillage, residue management and rotation. Bench mark observations also need to be taken to permit monitoring of farmers' practices and soil productivity over the long term.

- Experimental program involving both long-term as well as short-term experiments, largely on-farm. Long-term experiments are needed since the benefits of reduced tillage or changed rotation are usually not immediate. Management variables for testing include:

  a) Tillage practices: replacing current practice of deep disc plowing and repeated disc harrowing in the dry season with shallow tillage just before seeding, or with no tillage whatsoever. As occurs elsewhere (Fischer 1987), moisture conservation is one stated reason for the current tillage. Are there alternatives (grazing, herbicides) and what are the implications for seeding date, a particularly critical question for maize which is often sown on residual moisture before the onset of the summer rains? What is the importance of deep tillage?

  b) Crop residue management: replacing residue removal or burning with residue retention brings clear advantages for erosion control and for moisture conservation but there are costs, including possible increase in disease and weed incidence.

  c) Seeding practices. While row seeding is becoming common, the reduction or absence of prior tillage and the retention of crop residue can make seeding difficult and can reduce early crop growth (Fischer et al. 1988). Machinery designs new to the region need to be tried and the nature of mechanical disturbance of the immediate zone around the seed tested. Use of techniques such as tied ridges to reduce run off warrant testing.

  d) Crop rotation. The effect of breaking the wheat monoculture with maize, grain legumes, and even pasture legumes needs to be examined. Also can residual moisture, frequently remaining after the cereal crop, be used effectively to grow a legume forage or green manure crop, relay planted into the cereal.

- Modelling. Simulation models such as EPIC (Williams et al. 1989) which includes simulation of erosion, nutrient cycling, tillage and rotation offer the possibility of prediction, according to our understanding of key factors in a cropping system, in both time and space. Measurements in the experimental phase will be used to validate such a model for central Mexican conditions. This can then be used to predict long-term changes in Mexico, and in similar environments elsewhere after further validation in collaboration with local national program scientists.

Training opportunities--Because of the location of the project area close to CIMMYT Headquarters at El Batan and close to the nearby Colegio de Postgraduados at Montecillos, incorporation of trainee projects and thesis research into the overall project is facilitated. It is planned to boost the experimental measurements considerably through this mechanism, as well as through inviting more senior national program scientists to participate in specific aspects of the research. Finally, several specialized training courses of short duration and concentrating specifically on the project will be conducted.

Although not training, the project also provides an attractive framework into which scientists on sabbatical leave from developed countries can fit. They can thus be encouraged to apply their specialized skills on such issues as erosion, soil fertility, and system modelling in an important Developing World agricultural context with guaranteed logistic support. Already scientists at USDA and Texas A&M in Temple, Texas, have expressed considerable interest in this possibility.

Resources for project--The CIMMYT Wheat Program has started a very limited program of research on the issues described. Various staff members remain ready to contribute a portion of their time to an expanded initiative. This includes scientists from the Wheat Crop Management and Physiology and Crop Protection Subprograms. Scientists from the Economics and Maize Programs would also become involved. However, it is not possible to expand beyond the modest beginning with current core resources. This proposal therefore seeks special project support over a 5-year period for the following:

- An internationally recruited associate scientist to take responsibility for day-to-day execution of on-station and on-farm experimental program.

- Two nationally-recruited support staff to work as full time field assistants in the project.

- Temporary labor as needed, but especially for soil sampling and sample processing.

- Post-graduate scholarships for partial or full support of at least two students from national program to be working on aspects of the project.

- Support for visiting scientists from the national program to come to CIMMYT to work on the project and for specialized training courses.

- Transport and operations expenses.

- Support to collaborators in Mexican institutions and other national programs with tropical highlands.

- Capital items including a zero till plot drill, a plot combine, plant and soil monitoring equipment, and two vehicles.

Outcome

It is unrealistic to expect a major impact on farmers' practice within 5 years. However experience in the rice-wheat project suggests that new technology for demonstration to farmers could become available in that period. Demonstration and adoption will take longer and undoubtedly will take attention to policy issues; these activities lie more clearly in the hands of the Mexican national program and Secretaria de Agricultura y Recursos Hidraulicos.

It is expected that the project after 5 years will have achieved the following:

- Identified situations and machines for reduced or zero tillage cropping of wheat and maize in central Mexico and quantified the short-run costs and benefits of reduced or zero tillage.

- Identified costs and benefits of crop residue retention in wheat-maize rotations.

- Identified and quantified short-term effects of breaking wheat (and maize) monoculture with alternative crops, including legumes.

- Initiated several long-term tillage/rotation experiments on farmers' fields, with measurement of soil erosion, soil fertility change, weed and disease stress as well as standard crop parameters.

- Validated the EPIC model and its components under central Mexican conditions and run simulations of new tillage and rotation systems using historic weather records from Mexico and from elsewhere in the tropical highlands.

- Exposed approximately 100 crop production trainees and visiting scientists from the national program to the project and involved them in specific aspects of the research through individual research projects of short duration.

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4.3 Support to Breeding

An important part of CMP staff research activities is in direct support to breeding. Both, physiological and agronomical work are involved. Breeding and CMP activities interact in a way that it makes it many times difficult to separate. In what follows, the current projects and activities in this area are presented, these include those related to Mega-environment 5 (heat stress), Mega-environment 1 (potential yield), and drought and salinity resistance. Agronomic support for management of wheat program trials and nurseries is an important essential activity within CMP and a project in this area is also presented.

4.3.1 Physiology and Agronomy of Wheat Grown in Environments with Supra-optimal Temperatures (ME5): Development of Selection Criteria, Agronomic Recommendations, and a Conceptual Model

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Introduction

Wheat, although an extremely valuable and popular food crop, has not traditionally been grown in tropical climates. Poor adaptation of traditional varieties, and inadequate management practices contribute to low yields. Nevertheless, genetic diversity exists with respect to heat tolerance (Shpiler and Blum 1991, Al Khatib and Paulsen 1990, Rawson 1986, Shpiler and Blum 1986, Wardlaw et al. 1980) and there is increasing evidence that with appropriate management, respectable yields are possible in hot climates. For example, in the Sudan, a very hot dry environment, yields more typical of a temperate environment of 6 t/ha were reported (ICARDA 1991). With the ever increasing availability of agrotechnology and demand for quality cereals, CIMMYT is continuing its effort to produce heat-adapted germplasm and agronomic recommendations for hot climates. Some of the major problems for wheat in hot environments are pest and disease pressures. These problems are being tackled by CIMMYT outreach staff and by collaborative experiments between the Crop Improvement and Crop Protection Subprograms here at CIMMYT. For example, selection for resistance to Helminthosporium. The purpose of this project is to study the agronomic problems and selection strategies associated with heat stress without the confounding effects of disease or other pest problems. The target environment is referred to as mega-environment 5 (ME5), which includes 33 countries currently importing 10.6 million tons of wheat per year. The project is joining a larger ongoing thrust within CIMMYT's wheat program aimed at increasing wheat production in warmer and stressed environments which is funded by the UNDP (project GLO/90/001).

The detrimental effects of high temperature on wheat growth have been summarized as follows (Fischer 1989, Acevedo et al. 1991): yield reduction can occur at temperatures above a mean as low as 15°C, with the spike and grain growth phases being especially sensitive; with very hot conditions during stand establishment, lack of full ground cover will further contribute to yield loss; yield loss is mediated more through reduced crop duration than reduced partitioning or growth rate. Mechanistically, it seems that high temperatures effect a number of physiological processes, apart from rate of development, though causal links between these processes and yield loss in the field have not been established. The interaction between these mechanisms, genotype, and agronomic management practices, form the basis of our investigations in this project.

Probably the greatest challenge in understanding the physiological problems associated with high temperature stress is to encompass the diversity of hot environments that exist. These can be put into four broad categories: hot dry, hot humid, very hot dry, and very hot humid. Hot and very hot would be climates where the mean temperature for the coolest month of the cycle is greater than 17.5°C, and 22.5°C, respectively. Dry and humid are climates where the mean vapor pressure deficits are above and below 10 mb, respectively, for the crop cycle. So that our studies will be representative of the range of warm climates that exist, a major part of this project will focus on collaborations with national programs and CIMMYT outreach staff in different hot locations. Data for the international trials will be collated at CIMMYT base with the hope of being able to make generalizations both within and between these four types of hot environments. Research conducted in Mexico will concentrate on the hot and very hot dry environments, characterized by the spring season at CIMMYT's Tlaltizapan and Obregon stations.

We have also solicited collaboration with USA universities to conduct physiological work for which we lack the facilities. There is an ongoing collaboration to study photosynthesis of wheat in a hot environment in Mexico (Tlaltizapan) with the Botany Department, Colegio de postgraduados at Chapingo.

Objectives

- Evaluate selection criteria for "heat tolerant" wheat.
- Identify agronomic strategies that will ameliorate the detrimental effects of heat stress on yield.
- In collaboration with national programs and CIMMYT's outreach staff: stimulate interest in developing more heat tolerant germplasm and agronomic practises for hot locations internationally.
- Verify experimentally a conceptual model of the physiological mechanism involved in the transduction of heat stress to yield loss.

The remainder of this discussion will cover these four objectives individually, a collaborative study with the Colegio de Postgaduados at Chapingo, and some additional experiments. The following is a list of experiments that are currently being conducted and will be referred to in the text.

- In Mexico:

1) Heat Stress Genotype Experiment
2) Heat Stress with Genotypes and Soil Management
3) Drip Irrigation Experiment at High Temperature
4) Heat Stress Management Experiment
5) Comparison of Growth between Hill Plots and Canopies
6) Trait Evaluation on Hill Plots

- In collaboration with National Programs and CIMMYT outreach staff:

1) International Heat Stress Genotype Experiment (IHSGE)
2) International Heat Stress Management Experiment (IHSME)

4.3.1.1 Evaluating Selection Criteria For Heat Tolerant Wheat

Introduction

For a trait to be accepted as a selection criterion it must satisfy two main requirements:

- It must correlate with performance consistently in the field environment.
- The trait's value in predicting performance must be seen across the full range of germplasm used in the breeding program.

For these studies, genotypes were selected in consultation with the breeding programs and outreach staff in hot locations. The main criterion for choosing the traits to be evaluated was that they be amenable to qualitative assessment. Nonetheless, quantitative data are collected as part of the physiological study in order to examine the relationship between the trait and performance quantitatively.

Materials and methods

International Heat Stress Genotype Experiment (IHSGE)--This trial is designed to look closely at a small number of traits which, in preliminary studies at CIMMYT and in consultation with CIMMYT outreach staff and other researchers in hot environments, seem to have potential value as predictors of yield at high temperature. This will be discussed more fully under in Section 4.3.1.3 since it is part of an international collaboration. Here in Mexico the experiment is being conducted in five environments, based on sowing date (Table 4.13).

Screening material from a broad genetic base For heat tolerance selection traits--A trait observation trial is being conducted on replicated hill plots at CIMMYT's Tlaltizapan station, with an early February sowing date. Material has been provided by CIMMYT's Bread Wheat and Germplasm Bank Sections. The objective is to study plant characteristics that may serve as selection traits or even as genetic sources of heat tolerance (Acevedo et al. 1991, Edhaie and Waines 1989, Johnson et al. 1983). The following are some of the traits to be evaluated:

- Length of life cycle
- Leaf size
- Height
- Leaf glaucousness
- Awn length
- Leaf chlorosis

These observations made on material from a much wider genetic base than the IHSGE, may help to confirm our conclusions regarding selection traits.

Table 4.13. Five Environments for the Heat Stress Genotype Experiment at CIMMYT stations in Mexico.

Site	Mean max. T (cycle)	Mean min. T (cycle)	Mean T (cool month)	Type of Environment
Tlaltizapan				
sown:				
1) early Dec.	33°C	10°C	18°C	hot, dry
2) late Feb.	34°C	15°C	24°C	v.hot, dry
CIANO Obregon				
sown:				
3) late Nov.	26°C	9°C	16°C	temperate
4) mid March	32°C	15°C	20°C	hot, dry
5) late June	36°C	24°C	29°C	v.hot, dry

Comparing growth on hill plots with canopies at high temperature--In previous cycles of the IHSGE, the trait most highly correlated with yield was biomass at harvest, while harvest index was not well correlated. This is the opposite relationship to that seen under temperate, nonstressful conditions. This result implies that growth itself rather than partitioning to grain is more important in determining genetic differences in yield potential at high temperature. On the basis of this observation, the hypothesis is being tested that in warmer environments yield on hill plots may correlate with yield in solid stands better than it does in the temperate environment. The lack of correlation in the temperate environment is presumably a result of an interaction between vegetative growth and genotype in the different planting environments and the subsequent effect on partitioning to grain. Since partitioning seems to be a less important determinant of yield at higher temperature, presumably the interaction between vegetative growth and the planting environment will also have less impact on yield determination. In a trial of 70 genotypes, the yield of replicated hill plots is being compared with grain yield in traditional stands of wheat. A positive correlation would imply that yield testing for heat tolerant material can be conducted extremely efficiently on hill plots. Biomass of hill plots is also being collected at booting and anthesis to see whether even early growth on hill plots is a good predictor of final yield in canopies in warmer environments.

Discussion

Where traits are apparently well correlated with yield in hot locations, recurrent selection studies will be conducted to prove their value as a selection criterion. Based on our data from Mexico and those collected by CIMMYT outreach staff in Thailand with collaboration from national programs (Mann and Sirithunya 1990), a divergent selection study has been initiated to demonstrate the relationship between yield and biomass in hot environments. Four heat-adapted parents have been crossed with each other for selection at the F_2 in a hot environment and yield testing at the F_4.

Apart from simple morphological traits, there are examples of physiological traits that seem to be valuable in conferring heat tolerance. Heat tolerance of improved cotton genotypes has been attributed directly to increased stomatal conductance, leading to reduced leaf temperature in the field (Lu et al., pers. comm., UCLA). In rice, the problem of reduced pollen viability caused by temperature stress is avoided in genotypes which dehisce inside the floret thereby increasing the amount of pollen reaching the stigma (Mackill et al. 1982). More recently, some biochemical selection traits have been reported in the literature with regards to screening wheat for heat tolerance. Membrane thermostability, which is measured by electrolyte leakage of heated leaf tissue, has shown correlations with grain yield of field grown plants in hot environments (Shanahan et al. 1990). Chlorophyll fluorescence, an indication of thylakoid membrane stability, has also been shown to correlate with heat tolerance of plants grown at supra-optimal temperatures, (Moffatt et al. 1990). At CIMMYT, we concentrate on evaluating easy to measure morphological traits since these are compatible with the scale of our breeding programs and the resources available. However, we do seek collaboration with institutes whose facilities permit the evaluation of more complex physiological traits.

4.3.1.2 Identifying Agronomic Strategies That Will Ameliorate the Detrimental Effects of Heat Stress on Yield

Introduction

The incentive for this work stems from two main factors. First, the achievement of high yields in hot climates when agronomic management is high (ICARDA 1991). Second, a complementary hypothesis that, at high temperature, the crop growth rate of wheat is limited by the availability of nutrients and water because of the demands created by increased metabolic rate (Rawson 1986). All of CIMMYT's outreach staff working in warmer areas agree that research on agronomic recommendations for wheat is badly needed. They have observed excellent responses to a number of agronomic practices including mulching, deep cultivation, frequent irrigation, and incorporation of organic matter. Based on these observations, a collaborative experiment, the International Heat Stress Management Experiment (IHSME), was designed to examine the benefits and interaction of these practices in different hot environments.

Evidence is emerging as to the critical role of the soil environment in influencing crop responses. A drying soil profile can cause reduction in leaf growth rates well before leaf water potential is affected (Passioura 1991). Furthermore, the presence of compacted layers in the soil can constitute a drain of carbohydrate away from shoot to root development (Gregory 1991). In all environments, these factors will tend to reduce yield potential, and perhaps more so in the hot environment where accelerated life cycles may increase the need for good management.

Materials and methods

International Heat Stress Management Experiment (IHSME)--This experiment, designed to look at the effects of different levels of agronomic management, is part of the international collaboration and is described further in the Section 4.3.1.3. In Mexico, it is conducted in the environment of Tlaltizapan at both planting dates (Table 4.14)

Soil management effects on genotypes with heat stress--This study examines the interaction between soil management strategies and genotype at high temperature. It includes all 16 genotypes from the IHSGE in the three environments at Obregon (Table 4.14). In one treatment, the soil is chisel plowed to break up compaction zones and chicken manure is incorporated along with inorganic fertilizer. The control is not chiselled and inorganic fertilizer is applied to give a level of nitrogen availability equivalent to the other treatment.

Discussion

In subsequent years, the two hot environments may be replaced with a single environment, and the size of the experiment increased to allow a factorial design complementary to the IHSME. Different irrigation strategies or the interaction between organic matter and chisel plowing could then be examined.

We are particularly interested in observing how the impact of management may vary between genotypes. The result may have implications not only on deciding upon a package of agronomic recommendations (i.e., genotype, fertility, irrigation, etc.) in hot environments, but also for the management of selection nurseries aimed at evaluating heat tolerant germplasm.

4.3.1.3 Stimulating Interest in Developing More Heat Tolerant Germplasm and Agronomic Practices for Hot Locations Internationally

Introduction

The IHSGE and the IHSME are being conducted at CIMMYT base and at several hot locations in collaboration with a number of national programs. There are several reasons for sending trials out internationally. As stated earlier, our target environment has different types of heat stress--many of which cannot be found in Mexico. Thus, collation of data from different representative environments will make the study more comprehensive in terms of generalizing about ME5. Collaborating with outreach staff and with national programs also enables research to be clearly focused on the requirements of the target environments, avoiding a drift of research objectives into more theoretical areas. Furthermore, the collaboration is intended to stimulate national programs to produce germplasm and management recommendations that are specifically adapted to their own region. Each region may differ not only in the thermal environment, but also in soil types, pest problems, and local management practices. Given its global mandate, it is hard for CIMMYT to make firm recommendations in such specific environments without the participation of national programs.

Materials and methods

IHSGE--The objectives of the IHSGE are to:

- Measure growth, development, and yield response of a set of diverse genotypes in several hot irrigated environments and to identify genotype*temperature interactions.

- Elucidate potential selection traits and environments that can be used to select for superior performance under hot conditions.

Sixteen genotypes are used based on the recommendations of wheat researchers in hot locations. The potential selection traits being evaluated are:

- Seedling emergence.

- Canopy establishment (assessed visually and with biomass).

- Phenology, including date of anthesis and maturity.

- Biomass and ground cover estimate at anthesis.

- Plant height.

- Yield components, i.e., harvest index, final biomass, grains/spike, spikes/m^2, thousand grain weight, and grains/m^2.

We are recommending that the trials be highly managed in terms of fertility, irrigation, and complete pest control so as to avoid factors that will confound the effect of the thermal environment. We also request that all management treatments be documented. Investigators are also being asked to collect weather data, including daily maximum and minimum temperature, radiation, cloud cover, rainfall; as well as notes on soil type, pH, and approximate rooting depth.

National programs in the following countries are currently involved in collaborations:

- Bangladesh: hot, humid.
- Brazil (summer planting): hot, humid.
- India: hot, dry.
- Mexico: hot, dry & very hot, dry summer.
- Nigeria: very hot, dry.
- Sudan: very hot, dry.
- Syria: hot, dry.
- Thailand: hot, humid.

See Reynolds et al. (1992) for the results of the 1st International Heat Stress Genotype Experiment.

IHSME--This is a collaborative project with national programs designed to see what management practices can improve yields of locally adapted varieties in different hot locations. Collaborators are being encouraged to design their own trial based on the following treatment factors (Treatments are intended to represent the normal practice and a more highly managed scenario:

- Fertility treatments (from organic & inorganic sources).
- Number and timing of irrigations.
- Straw mulch (presence or absence).
- Deep cultivation (presence or absence).

The idea is that improved fertility and water availability will improve growth over the entire crop life cycle (Rawson 1988). Deep cultivation, as well as giving greater potential for soil exploration by the roots, may also decrease the drain of carbohydrates from the shoots to the roots associated with compacted soils (Gregory 1991). Mulching is intended primarily to improve seedling emergence and stand establishment early in the growth cycle before full ground cover is reached. In sorghum, hot soils are known to reduce seedling emergence Wilson et al. (1982) and Rawson (1988) conclude that early ground cover is especially important to realizing yield potential of wheat in hot conditions.

All of CIMMYT's outreach agronomists have reported extremely favorable responses to the use of organic matter in warmer environments, even when no response is seen to additional applications of inorganic nitrogen. The same has been found in our experiments in hot environments in Mexico. Many agricultural soils tend to be deficient in organic matter, which is known to improve nutrient availability, soil structure, and its water holding capacity (Sanchez 1976). For these reasons, we are suggesting that collaborators include incorporation of organic matter among the fertility treatments.

Discussion

We are encouraging individual collaborator input into the design of these trials because the environments and potential for management vary greatly. For example, deep cultivation should only be included if the soil has compaction zones. The timing of extra irrigations may be chosen to coincide either with the hottest periods of the crop cycle, the most heat sensitive stage of development, or simply the times when irrigation water is most economically available. Choice of fertility treatments will depend on the residual fertility of the soil after the last crop, and availability and cost of organic and/or inorganic fertilizers. The objective is to produce a set of agronomic recommendations that can be extrapolated to other sites based on the similarities to the environments of individual case studies. Some generalizations about management may be possible across all hot environments.

Data for both the IHSGE and IHSME will be sent back to CIMMYT for collation and redistribution to collaborators, with the conclusions that may have been reached, and suggested modifications to the trials for subsequent years. For example, in the IHSGE if one trait appears to be a particularly good indicator of yield across most hot locations, we may suggest emphasizing measurements related to this trait, while de-emphasizing others.

4.3.1.4 Varifying Experimentally a Conceptual Model of the Physiological Mechanisms Involved in the Transduction of Heat Stress to Yield Loss

Introduction

Germplasm enhancement for adaptation to adverse environments and improved performance via good agronomic management can be achieved both serendipitously and by the application of our understanding of the mechanisms that limit plant growth. For these reasons, additional treatments and data collection are included in many of the trials discussed, specifically to develop a conceptual model of the limitations of growth at high temperature.

Summary of a conceptual model for heat stress in wheat--High temperatures increase the metabolic rate of the crop, thus accelerating its life cycle and increasing the demand for growth inputs (nutrients, water, light, CO_2). Stress can be ameliorated by maximizing the availability of inputs where possible, and by timing a crop so that the most sensitive stage of development occurs at the coolest time of the cycle. Temperature effects can be decreased by reducing the temperature of the crop microenvironment; of the roots with mulch, and of the whole plant by frequent irrigation to allow evaporative cooling via transpiration when possible.

The model is based on some of the mechanisms that have been shown to effect wheat growth at high temperature. The purpose of developing it is to demonstrate causal relationships between the mechanisms studied and the growth of wheat plants in the field in hot environments. The relative importance of each mechanism depends on the timing of the stress and the interaction with the phenology of the genotypes. Evidence suggests that the crop is most sensitive to temperature stress during the spike growth stage. Realization of yield potential can be maximized if this stage of development coincides with the coldest period of the crop cycle (Shpiler and Blum 1986, Fischer 1985). However, almost any crop stage can be shown to be sensitive. Rapid early growth to maximize light interception is important (Rawson 1988). Temperatures of 30°C during meiosis reduce grain set and subsequent yield by causing abnormal pollen development resulting in reduced pollen tube growth (Saini et al. 1983; Zeng et al, 1985). Temperatures of 35°C also appear to be detrimental to grain filling via inhibited conversion of sucrose to starch in the endosperm (Bhullar and Jenner 1986, Rijven 1986). Complementary evidence shows elevated levels of carbohydrate in the vegetative parts of the wheat plant when grain filling is limited by high temperature (Spiertz 1977). It is also known that high temperature speeds up phasic development in the field and in reducing the duration of the crop impairs the potential for assimilation (Midmore et al. 1982, Shpiler and Blum 1986).

Management practices aimed at reducing crop temperature will improve growth. This can be achieved for example by well managed irrigation. Canopy temperatures as much as 10°C below air temperature have been reported for wheat in hot dry environments, when soil moisture was plentiful (Idso 1982, Idso et al. 1984). Reducing the temperature of the root environment through soil mulching and frequent irrigation may improve performance, especially during early canopy development when the soil surface is exposed to direct sunlight. In a study examining the differential response of wheat plants to root and shoot temperature, premature senescence and decreased root growth seemed to be attributable more to the sensitivity of roots to high temperature (35°C) than shoots (Kuroyanagi and Paulsen 1988). Mulching may also permit more vegetative growth by slowing down the rate of development of the vegetative apex.

Other evidence suggests that temperature is not necessarily stressful to wheat directly; instead yield loss is a result of the inability to meet increased demand for inputs caused by accelerated metabolic rates at high temperature. This has been demonstrated in growth cabinets where at temperatures of 30/25°C the growth rate of wheat plants grown hydroponically, and at high light intensity was equivalent to non stressed plants (Rawson 1986). From the point of view of crop physiology, this becomes somewhat academic since crop light intensity cannot be manipulated in the field. Furthermore, these data do not answer whether or not high temperature is directly inhibitory to plant processes since light, normally a major limiting factor to assimilation rates in the field, could at elevated levels mask the effect of partially inhibited metabolism in certain cases. This would be the case, for example, if light reactions or light harvesting complexes were inhibited. Nonetheless, part of the hypothesis can be tested by increasing the availability of nutrients and water in the field.

At the subcellular level, high temperature impairs photosynthesis (Al-Khatib and Paulsen 1984, Blum 1986) and some evidence suggests that accelerated respiration may be involved in reduction of grain dry weight (Wardlaw et al. 1980). In Sorghum, it seems that genotypic variability exists in the response of dark respiration to increased temperature (Gerik and Eastin 1985). We have one study in collaboration with the Botany Department, Colegio de Postgraduados at Chapingo, in which we are studying the effects of high temperature on carbon fixation, respiration, and chlorophyll content of plants in the field. Full details are given in Section 4.3.1.5.

Methods and discussion

Phasic development--Although it is well established that temperature increases the rate of phasic development, there is not much information on the genotype*temperature interaction for phenology. With the information from the different planting dates of the Heat Stress Genotype Experiments, we will be in a position to pinpoint the extent of G*E in phasic development and its relationship with heat tolerance. Secondly, the vernalization requirement of some genotypes can be evaluated in terms of its effect on phasic development and yield at high temperature by comparing planting dates and in a more controlled way with artificially vernalized seed in growth chamber studies or under nonvernalizing field conditions. In the Trait Evaluation Trial on Hill Plots, there is the opportunity to compare phenology with growth of a very wide range of genotypes.

Increased availability of inputs--In all of the trials involving management, there are treatments in which levels of nutrients, water, and light are made more available than the optimal recommended levels for the temperate environment. Measurements of the response to these factors and combinations of these factors will help reveal which factor(s) are primarily limiting growth. Analysis of leaf tissue for nutrients will indicate whether agronomic practises are improving yield by improving the availability of nutrients in the soil. Similarly in the experiment with genotypes, leaf tissue analysis might reveal whether genotypic differences in yield are also related to the ability to absorb nutrients at high temperature. Such data would complement Rawson's hypothesis (1986) for the mechanism of heat sensitivity in which still lacks evidence from field grown plants.

To test whether availability of nutrients and water is more limiting at high temperature than under temperate conditions, we are conducting a drip irrigation study with three genotypes from the IHSGE, sown in the field under the temperate and hot environments of Obregon (Table 4.13). These data will be compared with the response to normal management in the same environments.

Crop microenvironment--Relief of stress by management is being investigated in the IHSME. By comparing one genotype under two different irrigation regimes and collecting temperature data of the crop canopy, using infrared thermometry, we can investigate the effect of evaporative cooling on growth and the potential for increased irrigation as a management strategy in hot dry environments. The effect of straw mulch on soil temperature and growth response is also being examined.

Timing effects--The idea that one stage of development is more sensitive to stress than any other is difficult to test without resorting to experiments in controlled environments (Rawson and Bagga 1979). Nonetheless, these and other data (Shpiler and Blum 1986, Fischer 1985) indicate that the spike growth stage (from double ridge stage to heading) is the most sensitive to high temperature stress; presumably through decreased initiation of spikelets and florets before the 1-2 node stage and increased spikelet and floret abortion after it. In other studies with heat stress, the photothermal quotient (PTQ) between spike initiation and heading accounted for 69% of the yield variability of field grown plants and 92% of the yield variability in growth chamber studies (Rawson 1988, Midmore 1986). The whole of the period between the double ridge stage and heading seemed to be equally sensitive to heat stress in the growth chamber study.

In the IHSGEs, the PTQ during the spike growth stage can be compared between genotypes of different phenologies at each planting date. Rather than correlating PTQ during this growth stage with yield differences, more direct support for the importance of this stage to grain number determination may come from comparing the change in number of grains/spike between environments with the differences in PTQ for each growth stage. Presumably, grain number will not be confounded by temperature conditions during grain filling, and will to a greater extent be a factor of conditions during the spike growth stage. Recent data (Sphpiler and Blum 1991) suggest that the yield component kernels/spike may correlate best with yield in the hot environment, but that the number of kernels/spike correlates better with the thermal environment during the first 2 to 3 weeks of growth rather than the spike growth phase, although both were important. Apparent differences in what appears to be the most sensitive stage of development to temperature may be related to differences in the timing of the heat stress between experiments. Shpiler's experiment used an environment where mean daily temperatures decline from sowing to maturity which may explain why the early growth stage would be more critical to yield determination since it was also the hottest. Furthermore, the earliest growth stage is the most sensitive to the vernalization requirement so it is possible that the number of grains/spike was influenced, in part, by subtle differences in vernalization sensitivity between genotypes since none of the genotypes would have experienced vernalizing temperatures in this environment.

Modelling--Most of the experiments are being designed so that data collected can be used in growth simulation models. We are especially interested in developing an algorithm, which will distinguish between air and canopy temperature based on available water and vapor pressure deficit. This may enable irrigation and weather data to be included in a model to improve its accuracy in predicting wheat growth in hot irrigated environments.

4.3.1.5 Collaborative Study between Fisiologia, Colegio de Postgraduados, Chapingo and CMP, Wheat Program CIMMYT: Photosynthesis at High Temperature in the IHSGE and IHSME

Introduction

There are a number of studies in which photosynthetic metabolism has been carefully measured at high temperature in wheat with growth chamber grown plants. There is good evidence that both light (Harding et al. 1990, Al Khatib and Paulsen 1989) and dark reactions (Kobza and Edwards 1987, Al Khatib and Paulsen 1984) are impaired at high temperature (30 to 40°C). Furthermore, there is some evidence that heat tolerant genotypes were more stable in these processes than their heat-sensitive counterparts (Al khatib and Paulsen 1990, Sayed et al. 1989). Evidence on respiration is apparently contradictory. Some research shows that accelerated respiration may be involved in reduction of grain dry weight (Wardlaw et al. 1980) while a study with sorghum showed a positive correlation between growth rate and dark respiration on a per shoot basis between 30-40°C.

Impaired photosynthesis may be in part a result of premature leaf senescence, a process which is accelerated in wheat at high temperature (Harding et al. 1990, Al-Khatib and Paulsen 1984). In wild *Solanum* spp., premature senescence, chlorosis, and preferential loss of light harvesting complex (Chl b) over reaction centers (chl a) seemed to be causally related to differences in heat tolerance (Reynolds et al. 1990). In wheat, studies with near isogenic lines suggested that increased glaucousness conferred a yield advantage under drought by reducing leaf temperature and thus delaying senescence (Johnson et al. 1983).

Few systematic studies have been undertaken to establish whether a relationship exists between photosynthesis and growth of different wheat genotypes under field conditions (Acevedo et al. 1991). The purpose of the proposed study is to measure photosynthesis and respiration of attached flag leaves at different stages of crop development, and with this information determine whether genotypic differences in photosynthetic or respiratory metabolism may be causally related to yield potential at high temperatures. In quantifying photosynthetic rate on a per unit chlorophyll basis, information on chlorosis and changes in the chlorophyll a:b ratio will also be revealed. These parameters can assist in elucidating the nature of photosynthetic dysfunction and may represent the basis of a selection trait for heat tolerance.

Materials and methods

Management--Sixteen bread wheat genotypes, representing a range of yield under high temperatures, are being grown at 2 dates under optimal management in Tlatizapan, Morelos, Mexico. For the December 5 planting date, the mean maximum and minimum temperatures for the cycle are expected to be approximately 32/10°C and for the late February sowing date 34/14°C.

Photosynthesis measurements--Photosynthesis will be measured on flag leaves oriented at right angles to the incident solar radiation, using an ADC gas analyzer. Measurements will be made at three approximate stages of development: mid-booting, late heading, and 10 days after anthesis. Since genotypes will be out of phase phenologically, the developmental stage of the median variety will be used to schedule measurements and all genotypes will be sampled on the same day. However, to compensate for the confounding effect of phenology, the exact stage of development will be recorded for each genotype and used as a covariate in analysis of the data.

Due to the time constraints of making repeated measurements in the field, the following methodology will be adopted in an attempt to minimize the confounding effect of diurnal rhythms in photosynthesis, and environmental fluxes in temperature, light, and humidity during the light period. Measurements will be restricted to all genotypes within a single experimental replication on a single day, so that the experiment will be replicated on different days. A single estimate of photosynthesis will be made on all 16 plots in a random order in the shortest time possible. This will then be repeated as many times as possible during the day on the same plots but in a different random order, and on at least two different flag leaves per genotype.

Measurement of respiration--Towards the end of the light period, the same measurement procedure as outlined for photosynthesis will be repeated, but with a black out screen covering the measuring chamber to give an estimate of dark respiration. Measurements will be made on the same flag leaves as used for photosynthesis measurements.

Measurement of chlorophyll--After measurements have been completed, all leaves (previously labelled) will be removed from the plants, wrapped in moist paper and aluminum foil, placed in an ice chest at 2°C, and transported back to the laboratory. In the lab, the following data will be collected
Leaf discs of a known surface area should be punched out of the leaf and the following measured:

- Dry weight of leaf discs.

- Absorbance at 647 & 664 nm of chlorophyll extracted from the leaf discs and chlorophyll a and b calculated using the equations of Jeffrey and Humphrey (1975).

Expected results

The following parameters can theoretically be calculated from the information obtained in the experiments:

- CO_2 fixation rate/unit light/unit chl.
- CO_2 fixation rate/unit light/unit leaf area.
- Internal CO_2 concentration.
- Stomatal conductance-diurnal changes in above parameters.

- Respiration/unit leaf area.
- Leaf chlorophyll content.
- Chlorophyll a:b ratio.
- Specific leaf weight.
- Changes in the above with crop stage.

These can be used to determine some of the mechanisms that may be limiting carbon assimilation at high temperature e.g.:

- Limitations in stomatal conductance v CO_2 fixation.
- Loss of assimilate through respiration.
- Loss of light harvesting chlorophyll vs breakdown of Photosynthetic reaction centers.
- Inability to sustain high CO_2 fixation rates all day.
- Premature crop senescence.

4.3.1.6 Additional Experiments

Photosynthetic response to management
In addition to the 16 genotypes of the IHSGE, there are two experiments in which different aspects of crop management are being investigated on a single genotype to see whether the availability of nutrients and water are limiting growth at high temperature and whether this may be affected by reducing the soil temperature with a mulch. A similar series of measurements to those described previously are being made to investigate the effect of management on whole leaf photosynthesis. For example, one might expect to see higher rates of photosynthesis in plants where roots are maintained at a cooler temperature if the roots are the primary mechanism for transducing heat stress as has been proposed by Kuroyanagi and Paulsen (1988). If nutrient availability is another factor limiting growth, then differences in chlorophyll content and rates of senescence might be expected to reflect differences in nutritional management strategies. A fall in CO_2 fixation accompanied by stomatal closure in the afternoon would indicate a problem with water availability if contrasted with sustained rates of CO_2 fixation and stomatal opening in moister soil profiles

Spike photosynthesis
Another factor that may be of relevance to heat tolerance is the contribution of spike photosynthesis during grain filling. Blum (1986) found that the awn photosynthesis was much more stable at temperatures up to 32^oC than that of leaves and concluded that a large amount of awn tissue in the spike might be a useful selection index in wheat for hot, dry regions.

Spike photosynthesis could easily be measured using a LICOR type gas analyzer. Standardizing the units represents a problem in terms of estimating the surface area of a the spike. However, a more meaningful number in terms of the relative contribution to yield of different genotypes may be the rate of spike CO_2 fixation per grain, a figure which could calculated from the yield components after harvest.

Chlorophyll fluorescence
Chlorophyll fluorescence has been discussed in the literature as a potential tool for screening germplasm for various stress tolerances, including heat (Hetherington et al. 1983). The technique has not been widely adopted perhaps because causal relationships between photosynthetic metabolism and heat tolerance have not been well documented at the cultivar level. Furthermore, fluorescence transients in most apparati are measured

under conditions not representative of the field environment. This applies particularly to light levels which are extremely low when fluorescence is measured. It is the interaction of a stress with high light intensities that is particularly harmful to the photosynthetic apparatus (Al-Khatib and Paulsen 1989). Although not very sensitive to temporal inhibition of photosynthesis, measurements of chlorophyll fluorescence at low light intensities are capable of detecting more permanent structural damage that may be incurred due to stress. Moffatt et al. (1990) found a negative correlation between variable fluorescence and yield of wheat plants maintained at 37/25^{o}C in a growth cabinet. However, no interpretation in terms of photosynthetic metabolism was used to explain this finding.

If a relationship between carbon fixation of leaves and yield at high temperature is detected in our experiments then it may be worth measuring chlorophyll fluorescence. This would be carried out firstly to see if structural damage to the photosynthetic apparatus is indicated. If that were the case fluorescence measurements may be useful in screening for heat tolerance.

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4.3.2 Morpho-Physiological Traits of Adaptation in Wheat: Yield Potential and Stress (Drought and Salt) Resistance

The thrust of CIMMYT's wheat germplasm improvement is the production of material that has wide adaptation, high yield potential, and disease resistance from which national programs can select for their specific conditions. The aim of this work is to study the physiology of yield potential, to test presently used morpho-physiological traits in selections for high yield potential in wheat targeted to ME1 (Annex 1) and to suggest other traits if deemed necessary (see Acevedo 1992).

This work is also searching for drought resistance traits that interact little with the environment. Osmotic adjustment of wheat is presently being studied based on promising preliminary results.

As a follow-up to an in-house workshop on salinity resistance of wheat, we are interacting with CIMMYT's ongoing activities in wide crosses as well as in wheat improvement.

4.3.2.1 Evaluation of Agronomic Practices and Plant Characteristics for Yield Formation In Wheat

Project Leader:	Dr. E. Acevedo
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This is a Ph.D. thesis project of Mr. P. Brindaban, Department of Theoretical Production Ecology, Agricultural University, Wageningen. The project was elaborated in 1990-91 in consultation with E. Acevedo and R.A. Fischer of CIMMYT. It is to be carried out at CIMMYT and it is presently being considered by DGIS (The Netherlands) for partial financial support. It addresses potential wheat yields in irrigated wheat (ME1).

Purpose
The development of operational methods for a qualitative and quantitative evaluation of the potentials and physical constraints for wheat production in a major developing world agro-ecological zone; and the identification of plant characteristics and agronomic practices associated with yield formation, the implementation of which, for improvement of crops or cropping systems, could result in a sustained increased productivity.

Introduction
In principle, the implementation of agronomic practices and the cultivation of improved cultivars--here considered under a separate heading--developed on the basis of the eco-physiological functioning of the crop could result in a sustained increased productivity

(in terms of yield) and/or a temporally higher yield stability. This approach is followed in this project, aiming at the identification under a well defined set of environmental conditions of plant characteristics and agronomic practices that are clearly associated with the specified objectives (productivity and stability) through their relation with the formation of yield.

Experimental identification of these plant characteristics and agronomic practices is cumbersome and time-consuming because it requires experimentation under a wide range of environmental conditions and often is of a trial-and-error nature.

Correlations between seemingly relevant plant characteristics or agronomic practices and crop performance have often proved not to hold for a temporal and spatial generalization and extrapolation. Plant characteristics are frequently determined on the basis of point measurements, both temporal and spatial, while intra-seasonal significance as an actual crop attribute cannot be assessed. The causal relationship between two parameters is not always clear.

Uncertainty about the qualitative and quantitative relationships will only complicate the interpretation of the interaction between genotype and environment resulting from inter-seasonal variation. Environmental conditions are, to a large extent, characterized by temporal variability. Plant characteristics and agronomic practices, which result in a better adaptation to this variability, could lead to a higher yield stability, however, consequences for the long-term yield average are likely to occur.

Application of crop growth simulation models could facilitate the identification procedures. A methodology applied that systematically relates environmental data to crop performance through explanatory crop growth simulation models would allow a more efficient use of available physical, agronomic, and physiological information. At the same time, it could become an instrument to set priorities to experimental research.

This project aims at the development of operational methods that first allow a qualitative and quantitative evaluation of the potentials and physical constraints for wheat production on a regional scale within a selected agro-ecological zone. Following this evaluation, agronomic practices and plant characteristics will be identified that potentially result in sustained increased yields or higher yield stability--taking into account the prevailing socio-economic conditions.

Project Methodology

Crop growth simulation--CIMMYT currently distinguishes seven mega-environments for wheat production (Annex 1), each representing an agro-ecological zone with homogeneous characteristics with respect to crops and cropping systems. The target region for the project is ME1, a major agro-ecological zone in the developing world. In 1988, 43% of the total bread wheat production in the regions covered by CIMMYT originated from ME1. ME1 represents areas under very low rainfall with deep, fertile and sometimes saline soils. With irrigation, soil moisture supply may be considered optimal. The pre-anthesis phase of the wheat growing period is characterized by a temperate climate. Sudden increases in temperature after anthesis are common. The focus in ME1 is on realizing potentially high yield through the development of highly responsive cultivars and optimum agronomic practices.

For factors affecting potential production, determining factors (temperature, radiation), limiting factors (moistures, nutrients), and reducing factors (pests, weeds) can be distinguished. Considering its environmental conditions, it may be assumed that, in ME1, moisture and nutrient availability do not appreciably affect crop productivity. To test the hypothesis that the level of production in ME1 is mainly determined by crop genetic properties (optical, geometrical, physiological, and phenological characteristics of the crop) and defining factors such as radiation and temperature, WOFOST (Van Diepen et al. 1989, Van Keulen and Wolf 1986) could be applied. WOFOST is a crop growth simulation model developed to simulate growth of annual crops under a wide range of weather and soil conditions.

Because WOFOST has been specifically developed for the evaluation of production levels, other simulation models seem more desirable for modeling purposes. For example, SUCROS87 (Spitters et al. 1989) and CERES are crop growth simulation models for spring wheat at similar levels of aggregation. They both assume optimum moisture and nutrient availability and the absence of weeds and pests. SUCROS87 deals with photosynthesis by means of detailed algorithms describing light distribution in the canopy and photosynthetic characteristics of individual leaves; CERES combines intercepted radiation and a light use efficiency, which is defined as a function of phenological development. Morphogenesis, and hence leaf area dynamics, is treated more thoroughly in CERES than in SUCROS87. Other differences exist between CERES and SUCROS87. SUCROS87 in its standard version can be extended with modules for sink-source relationships, crop transpiration, and a simple water balance--the latter being less sophisticated than in WOFOST.

WOFOST, SUCROS87, and CERES are relatively simple simulation models with response functions at a relatively high level of aggregation. The lower the explanatory level within the hierarchic structure of the simulation model, the higher, in theory, are the explanatory capabilities of the model. The level with the explanatory character is determined in part by the available knowledge, but mainly by the objectives of the simulation model, which results in a required simplification (Loomis et al. 1979). Crop growth simulation models with the explanatory level at lower levels of aggregation do exist; however, they do not yet fully meet expectations. A comprehensive model developed by Van Keulen and Seligman (1987)--that simulates growth, water use, and nitrogen nutrition--could be applied when the model is calibrated for a combination of environmental conditions and cultivar-specific parameters and response functions. These simplifying assumptions imply an uncertainty about the extent to which the results may be extrapolated to other cultivars.

Project execution--Based on the current views, the following sequential outline explains the different stages of the project:

1) ME1 is defined in terms of its environmental conditions and temporal and spatial variability. For this purpose, a limited number of regions within ME1 is selected, on the basis of data availability. Regions located within Mexico should be included to allow experiments at later stages. The required data are dictated by the simulation models used, but they should, in principle, comprise: a) both the irrigation and weather data (minimum and maximum air temperature; irradiation, humidity, wind speed, precipitation) on a daily basis over a reasonable number of seasons; b) the soil conditions (texture class, maximum rooting depth, pressure of ground watertable with its initial depth, noninfiltrating fraction of rain, surface water storage capacity, base uptake of nitrogen, phosphorus and potassium from underfertilized soil, recovery fractions of N-P-K fertilizers), and c) the exact period of the growing season. Weather and soil databases at Texas A&M University as well as CIMMYT expertise on Geographic Information Systems (GIS) will be used. Weather generation may be applied to extend the number of seasons available (Larsen and Pense 1982).

2) Because WOFOST and SUCROS87 are similar, either one of these crop growth simulation models may be used. WOFOST and SUCROS87, or one of these and CERES--including sections accounting for the water valance--are validated with the criteria listed in 1) using specified weather and soil data and experimental crop data. These crop data should comprise a series of temporally and spatially discrete observations on stated variables (biomass, leaf area, development stage) and independent, rate variables (leaf photosynthesis, crop photosynthesis) (Loomis et al. 1979). While some data may already be available or collected in regular experiments, there may be a need for additional, specific field observations in the experimental plots. Data for cultivar-specific functions and parameters may have to be collected. To assess the possibilities and limitations of future applications of the selected crop growth simulation models, sensitivity analyses will be needed to show how they perform with different time-interval averages of irrigation and weather data. The same data from the preceding validation will be used.

3) WOFOST or SUCROS87 will assess the extent that crop production in the ME1 regions selected in 1) is determined by the defining and limiting factors. The effects of defining factors of temperature and radiation and the limiting factor of moisture availability are assessed by calculating both potential production (production level 1: water and nutrient supply taken to be optimum) and production under the prevailing irrigation conditions (production level 2: nutrient supply taken to be optimum). Following these calculations, an assessment is made of the extent to which the crop genetic properties, which affect the length of the crop cycle, determine production. With respect to a possible re-allocation of water resources, it might be useful to carry out a similar analysis for different, but well defined input levels (production level 2). Analyses of the long term and risk analyses for the individual seasons are compared. Taking into account different farm sizes, individual farmers and interests are considered. These calculations will result in a ranking of the quantitative importance of the tested factors for determining crop performance under the prevailing environmental conditions.

4) Under the environmental conditions of the selected regions in Mexico, experiments will show how much production falls short of potential set by the defining factors. The results will be a verification of the outcome under 3). These experiments are to be carried out in the same growing season as the experiments mentioned in 2).

5a) Agronomic practices (single or combined)--which have previously been associated with increased yield and/or higher yield stability under the environmental conditions of the selected regions in Mexico and the physical production constraints as determined under 3)--are tested on quantitative importance and in terms of long-term consistency and risk analyses. For this purpose, WOFOST or SUCROS87 and CERES are applied. Data from relevant experiments with variations in the implementation of agronomic practices in the appropriate experimental setup are collected. This applied variation is used as a basis for sensitivity analyses. The outcomes of the group growth simulations are to be verified by means of the crop data from the available experiments. These crop data do not need to be as detailed as the validation data in 2). Efforts will be focused on sowing date, seed density, and row spacing.

5b) Agronomic practices under current research for their effects on yield and/or yield stability, and those that seem promising based on other analyses, can be tested under 5a). Applicable and relevant variations in the implementation of the considered agronomic practices can be used for density analyses.

6a) The effects on crop performance of plant characteristics--that have been previously associated with increased yield and/or higher yield stability under the conditions mentioned in 5a)--are finally tested for quantitative importance and in terms of long-term consistency and risk analyses. Plant characteristics can comprise both morphological and physiological traits.

WOFOST or SUCROS87 and CERES can finally be applied to evaluate the plant characteristics at the crop level like the agronomic practices in 5a). These simulation models may require adaptation. New algorithms may have the character of a response; function, or more elaborate subprograms may be needed. Such new algorithms may be derived from site-specific data sets or from simulations with a more comprehensive crop growth simulation model, e.g., as developed by Van Keulen and Seligmna (1987). Moreover, the simulation model of Van Keulen and Seligman (1987) could serve as a basis for an explanatory model.

A comprehensive simulation model like the one developed by Van Keulen and Seligman (1987) and previously established genotypic variation for the considered plant characteristic are used for sensitivity analyses. The plant characteristic itself and the outcome of the sensitivity analyses determine whether the comprehensive model is used as a whole, calibrated for the local environmental conditions, or to derive an algorithm. Processing of the data for the plant characteristics and the derivation of an algorithm may indicate the necessity for additional experiments for calibration.

The simulation model of Van Keulen and Seligman (1987) and other comprehensive simulation models--or algorithms derived from these models and subsequently incorporated into WOFOST, SUCROS87, or CERES--require validation. To a great extent, the validation procedure mentioned 2) will apply. Additional experiments for validation of the processes at lower levels of aggregation may be required. The processes at a lower level of aggregation usually have a smaller time-coefficient than the processes at a higher level of aggregation. For validation procedures, it may be useful to compare independently acquired data for the same rate variable at the organ and organism level.

6b) WOFOST, SUCROS87 or CERES with the incorporated algorithms derived in 6a)--or the comprehensive simulation model calibrated for the local environmental conditions--are applied to test the effects of the plant characteristics on crop performance as described in 6a). Known genotypic variation for the relevant crop characteristics is used for sensitivity analyses. The outcomes of the crop growth simulations are to be verified by means of the crop data from the available experiments. These crop data do not need to be as detailed as the validation data in 6a).

7a) Plant characteristics--currently being studied for their effects on crop performance under the conditions mentioned under 5a) and those that seem promising based on other analyses--can finally be tested as under 6a). The same procedures those in 6a) can be applied to incorporate the plant characteristics into a crop growth simulation model.

7b) The effects on crop performance of the plant characteristics described in 7a) can be tested following the same procedure described in 6b).

8) After identifying agronomic practices and plant characteristics relevant to the

objectives of the selected regions in Mexico, an assessment is made of the usefulness of these procedures. The operational methods developed within the project will be compared with conventional methods. For example, do they make better use of available information. Recommendations for future applications of the methodology are given.

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4.3.2.2 Increasing Drought Resistance Through Selection for Osmotic Adjustment in Wheat

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Introduction

Producing sufficient amounts of food for a rapidly growing human population is one of mankind's most important challenges. The production increase must come from increased yields to a large extent because most of the land suitable for arable crops is already in use (CIMMYT 1989).

Abiotic stress factors--the most important of these being drought--together severely restrict yields. Wheat is mankind's most important food crop and more than 20% of the wheat producing areas in developing countries are regularly subject to drought stress, especially where small farmers are found. Drought resistance would be a highly desirable trait that could increase yield and yield stability substantially in the semi-arid areas.

Drought Resistance

In plant breeding, drought resistance is usually defined in terms of grain yield under stress. Grain yield under drought stress, however, is not only a function of drought resistance, but also of the yield potential (fully expressed under nonstress conditions). To assess drought resistance properly one has to separate it from the effect that yield potential has on grain yield under drought stress. This, together with the fact that grain yield per se is not easy to measure accurately, makes drought resistance very hard to assess correctly and accurately (Acevedo 1991).

Besides the problems of estimating drought resistance correctly, it is a highly complex trait. Drought resistance can be seen as the collective expression of a fairly large number of traits that influence grain yield under drought stress. These traits include:

- Earliness. In regions with terminal drought, earliness can be quite effective. However, earliness may reduce yield potential and can be undesirable in areas with intermittent drought.
- Rooting depth. Available water is used more efficiently, but it may reduce yield potential.
- Water conductance of the roots. This can positively affect drought resistance, but at the same time negatively affect yield potential.
- Light reflection. Affected by leaf position and leaf surface, this can influence leaf temperature and transpiration under drought.
- Stomatal and epidermal conductance. Both can influence transpiration and yield potential (in the case of stomatal conductance).
- Transpiration efficiency, the amount of C or CO_2 fixed per unit of water transpired. An unclear relationship with yield under drought exists.
- Osmotic adjustment. Through the accumulation of solutes in the cells, plants can maintain cell turgor under increasingly dryer conditions. This trait seems to be a good adaptation to drought stress in both wheat and sorghum.
- Mobilization of assimilates formed before flowering. This is only of interest in cases of terminal drought.

Under any given drought stress regime, only some of the above mentioned traits may significantly influence drought resistance. The set of traits affecting drought resistance may vary with the drought regime. This almost unavoidably leads to genotype x environment interactions. For example, under terminal drought conditions, early entries without a dense, deep root system and growing in residual soil moisture may emerge as drought resistant, while the same entries may appear quite drought susceptible under intermittent drought stress.

Genotype x environment interactions important to selecting for drought resistance in one drought stress environment may not be important in another drought stress environment (Ceccarelli et al. 1991).

Selecting for Drought Resistance

In order to select successfully for a complex trait like drought resistance, several requirements have to be met:

1) The stress should occur homogeneously over the experimental area.

2) The stress should occur homogeneously in time and space, i.e., it should be the same over locations and years.

3) There should be genetic variation among the entries to be selected for the trait to be improved.

4) The breeder should be able to easily recognize and assess these genetic differences among the entries for the trait, i.e., the heritability of the trait should not be too low.

5) The variance for the genotype x environment interaction should not be too large.

In the case of drought resistance, only requirement 3 is met. Requirements 1 and 2 are normally not satisfied because drought stress is extremely variable both in time and space. Rainfall varies in total amount and distribution from year to year and from location to location. Variation in depth, type, and slope of the soil add considerably to variation in drought stress.

Requirement 4 is not met because the drought resistance of an entry is difficult to measure. Requirement 5 is not met because the complexity of this trait causes the genotype x environment interaction variance to be high.

Indirect Selection

The response to selection of a trait with low heritability, such as drought resistance, can be improved if another trait is found that has a much higher heritability and is well correlated with the trait to be improved.

Much effort has been made to find such associated traits to drought resistance. Most traits appear to be either not consistently associated with drought resistance and/or not easy to handle themselves and/or associated with a reduced yield potential.

A promising trait for the use in indirect selection of drought resistance in wheat is `osmotic adjustment'. Wheat and sorghum can adjust their osmotic potential in response to drought. This osmoregulation involves an increase in the number of solute molecules inside the cells in response to a decline in external water potential (Hsiao et al. 1976). This has the effect of reducing the outflow of water from the cell, thereby maintaining turgor pressure with all its associated positive effects:

- Maintenance of stomatal conductance and photosynthesis.
- Prevention of large increases in abscisic acid and so maintaining seed set, spike development, and harvest index.
- Increased rates of extension of shoots and roots under stress.

Osmotic adjustment has been proposed as an important drought resistance trait in wheat and evidence supporting this assumption has been produced (Morgan 1983, 1984, 1989a, 1989b; Morgan and Condon 1986; Morgan et al. 1986; Moinuddin (CIMMYT) in preparation). Ludlow and Muchow (1988) have reviewed the physiological effects of osmotic adjustment. The trait is positively correlated with grain yield under drought stress.

Turgor is maintained by osmoregulation and, within species, variation has been found in osmoregulation (Morgan 1989b). If osmotic adjustment is not an environment-specific trait (osmotic adjustment measured in the greenhouse correlates with wheat grain yield measured in the field, Moinuddin, pers. comm.; Morgan 1984), then it is a trait that might be very suitable for use in indirect selection of drought resistance in wheat.

According to Morgan (1983), the inheritance of high levels of osmoregulation seems to be simple, possibly involving a single recessive gene. Heritability estimates made at CIMMYT indicate values between 0.65 and 0.80, depending whether osmotic potential or osmotic adjustment (both are highly correlated) is measured. Selection studies done with wheat indicate that F_4 lines with a high level of osmoregulation are higher yielding in F_4, F_5, and F_6 than F_4 lines with low levels of osmoregulation, the difference being about 17% (Morgan 1989b).

The above mentioned results are encouraging and suggest further research that should be aimed at:

- Confirming those data.
- Developing a screening procedure that plant breeders can use directly. Assuming that the results can be confirmed, this particular aim is essential.

Determining the level of osmoregulation can be done quite well on a limited scale. For screening purposes, breeders need a method with which they can test the osmoregulation level of a large number of entries rapidly and fairly accurately.

Research Proposal

The proposed project will involve three major aspects:

1) Lines will be identified from the wheat germplasm that are highly diverse in the level of osmoregulation. The selected parents will be intercrossed. Through single seed descent, F_6 populations will be selected for high and low osmotic adjustment. Progeny of the high and low adjustment lines will be yield tested under both nonstress and drought stress conditions.

2) Concurrent research will be done to find out how the osmotic adjustment of entries can be assessed in a simple way, e.g., measuring the solute concentrations of entries under both nonstress and certain standardized drought stress conditions.

3) Establish a possible relationship with high osmoregulation and one or more RFLP markers. If the findings of Morgan are true (monogenic recessive inheritance), selection through a closely linked RFLP marker would be quite possible. The segregating material (F_6 lines) obtained in the crosses described above could form suitable material for this research.

Aspect 1) of this research investigates the association of osmoregulation with drought resistance. The yield tests should be carried out quite extensively over at least 2 years and under several different drought stress conditions. The yield tests under nonstress conditions should give information on the effect of osmoregulation on yield potential.

Aspects 2) and 3) are aimed at finding an indicator (i.e., cell solute concentration response to drought stress, RFLP marker) that is highly associated with osmotic adjustment and more easily and/or cheaper to measure in order to develop a simple and effective osmoregulation selection procedure.

The research should be carried out at CIMMYT in Mexico. Aspects 2) and 3) will be done at El Batan. The yield tests mentioned in aspect 1) will be carried out predominantly at Cd. Obregon.

Research Chronology

Aspect 1) can be considered to be the time limiting part of the research. Table 4.14 summarizes the various steps to be taken and the research aspects to be investigated. The total duration of the project is 5 years; the best time to start would be during June/July period.

Table 4.14. Chronology of the proposed project's research activities.

		Aspects		
		1	2	3
Year		El Batan	Obregon	El Batan
1	Selecting parents		Preliminary research on measuring osmotic adjustment	
2	Crossing parents & F_1-F_2 Single Seed Descent up to F_6 lines	Yield testing of parents under drought and under non-stress conditions	Comparing high and low osmotic osmotic adjustment parents for cell solute concentrations (or other associated traits)	
3	Multiplication of selected lines			Start with investigating possible linkage of osmotic adjustment with RFLP markers
4		Yield testing selected lines under drought	As in years 2 and 3 but now with selected lines and under non-stress conditions	
5				

Expected Gains

Expected gains of the project include:

- Establishing beyond any doubt that osmotic adjustment varies considerably in bread wheat.

- Establishing beyond any doubt that high osmotic adjustment considerably increases yield under drought stress.

- Establishing beyond any doubt that high osmotic adjustment does not affect yield potential too seriously if at all.

- Developing a rapid and easy method to measure/assess the osmotic adjustment of wheat entries.

- Determining whether RFLP markers are suitable to select indirectly for osmotic adjustment.

- Using this as a model to do the same for other crops if this approach improves the selection for drought resistance in wheat.

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4.3.2.3 Resistance to Salinity Stress in Wheat

Background

The 1988 External Program Review recommended that CIMMYT conduct activities in the area of breeding for salt resistance in wheat. An in-house workshop was organized on August 29, 1990, with the aim to streamline such work. The workshop was attended by Prof. Garth Wyn-Jones from the Center for Arid Zone Studies, University College of

North Wales, Bangor, U.K.; Ing. Homero Fraga and Dr. Jose Luis Diaz de Leon from the "Universidad Autonoma de Baja California Sur", La Paz, Mexico; and by CIMMYT Wheat Program Staff.

The objectives of the workshop, as stated by Dr. Roger Rowe, DDG-Research of CIMMYT, were to:

- Analyze the progress made by CIMMYT in this area to date.
- Define the extent of the current salinity problem.
- Plan future activities and areas of collaboration with advanced institutions and leading national programs.

The conclusions and recommendations of the workshop were expected to provide additional information for the allocation of resources into this area of research.

Highlights of Workshop Findings

Progress made by CIMMYT--A joint project between CIMMYT and the Center of Arid Zones Studies at Bangor, U.K., has produced the following results:

- After screening a wide variety of wild wheats to find useful donors, *Thinopyrum bessarabicum* (J genome) showed outstanding tolerance. Amphidiploid hybrids with hexaploid wheat have salt resistance, but very low yield potential.
- The salinity resistance has been found to be located mainly in the long arm of chromosome 4D. Professor Dvorak, working with D Chromosomes of *Aegilops squarrosa* at the University of California, has recently reported an additive effect of chromosomes 3, 4, and 7D in discrimination against sodium. He also found that, by introducing segments of chromosome 4D into durum wheat mediated by using the Capel Ph mutant, salinity resistance is enhanced. Professor Dvorak is also working with the salinity resistance source *Thinopyrum elongatum* (E genome).
- Growth rate is slowed under saline conditions. Studies show that the decrease in growth rate is related to cell wall chemistry and not to changes in turgor pressure.
- A greenhouse screening method was developed at Bangor and tested both at Bangor and CIMMYT.

Other work done in Mexico:

- Field screening for salinity resistance has been facilitated by using highly permeable soils irrigated by water with high salinity (3000-5000 ppm). These conditions should allow for relatively uniform field screening, but confirmation from 1989-1990 results were not yet available. Such screening is presently being conducted at the University of Baja California Sur in a joint venture with CIMMYT.
- Efforts to detect salinity resistance in bread wheat lines with high yield potential show that, within species, variation for this trait exists. Screening for salinity resistance is done at La Paz (U. de Baja California Sur) by Ings. Homero Fraga and Roberto Pargas Lara and Dr. J. Luis Diaz de Leon. The same lines at Obregon are screened for yield potential. Biomass screenings at the two sites are complemented with a germination test in a 10,000-ppm NaCl solution and through observations of

early leaf senescence (salt necrosis in the leaves). Final yield trials are done under both high and low salinity conditions. Salient genotypes have been identified.

- Genetic sources of bread wheat for salt resistance have been identified. These include:

Genotype	Origin
Candeal	Mexico
Shorawaki	Pakistan
Lu 26S	Pakistan
Kharchia 65	India
KRL 1-4	India
WH 157	India
SNH 9	India

- There is some evidence that somaclonal variation for salinity tolerance might exist. Definite evidence may come from the TCCP, Colorado research mandate with CIMMYT's logistical and professional assistance.

- Preliminary observations in Baja California Sur indicate that there may be a good range of salinity tolerance in durum wheats.

- Fifty synthetics have been produced through interspecific hybridization. These need evaluation for salinity tolerance.

- Intergeneric hybridizations using *Thinopyrum bessarabicum* and interspecific hybridization (*T. turgidum* x *T. tauschii*) show promise. Adequate screening methodologies still need more development.

Extent of current salinity problem--At present, it is not known exactly how much wheat area would benefit from a salt resistance improvement program in wheat. It appears that soil heterogeneity in salt distribution under typical field situations is a critical consideration in salty environments. In salty fields, the grain yield is dominated by that obtained in nonsaline patches, therefore selections with higher Yp have a higher yield in heterogeneous salty environments, regardless of the yield under salinity stress. Furthermore, improving salinity resistance appears to have a small effect on yield stability.

Recommendations

At the 1990 workshop, the following recommendations were produced.

- CIMMYT, through its Economics Program, should try to quantify the developing world wheat area affected by salinity and alkalinity. Present estimates fluctuate widely (8 to 20%). Key questions include: 1) How much area could benefit if the salinity resistance level of wheat were increased?, 2) By so doing, how much would wheat production be increased?, 3) What is the priority of the salinity problem as compared to other biotic stresses? Action: R.A. Fischer, D. Byerlee.

- A group of genotypes should be grown under various salinity conditions and be used as a reference set in salinity experiments. This reference set should include these genotypes: Candeal (resistant check), Shorawaki, Lu 26S, Kharchia 65, KRL 1-4, WH 157, SNH 9, Sakha 8, and Yecora (susceptible check). Action: S. Rajaram, A. Mujeeb-Kazi, E. Acevedo.

- The importance of soil heterogeneity on yield in salty environments should be verified by CIMMYT. To what extent is there any gain in yield by improving salinity tolerance? Action: J.L. Diaz de Leon, E. Acevedo.

- Repeatable, usable variation within conventional hexaploid wheats should be established. The same applies to TC-derived variation. More reliable field tests and glasshouse screening are needed to achieve this goal. Action: A. Mujeeb-Kazi, J.L. Diaz de Leon, E. Acevedo.

- The work on the role of alien germplasm in improving salinity resistance (*T. tauschii*, *Th. elongatum*) should be carried to completion. It must be shown that alien derivatives have an unequivocal salinity resistance potential for use in the conventional breeding programs. Action: A. Mujeeb-Kazi, S. Rajaram, E. Acevedo.

- A salt screening routine should be established, i.e., Lab test (germination, K/Na), Greenhouse (backcrosses), and Field (F_3 bulks, augmented design).

- The *Th. bessarabicum* (J) addition lines using Genaro and produced at CIMMYT should be studied physiologically at Bangor. Action: A. Mujeeb-Kazi, G. Wyn-Jones.

- Wheat salinity resistance studies should be maintained at current levels. Collaboration with appropriate national programs (Mexico, India, Pakistan) should be maintained and/or increased. In particular, the collaboration with the University of Baja California Sur at La Paz should be continued and strengthened. Note: In 1991, a collaborative agreement was reached between CIMMYT and the Universidad de Baja California Sur (La Paz, Mexico) for work on salinity resistance in wheat.

4.3.3 Agronomic Support for Management of CIMMYT Wheat Program Trials and Nurseries at Experiment Stations in Mexico

Leader:	Dr. Ken Sayre
Cooperators:	
Wheat Program:	Dr. Edmundo Acevedo Dr. Ivan Ortiz-Monasterio
Experiment Stations:	Mr. J. Stewart Dr. M. Bell Ing. R. Rascon, Obregon Ing. A. Miranda, Toluca Ing. R. Marquez, El Batan

Background

The development of management practices used by CIMMYT wheat scientists for their diverse nurseries and trials at CIMMYT experiment stations in Mexico has become a routine function of agronomists in the Crop Management and Physiology (CMP) Subprogram. Trials are regularly conducted at the different stations to improve or develop new management recommendations that intend to provide CIMMYT wheat scientists necessary trial conditions at the most economic cost.

New or improved management recommendations that evolve from this work are discussed with the experiment station staff at the relevant station and a decision is made concerning implementation. The CMP agronomists work with the station managers, wheat scientists, and others involved to ascertain if the management practices are useful and if further modifications are required.

Management factors that CMP agronomists continually strive to improve include:

- Weed control practices (including screening for potential phytotoxic effects of herbicides on the different cereal crops/genotypes).
- Soil fertility and fertilizer use for optimizing production.
- Irrigation practices for optimizing production.
- Trial and nursery planting procedures.
- Station crop rotations (including off-season cover/green manure crops) for better integrated weed control, reducing chronic soilborne diseases and maintaining or improving soil conditions.
- Field screening methodologies for breeders (emphasis has been given to developing irrigation schedules to simulate drought in the flooded-basin irrigation system and to develop a line source gradient irrigation system, both for the CIANO Station).

Another area that has been given more attention recently is the development of yield trial management strategies for the CIANO station to assure optimum conditions for expression of genetic yield potential. This station continues to be the principal site where breeders assess differences in genetic yield potential, particularly for ME1. Efforts have been focused towards developing soil management practices to alleviate problems apparently associated with soil physical characteristics that may be constraining expression of yield potential (soil compaction, low % OM, etc.)

CMP support to trial management largely enters the category of a "service" activity. However mundane this may sound, it plays a crucial role within the Wheat Program. This effort has led to the development of improved management practices that provide considerable reduction in trial operational costs. For example hand-labor for weed control at the CIANO station has been reduced by two-thirds since the 1985-86 cycle. Trials have also demonstrated that a substantial amount of yield-testing can be conducted on beds instead of flooded basins with considerable reduction in management costs--both in manpower and land requirements. Trial layout is also greatly facilitated. Rotation trials at El Batan have shown that the Maize and Wheat Programs can rotate land between themselves with mutually beneficial results.

This type of research also has additional benefits. It provides a direct link to practical agronomic problems in wheat production. CIMMYT base agronomists should maintain a high level of experience and expertise to understand these types of problems, for our own requirements and to continue to be able to relate to and understand similar agronomic problems/issues of the national programs. This research provides useful information for our outreach staff and is highly relevant to visiting agronomists from national programs. We also use the trials for demonstrations and hands-on involvement in the crop management training courses.

Finally, perhaps the most interesting facet of this research has been observations from trials that have led to new, relevant research activities in both agronomy and physiology. An example is the series of genotype x planting methods trials now ongoing in CMP. These resulted from the interesting interactions encountered when comparisons were made between yield trials conducted on beds versus yield trials conducted on the traditional system using flooded basins.

Objective

The principle objective of this project continues to be the generation of improved trial and nursery management practices for CIMMYT wheat scientists in Mexico. To provide the conditions required for successful trials in the most efficient manner and at the most economical cost, emphasis will continue to be given to:

- Weed control.
- Irrigation methods.
- Soil fertility management.
- Planting methods.
- Crop rotations.
- Field screening methodologies required by breeders.
- Other management aspects as they are identified for possible improvement.

All activities listed above are not necessarily pursued each cycle at each station. Observations made by experiment station and wheat program staff on need for improvement in a given area normally determine the level of emphasis. Opportunity to reduce trial operation costs without loss of trial precision or relevance is an important factor that determines research activities--particularly in view of the current tight budget situation.

Specific new and/or continued activities that appear to have high priority for research are:

- Improving economical insect control at CIANO, particularly soilborne cutworms, stemborers, and aphids (new).

- Using bed-planting methods for yield trials at CIANO--optimum plot size, potential use for drought trials (continued).

- Improving weed control, especially at El Batan (continued).

- Identifying and alleviating potential factors constraining expression of genetic yield potential, particularly at CIANO (continued).

- Improving crop rotation strategies--emphasis at El Batan to reduce effect of chronic soilborne disease like root rots and take-all (continued).

- Developing field screening techniques to simulate well defined waterlogging conditions for support of genotype screening and investigations of waterlogging effects on plant growth (new).

Operational and Implementational Framework

Agronomic support constitutes a rather small portion of the CMP Subprogram activity. Approximately 25% of the time of one agronomist with corresponding support staff use is normally involved in the research each year. Occasionally, relevant trials are carried out by experiment station personnel with advice and support from CMP agronomists. Through these efforts, rather dramatic improvements in station management and reduction trial costs have occurred. However, as mentioned above, the additional benefits obtained by the CMP Subprogram (linkage to practical agronomic problems, generation of useful information for outreach staff and for national programs and utility for visiting scientists/training courses) strongly argue for continued support of this activity. It is recommended that additional emphasis be given to supporting breeders in the development of new field screening methodologies for selecting agronomic performance characters. Obvious candidates are tolerance to salinity, tolerance to low pH (high Al^{+++}), and efficiency in use of P and N at low availability levels. Research on the latter two has recently been initiated by Ivan Ortiz-Monasterio (CMP) and Maarten van Ginkel (Bread Wheat Section).

It is also recommended that the nature of the activities considered for investigation be strongly oriented towards problems that wheat and/or experiment station staff clearly identify and for which sound potential solutions are likely to be found. In addition, there must be built-in flexibility that allows immediate attention to be directed at unforeseen problems that arise and for which solutions are rapidly needed.

Research Support

This activity comprises a part of the core CMP effort within the CIMMYT Wheat Program. Furthermore, the CMP Subprogram is essentially the only entity within CIMMYT that is in position to react to trial and nursery management problems and to seek solutions.

Funding support will most likely have to continue to come from Core, since it would be difficult to develop special projects to support this type of research activity. Interesting and important new avenues for research may, however, be identified for wheat special project funding.

CHAPTER 5
ADAPTIVE CROP MANAGEMENT RESEARCH

The Crop Management and Physiology Subprogram has two adaptive CM research activities financed by the Canadian International Development Agency (CIDA), one in East Africa and the other in Bangladesh. These are described in the following sections.

5.1 East Africa Cereals Program--Wheat

D.G. Tanner

Background information on wheat production in East Africa
In Sub-Saharan Africa (SSA), FAO classifies 38 million hectares as suitable for wheat production versus 424 million suitable for maize. The current production of 1.06 million hectare of wheat in SSA represents only 1% of the developing world's wheat production (at an average wheat yield level of 1.45 t/ha). Demand is increasing rapidly concomitant with urbanization.

Of the total wheat area in SSA, 81% is concentrated in the rainfed highlands (>1700 masl) in East Africa (i.e., Ethiopia, Kenya, Tanzania, Burundi, Rwanda, Uganda, and Somalia), while 12% is produced under irrigation in the dry winter seasons of southern Africa (i.e., Zimbabwe, Zambia, and, Malawi). The mean yields for the two production systems are 1.34 and 2.35 t/ha, respectively.

Production technologies are generally low in SSA: only 39% of the wheat area is planted to semidwarfs, while nutrient application/ha of arable crop land averages only 8 kg (N + P + K)/ha. In Ethiopia, which accounts for 725,000 ha of bread wheat and durum wheat (>80% of the total in East Africa), inputs are particularly lacking.

Table 5.1 summarizes the wheat production environments in the East African highlands.

Table 5.1. Wheat production environments in the East African highlands.

	Mega-[a] Environment	Wheat area (ha)	Wheat yields (kg/ha)
Ethiopia (DW)	ME2	425,000	1,100
Ethiopia (BW)	ME2	300,000	1,500
Kenya	ME2 + ME3	100,000	2,300
Tanzania (North)	ME2	35,000	1,700
Tanzania (South)	ME2 + ME3	20,000	1,000
Zaire	ME2 + ME3	9,000	700
Burundi	ME3 + ME2	8,000	1,200
Uganda	ME2	7,000	1,000
Rwanda	ME2 + ME3	4,500	1,200

[a] See Annex 1.

Wheat production systems, country profiles, and major constraints

Ethiopia (Durum Wheat)--Peasant production of largely traditional germplasm (landraces) on waterlogged soils (Vertisols).

Major constraints include:

- Soil management--the broadbed technology developed by ICRISAT/ILCA has not been accepted by farmers due to the high draught requirement and the cost of the implement. If adopted, it has the potential to increase yields by more than 150% in wet seasons.

- Soil fertility--where drainage problems are addressed then nutrient response increases dramatically.

- Varieties--where drainage problems are addressed, HYVs with stem and leaf rust resistance could replace the landraces (which are more tolerant of waterlogged conditions).

Ethiopia (Bread Wheat)--Peasant production under ox-plow systems (80%) and the state farm mechanized system (20%).

Major constraints include:

- Varieties--need for stripe rust resistant germplasm for most of the high potential areas. Although the state farms have access to foliar fungicides and high levels of fertilizer, stripe rust is particularly acute on these farms. All HYVs released over last 15 years have succumbed to stripe rust.

- Soil fertility--OFR results have indicated that zone-specific fertilizer recommendations could increase national wheat yields in the order of 70%, providing a 260% rate of return to cash invested by peasant farmers. Furthermore, for cash-poor peasants, recommendations for the optimal fertilizer rate (based on urea and TSP application) can be obtained for each zone.

- Weed control--currently, farmers only have access to limited quantities of herbicide (usually 2,4-D) at triple the official price level on the black market. Results from OFR indicate that on weed-infested farm sites, grain yield was increased by more than 75% with the use of select herbicides. Furthermore, even at triple the official price level, the herbicides were more profitable than handweeding. It should be noted that labor bottlenecks constrain timely, thorough, and effective handweeding throughout Ethiopia.

- Rotations--cropping systems in Ethiopia are dominated (>85% of total crop area) by subsistence cereal crops: in the highlands, bread wheat and barley are predominant. However, 6-year rotation trials have indicated significant benefit from the use of faba beans, in particular, in either 2- or 3-year wheat or barley rotations. Ethiopia has exported faba beans in the past, however, the production system has degraded to the extent that low yield levels have forced farmers to emphasize subsistence cereal crops.

- Soil erosion--soil losses are serious in many wheat production zones. Research results indicate that minimum tillage systems are feasible for both the ox-plow and the mechanized production systems. However, government policy must be mobilized towards the provision of all necessary inputs, primarily herbicides.

Kenya--Large, mechanized estates in high potential areas for bread wheat production have been partitioned (and continue to be) for settlement of landless peasants. Wheat production is thus shifting to more marginal areas (lower altitude and rainfall zones, erodible Vertisols). Technology is required for sustainable production in these zones (i.e., minimum tillage, control of *Setaria verticillata*). Lip service is given to the need for small-scale technology, although small-scale wheat production is likely to be only a transitional stage as the farms subdivide further and ultimately result in maize-dominated subsistence enterprises. Small-scale wheat farmers in Kenya opt for rented mechanization services and resist labor-intensive technology.

Tanzania--Mechanized wheat production in the northern zone is very similar to that in the marginal areas of Kenya. In the southern zone, on-farm research is required to develop a production package for peasant farmers (hand-hoe system).

Rwanda/Burundi/Uganda--These three countries represent a homogeneous agroecological zone with high pressure from stripe rust and acid soils. Average wheat holdings are approximately 0.1 ha/producer. Hand-hoe cultivation is predominant.

Major constraints include:

- Lack of fertilizer for peasant farmers.
- No lime or other amendments available (i.e., Cu deficiency common, but localized).
- No well-developed seed distribution system.

Strength of region's national programs

Of all the programs, the bread wheat program of Ethiopia, and the wheat programs of Burundi, Rwanda, and southern Tanzania (Uyole Agricultural Center) have had both the soundest budgets for wheat research and the highest commitment to a research program balanced between on-farm and on-station research activities. Table 5.2 lists the number of people engaged in CMR by country in the region.

Table 5.2 Number of national staff engaged in wheat CMR in East Africa.

	Ph.D.	M.Sc.	B.Sc.
Ethiopia/IAR & AUA	2	7	8
Kenya/KARI	-	4	-
Tanzania/MOA*	1	2	3
Burundi/ISABU	-	-	2
Uganda/MOA	-	-	1
Rwanda/ISAR	-	-	1
Somalia/CARS	-	-	2
Total	3	13	17

*) 1 in private sector.

Adoption of on-farm research
In Ethiopia, the number of on-farm trials on bread wheat, which increased from 0 in 1984 to >100 in 1988, have addressed the priority constraints in the peasant production system. On-station CMR research complements the OFR program, and all members of the national wheat research team recognize the value of OFR.

In Burundi, Rwanda, and southern Tanzania, the merits of OFR have been similarly recognized, and OFR has been "informally institutionalized" in all the concerned programs.

OFR methodology has been adapted to the specific requirements and characteristics of each production system in East Africa, evolving over the initial period of introduction.

Links with CIMMYT Headquarters CMP
The links are minimal and informal. HQ has been most useful in providing in-service training for wheat CMP trainees from East Africa and in providing some specific training materials upon request.

Training activities
Wheat CMR in-Country Training (1987-1991)--The following in-country training courses were conducted in recent years:

- OFR methodology training:

Ethiopia: Call system (4 calls), between Sept. 1985 and Jan. 1987; IAR/CIMMYT/ILCA.
Uganda: OFR orientation workshop, April 20-24,1987.
Ethiopia: OFR research planning, Sept. 20-24, 1988, Nazret; IAR/CIMMYT/CIAT.
Kenya: Diagnostic survey methodology, June 18-22, 1990.

- Agronomic research methodology training:

Ethiopia: Agronomic research methodology, Feb. 2-12, 1987, Nazret; IAR/CIMMYT/CIAT.
Somalia: Herbicide research training for agronomists, April 26-29, 1987, CARS).
Ethiopia: Data analysis on microcomputers and interpretation, Apr. 12-22, 1988, Addis Ababa; IAR/CIMMYT/CIAT/ILCA.
Ethiopia: Soil and agroclimatology research, Feb. 20-24, 1989, Holetta; IAR/CIMMYT/CIAT/ICRISAT.
Ethiopia: MSTAT for data analysis, Dec. 4-7, 1989, DZARC.
Kenya: MATAT for data analysis, Apr. 18-21, 1990, NPBRC.
Ethiopia: Cropping systems research methodologies, March 11-15, 1991, Addis Ababa; IAR/FAO/CIAT/CIMMYT/ILCA.

- Wheat research methodology training:

Ethiopia: research methodology training for junior IAR research staff, Sept. 13-17, 1988, Kulumsa.
Ethiopia: National Wheat Research Review Workshop, Oct. 17-19, 1990, Addis Ababa.
N & S Tanzania travelling wheat workshop, May 16-26, 1989 and May 15-27, 1990.

Regional Training Activities--The following regional activities have been (or will be) conducted:

- Regional Wheat Workshop (biennial):

Fifth/Oct. 5-10, 1987/Antsirabe, Madagascar.
Sixth/Oct. 2-6, 1989/Addis Ababa, Ethiopia.
Seventh/Sept. 16-19, 1991/Nakuru, Kenya.
Eighth/June 7-10, 1993/Kampala, Uganda.

- Regional MSTAT training workshops:

Addis Ababa, Ethiopia: Dec. 14-21, 1987.
Egerton, Kenya: Oct. 30 - Nov. 5, 1988.

- Regional OFR/FSP training:

CIMMYT/U. of Zimbabwe: Feb.- Mar. (Phase I), Sept.-Oct. (Phase II); trainees sponsored: 1 in 1988, 3 in 1989, and 2 in 1990.

- Travelling wheat workshops:

Great Lakes Region (Rwanda, Burundi, Uganda): June 7-15, 1988, June 6-14, 1989, June 5-12, 1990.
Kenya/Ethiopia exchange: Sept. 23-Oct. 6, 1990.

Regional exchange visits--The following were involved in exchange visits:

- Jamal Mohammed (Ethiopia) and Mohammed Tahir (Somalia): visited Sudanese and Egyptian wheat research programs, Jan. 15-27, 1987.

- Giref Sahile/Ethiopia: visited Tanzanian wheat research program, (May 24-29, 1988).

M.Sc. Students (Ethiopia)--Three M.Sc. students include:

- Two IAR agronomists sponsored to study for an M.Sc. at Alemaya University of Agriculture. Research topics: a) Comparison of alternate N sources on Vertisols; Study of increased yield potential of bread wheats and Durum wheats released in Ethiopia.

- One IAR agronomist sponsored to study for an M.Sc. at the University of Manitoba. Research topic: Zero-tillage for wheat production.

Visiting Scientist Fellowships (1987-1990)--All visited CIMMYT/Mexico and most visited Hoechst or Bayer HQ in Germany. The Kenyan also travelled to the Tropical Wheat Workshop in Brazil during summer 1990 and visited the stripe rust research laboratory, IPO, Netherlands.

- 2 Ethiopians, Aug. 14-Sept 17, 1988; Aug. 4-Sept. 6, 1989.
- 2 Tanzanians, Aug. 14-Sept. 17, 1988; June 25-July 15, 1990.
- 1 Kenyan, July 27-Aug. 15, 1990).
- 1 Burundian, (Aug. 5-15, 1990).

CMR IN-Service Trainees (1987-1991)--The following participated in CMR training in Mexico:

- 1987: 2 Ethiopia, 1 Somalia.
- 1988: 2 Ethiopia, 1 Rwanda, 1 Somalia.
- 1989: 1 Uganda.
- 1990: 1 Ethiopia, 1 Tanzania.
- 1991: 1 Kenya, 1 Burundi.

5.2 Bangladesh Wheat Program

C. Meisner and D. Saunders

Introduction and Summary

Pakistani scientists introduced wheat in the late 1940s in the region then called East Pakistan. Average wheat yields at that time were less than 1 t ha^{-1}. After independence from Pakistan in 1972, the government of the new country of Bangladesh became equally committed to expanding wheat production as well as continuing to recognize CIMMYT as a potential source of information and germplasm to increase their yield potential and production. CIMMYT had begun informal consultation work prior to independence in 1968 when a CIMMYT scientist first visited East Pakistan. CIMMYT arranged for three key Bangladesh scientists to come to Mexico for training. Dr. Sufi Ahmed, after his training and under his leadership, developed the Bangladesh Wheat Research Center (WRC) into what external reviewers have claimed is one of the strongest agricultural research institutions in Bangladesh. His successors, Dr. M.A. Razzaque and Dr. A.B.S. Hossain also received training at CIMMYT and are presently in key leadership positions. Dr. Norman Borlaug, breeder and former director of the Wheat Program at CIMMYT, was recognized in 1975 by the Bangladesh Academy of Science as a foreign fellow. He remains one of two non-Bangladesh scientists to have received such an honor, further illustrating CIMMYT's close ties with Bangladesh.

A joint Bangladesh-FAO soil survey interpretation project in 1975 determined that 2.3 million hectares of land were physically suitable for wheat production under rainfed conditions. An additional 0.8 were suitable under irrigation. However, wheat cultivation in 1991 was approximately 600,000 hectares, representing only 20% of the total suitable land for wheat cultivation in Bangladesh. Wheat production areas have ranged over the years from 120,000 to 700,000 hectares. Thus, the room for expansion of wheat area in Bangladesh remains. Yet, even with only 20% of possible area being cultivated, wheat is the second most important cereal crop in Bangladesh's rice-based cropping system.

In 1982, CIMMYT assigned the first two bilateral CIMMYT scientists to Bangladesh. Dr. Larry Butler, a breeder/pathologist, and Dr. Mehmet Guler, an agronomist, served during Phase I from 1982-88. The project was supported by the Canadian International Development Agency (CIDA), executed by CIMMYT and implemented by the Bangladesh Agricultural Research Institute (BARI).

The purpose of the project was to improve applied research and institutional capabilities of the WRC and to promote increases in national wheat production. The project supported overseas training for Bangladesh scientists, local research and demonstration activities, and equipment acquisition. Phase I emphasized wheat breeding and made much progress in developing appropriately adapted, higher yielding varieties. Subsequently, the project was extended to June 30, 1991. The 3-year extended phase placed greater emphasis on crop management research (agronomy). Dr. David Saunders, an agronomist, was the bilateral scientist during this 3-year extension. Over the 23 years of relations with Bangladesh, CIMMYT has received over 60 scientists in Mexico for various short courses or training experiences. In addition, the project has sponsored 11 Bangladesh wheat scientists to complete their Ph.D. degrees both in Bangladesh and abroad.

The project was reviewed favorably by external reviewers. In 1985 by Dr. L. Sebeski, University of Manitoba; Mr. D. Clements, Agricultural Sector Team CIDA; and Dr. A. Latif, Bangladesh Agricultural University; and in 1988 by Prof. J. Tanner, University of

Guelph. Progress was made in producing and promoting five new varieties (Table 5.3), developing and showing improved agronomic management, and training a multidisciplinary team of 29 wheat research scientists. During Phase I, the newly built facilities of the Wheat Research Centre (WRC) in Dinajpur received substantial equipment to fulfill its goals. Due to uncontrollable factors (e.g., unfavorable input and product pricing, producing a shift of wheat farmers raising winter rice), wheat area and productivity did not continue to increase as planned and actually has decreased to about 600,000 ha.

Nonetheless, increased wheat production remains biologically feasible, environmentally sound, and economically sensible for Bangladesh, which now imports over 1.5 million tons (mT) of wheat annually. Phase II of the project, which began in July 1992 and will continue into 1996, is providing WRC with further support to consolidate progress thus far. Without such support, the gains made under the Bangladesh Wheat Research program might not be able to be supported by BARI. In addition during Phase II, Bangladesh wheat scientists are conducting further research on the constraints to wheat production (e.g., resistance to spot blotch, soil fertility within rice-wheat rotations, boron deficiency) to increase wheat production on a sustained basis. To address sustainability questions, long-term trials may be initiated to study the rice-wheat rotation more thoroughly in cooperation with BRRI.

Research Highlights of Phase I

Varietal Improvement--The WRC recommended 15 varieties during their operational period, much of the germplasm originating from CIMMYT. Strategy for varietal improvement included: short duration (90-100 days), early planting (15 Oct.-10 Nov.), optimum planting dates (10 Nov.-30 Nov.), late planting (1 Dec.-25 Dec.), drought and heat tolerance, disease resistance, and salt tolerance. In 1989, scientists evaluated 35 sets of 23 nurseries and yield trials from CIMMYT, ICARDA, and the wheat programs of Pakistan and Thailand. These trials were conducted over seven stations located under different growing conditions of Bangladesh. Four sets were irrigated and sown at the optimum date, four sets were sown late with irrigation, and three sets were grown under dryland conditions.

Table 5.3 illustrates the change in percent production of certified wheat seed of older varieties compared to newly introduced varieties. WRC scientist distributed on-farm varietal demonstration kits (400-800 per year), which compared Sonalika, representing a standard, acceptable variety, with three of the newer varieties developed by the WRC and introduced in the 1980s (Kanchan, Akbar, and Aghran). Recent results show that Kanchan outyielded Sonalika consistently by 16-18%.

Table 5.3. Certified seed production by variety in 1983, 1987 and 1990 expressed as a percent of the total.

VARIETY	ORIGIN	YEAR INTROD.	PRODUCTION SHARE (%) 1983	1987	1990
INIA 66	Mexico	1972	0.6	0	0
SONALIKA	India	1973	82.6	33.9	2
JUPATECO	Mexico	1974	6.2	0	0
PAVON 76	Mexico	1979	3.7	0	0
BALAKA	Bangladesh	1979	6.2	7.6	0
KANCHAN	Bangladesh	1983	0	46.2	72
AKBAR	Bangladesh	1983	0	9.4	25
ANANDA	Bangladesh	1983	0	1.9	0
BARKAT	Bangladesh	1983	0	1.0	0
AGHRANI	Bangladesh	1987	0	0	1
Total production (t)			13,448	11,597	19,500

Crop and Soil Management Research--Over the years, research has centered on the following:

- Obtaining proper plant stands.
- Identifying factors constraining yield.
- Fertilizer and management requirements for irrigated and nonirrigated areas under optimum and late planting conditions.
- Crop response to fertilizers.
- Improvement of tillage practices and cropping patterns.
- Physiological approaches toward better crop management.
- Screening against stresses.
- Crop and soil management in relation to nutritional deficiency.
- Water and soil management in relation to crop growth.

Data revealed that seed rates higher than 120 kg/ha had no effect on yield, but that at lower rates, there were significant yield reductions. Experiments revealed ideal seeding dates for the currently grown varieties to be Nov. 15 to Dec. 1. After the Dec. 1 seeding, the rate of potential yield loss was 1.3% per day. Varietal factors increasing yields of the recently introduced varieties included: increases in the number of grains/spike, thousand kernel weight, and disease resistance.

Average yields of 760 on-farm demonstrations in 1989-90 were 3.0 t ha^{-1}. Yet, growers obtained yields of 5 to 6 t ha^{-1} in the maximum yield trials. The national average wheat yield in that year was 1.8 t ha^{-1}. Thus, future research into constraints restricting higher yields appear to be concentrated around agronomic aspects of crop improvement. Experiments conducted in Phase I revealed that soil fertility was a major yield constraint in growers' fields. In addition, various seed/soil treatment experiments showed that the use of Vitavax-200 or Furadan increased yield up to 12.7% (Table 5.4) by sustaining high plant densities. Thus, the response of seed treatment in giving higher yields illustrates a complex of soil pest problems that will require further research. Phase II will emphasize more research into these and other agronomic constraints affecting yields.

Table 5.4. The effect of seed treatment with Vitavax-200 on wheat yields in farmers' field demonstrations, 1988-89 (means of 87 demonstrations).

	Sonalika		Kanchan	
	Irrigated	Non-irrigated	Irrigated	Non-irrigated
Untreated	2880	2325	3300	2568
Treated	3245	2614	3666	2819
Yield Increase (%)	12.7	12.4	11.1	9.8

Yield constraints based on data collected during Phase I are summarized below. More experimentation in determining yield constraints will continue during Phase II.

- Foliar disease reduces yields by 42% for Sonalika and 23% for Kanchan.

- Use of growers' levels of fertilizer reduces yields from 25 to 46% compared to yields attained with recommended inputs.

- Dependence on residual moisture alone reduced yields by 34% under low fertilizer inputs. Yet, yields under the same conditions with recommended inputs did not significantly differ from irrigated wheat with recommended inputs.

- Not controlling soil pathogens/insects reduces yields from 8 to 16%.

- Seeding after the optimum date (Dec. 1) results in a potential yield loss of 1.3% day of delay of seedling, independent of fertility levels used.

Phase II Wheat Research Project

The overall goal of this project, which began in July 1992, is to increase wheat production in Bangladesh, thereby contributing to improved food security and to poverty alleviation in Bangladesh. The purpose of this project is to continue to strengthen the BARI/WRC's applied research, training and institutional capacity. Emphasis is being placed on crop management research, continuing the work on varietal improvements started in Phase I, and the training of extension workers and farmers to disseminate improved crop production practices. The project is also initiating research on the rice-wheat cropping system.

The Bangladesh Wheat Program, Phase II, is assisting BARI in taking over the full funding of the Bangladesh Wheat Program, before phasing out external support. This phase is supporting a CIMMYT scientist based in Dhaka, short-term consultancies, local training, visits by wheat scientists, short term training locally and at CIMMYT, local research and demonstration activities, equipment acquisitions and facility improvements.

Under this project, the funds made available by CIDA are enabling BARI/WRC to expand and diversity in the areas of improving crop management research systems, sustaining and enhancing varietal improvement, and expanding field demonstrations of existing and new varieties. Continuation of the on-farm diagnostic surveys observing the agronomic practices used by farmers is providing information for which to base future research priorities. In addition, training and equipment will be purchased to strengthen research and development capacity. CIMMYT and BARI are jointly sharing responsibility during this 4-year project.

Research to develop improved cropping systems is receiving the highest priority under this project. Although there is still area available for expansion of wheat (1.7 million hectares), the potential for production gains is believed to be higher both on established areas and on irrigated areas now committed to winter rice. These gains can be realized through better soil management practices and the more efficient use of fertilizer and water resources. Therefore, crop management research and the study of soil management techniques will be undertaken. Long-term trials to study rice-wheat rotation in Bangladesh may be initiated to address the sustainability of this rotation as well as better answer the declines in yields in the rotation that have been documented in India and Nepal.

In addition, the project is continuing to strengthen the research/extension linkages that support the BARI/WRC. The extension demonstration kit program by the WRC provides an immediate introduction and promotion of new varieties on farmers' fields as well as provide on-farm data of agronomic trials described previously. These extension demonstration kits have provided a vehicle for direct contact with growers, have increased cooperation with Department of Agricultural Extension (DAE) personnel, and have strengthened extension programs through farmers' rallies and training. Pilot programs of farmers' seminars and single-issue training, such as on-farm seed storage, for which selected extension officers are included, have been successful and will be increased under this phase for a wider impact. To ensure the timely dissemination of appropriate technology through demonstrations and farmer training, the project will strengthen and improve the extension activities. The WRC will provide crop management and adaptive research courses.

Technical Assistance from the CIMMYT Scientist for Phase II

The Project Director/Crops management specialist (agronomist) has the following technical responsibilities as listed in the CIDA-CIMMYT Management Plan for Phase II:

- Intensify research to establish yield potentials of representative areas and to identify constraints hindering achievement of the potential within the farming systems, climatic, and economic circumstances prevailing in Bangladesh.

- Cooperate with BARI's On-farm Research Division, for verification of improved crop management practices under farmers' conditions and in monitoring wheat yields in representative regions of the country.

- Participate in the planning and maintenance of the wheat research and development.

- Conduct training in data collection, analysis, and interpretation and encourage publication of research findings.

- Advise and monitor local Ph.D. students in wheat breeding, pathology, and agronomy.

- Visit, collate, interpret, and disseminate research and production information from relevant regional programs (e.g., India, Pakistan, Nepal, Bangkok).

- Oversee the following technical and liaison responsibilities:

    a) Ensure the continued inflow of germplasm from CIMMYT and other sources. Assist the Bangladesh national crossing programs.

    b) Promote the design of appropriate field demonstration activities.

    c) Improve linkages among the DAE, BARI's wheat programs, and BARI's rice program as it affects addressing the rice-wheat rotation.

    d) Ensure strong lines of communication between project administration and GOB.

    e) Foster the participation of the WRC in regional networks (e.g. addressing the rice-wheat rotation, boron nutrition investigations, etc).

    f) Encourage links between WRC and other relevant national agriculture projects (e.g., the Crop Diversification Program, land-use mapping).

    g) Monitor socio-economic factors affecting production and adoption of management techniques through the use of farm-level surveys and utilize the information for formulating further research agendas.

- Oversee the training program, including the possible hiring of consultants to:

    a) Participate in the planning and maintenance of the training facilities at the WRC.

    b) Plan the training courses in crop management and adaptive research.

    c) Coordinate instruction of the courses.

    d) Monitor and evaluate training impact.

    e) Initiate training opportunities for Bangladesh women in aspects appropriate to wheat.

    f) Participate with BARI in the selection of trainees and visiting scientist.

    g) Participate in the design of appropriate field demonstration activities.

Ideas for fulfilling some of the responsibilities listed above include:

- Promoting the writing of research grants by the wheat researchers for their work to be funded by CIDA funds. This will enable the scientists to plan better, organize their research, and become more knowledgeable concerning the financial costs of conducting research. "Grants" would be supplied using CIDA funds as before, but based on formal, well documented proposals written by the researchers and reviewed by a committee of the CIMMYT Project Director and other Bangladesh scientists.

- Use of CD-RAM databases such as CAB and AGRICOLA will be made available to the wheat scientists in order for them to be more aware of other wheat research efforts abroad. Not only will this provide timely information, but will enable them to write better grant proposals that after Phase II, could be appraised by any granting agency within Bangladesh or abroad.

- Provide training to appropriate personnel within WRC in modern communicative, financial, and administrative procedures for them to remain administratively and financially able to maintain themselves professionally without further assistance from CIMMYT after the completion of Phase II.

During Feb. 13-16, 1993, a UNDP Project Regional Workshop with Elements of Rice-Wheat was held in Nashipur, Bangladesh. The proceedings will be published later in 1993.

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CHAPTER 6
CROP MANAGEMENT RESEARCH (CMR) TRAINING

Here we report on the format of past and present CMR training activities at CIMMYT, Mexico.

6.1 Types of Courses

Wheat CMR training has been in a period of transition since 1988. During the 1988-91 period, three traditional courses were run (one under the normal format of 8 months in 1988 and two under a reduced format of 5 months in 1989 and 1991). The 1991 course was the last traditional CMR training held in Mexico. In 1990, a new initiative, the "Advanced Agronomy" short course was first introduced.

Traditional Course
The traditional course (i.e., 5-8 months) maintained the focus of practical "hands-on" training that developed since the course was first introduced to the Wheat Program in the early 1970s.

The objectives of the course were best understood by asking three main questions, namely:

- What are the factors limiting production (both socio-economic and physical)?
- What can be changed to improve productivity and efficiency given the resources and environment?
- How can the best technologies be developed, tested, and extended?

The course relied heavily on a strong field orientation having trainees run through the entire gamut of activities required to develop appropriate recommendations combining both on-farm and on-station research. Consequently, all class, laboratory and tutorials were focused on providing the trainees with enough (but not too much) theoretical background to sensibly apply the practical skills required to conduct their research. For an historical perspective, the traditional course's contents and evaluation of the subjects are discussed in Section 6.2.1.

Advanced Course
The advanced course has been introduced in response to requests from national programs. This course is aimed at national program scientists, who held higher positions of responsibility than held by the traditional trainee. The course content basically mirrors the points considered important in the discontinued traditional course, the exception being the reduction in field work. This course concentrates more on the "how to develop" a research program rather than on the "how to conduct" such a program.

The following sections discuss the structure and assessment of traditional CMR training course. Section 6.1.2 is a reprint of an article from the Journal of Agronomic Education.

6.1.1 Structure of CIMMYT's Traditional Wheat and Maize Crop Management Research Courses

M.A. Bell, H.R. Lafitte, A.D. Violic, and A.F.E. Palmer

Introduction

CIMMYT's mandate is "to contribute to rapid and continuous improvement in the productivity of resources committed to maize and wheat research and production in the Third World" (CIMMYT, 1989). To help achieve this mandate, CIMMYT has for many years conducted training courses in both crop management research (CMR) and crop improvement.

The majority of the CMR courses were conducted at CIMMYT headquarters in Mexico. These practical, field-oriented courses were considered successful in enhancing the research capabilities of many national programs (TAC, 1986). During the years they were conducted (since the early 1970s), the CMR courses provided training to over 600 agronomists from over 60 countries. The courses evolved over time. This section uses examples from the 1983-88 period to document CIMMYT's research philosophy and course outline, which may be helpful to others working in developing countries, who plan to conduct similar courses.

The information may also be useful for agricultural scientists in developed countries, particularly in view of recent trends. One of these is the large number of agricultural researchers and extension workers who came from urban backgrounds. They clearly benefitted from a practical curriculum like that which was employed at CIMMYT in which theory was linked with practice. Another feature of the course that enhanced its appeal in developed countries was its heavy emphasis on on-farm research, a topic of growing interest to persons concerned about sustainability and the high cost of research (e.g., Franzluebbers et al. 1988). Institutions in developed countries that are formulating practical curricula to address these topics could profit from documentation of CIMMYT's CMR courses.

Philosophy of the CMR Courses

While technologies exist to produce satisfactory crops of maize and wheat in most areas where these crops are grown, few farmers in developing countries reach the yield levels observed on experiment stations. Such "yield gaps," are generally associated with the lack of adoption of recommended technologies, some of which are inappropriate (Gomez and Gomez 1983). This situation prompted the development of a CMR strategy especially suited to developing countries (e.g., Zandstra et al. 1981, CIMMYT 1988). A major problem with the traditional research approach was that the bulk of research was conducted on research stations, which often were not representative of the farmers' environments or circumstances. The modified strategy, in contrast, combines both on-station and on-farm research, but concentrates on developing and testing appropriate technologies in farmers' fields to take into consideration the physical and socioeconomic circumstances of the farmers. The steps in on-farm research are generally defined as diagnosis, planning, experimentation, assessment and recommendation (e.g., Byerlee et al. 1982, CIMMYT, 1988). On-farm research was central to the CIMMYT CMR courses, which enabled participants to gain "hands-on" experience of these five important steps.

In order for researchers to apply the research methodology that was taught at CIMMYT, the following abilities were essential:

- Researchers had to be able to grow a good crop, conducting all necessary activities from planting through harvest themselves. The practical experience of growing a crop allowed the researcher to appreciate the significance of agronomic factors limiting productivity (which are frequently theoretical abstractions before this experience), and to better communicate with farmers.

- They needed to understand how the crop responds to various inputs and environmental factors in order to identify the factors limiting productivity within an area, prioritize those factors, and propose appropriate solutions.

- They needed be able to test the technological solutions by efficient, well-executed experimentation. The experiments should be designed with the aim of developing recommendations that address the whole complex of production problems identified and not just single problems in isolation. This approach developed an appreciation of the importance of the researcher's being directly involved in field activities and data collection. The successful interpretation of results required the ability to perform agronomic, statistical, and economic analyses of trial data.

To develop these general abilities required certain experiences, attitudes, and skills. Participants needed to 1) have "hands on" experience, 2) appreciate the importance of field work, 3) be able to link their theoretical knowledge with practical application, 4) be observant in the field, 5) be able to communicate with farmers and appreciate their circumstances, and 6) question institutional wisdom when necessary to develop appropriate recommendations. These points are discussed in greater detail below.

Course Content

The course curricula were developed in response to the needs of client countries. The skills relevant to the major topics covered in the courses were taught with the aim of enhancing a researcher's ability to be a practical agronomist. A list of 54 of the specific skills considered important in a CMR course are listed in Raab and Bell (1990). The distinctive character of the CIMMYT courses, however, was not only in their content but also in their practical focus.

CIMMYT staff traditionally combined field, class, and laboratory work to achieve course objectives. A key feature of the courses was their emphasis on practical experience, with approximately 40-50% of course time being spent in the field or in practicals. The emphasis on practical application of knowledge was particularly important since participants often had a satisfactory level of theoretical knowledge, but were unable to apply this information in the field. For example, trainees often stated what is important for calibrating a backpack sprayer, but they could not satisfactorily perform the calibration. Similarly, a participant may have been able to describe the effect of N deficiency on plant growth, but could not recognize this problem in the field. Furthermore, trainees often overrated their ability to perform various research and agronomic activities (Raab and Bell 1990).

Throughout the course, participants regularly worked alongside CIMMYT staff in the field as they conducted various research activities. The experience thus gained fostered camaraderie between staff and trainees, promoted trainee confidence, and increased both their competence in and appreciation of field activities. To further encourage participation and interest in field work, each trainee was assigned direct responsibility for various field research activities, normally trial establishment, data collection, harvest, analysis, interpretation and presentation of the results and recommendations.

In the classroom, CIMMYT had little comparative advantage in the presentation of theory, but did more so in the application of theory to practical CMR. For example, as part of a CIMMYT CMR course, instruction in soil science did not concentrate on soil mineralogy, soil chemistry, or soil physics, but rather on aspects of these topics that would be of immediate use in the field. Lectures were not presented on the composition of 2:1 vs 1:1 clays, but did focus on the evaluation of soil characteristics in a field and their effect on production. This approach required the development of a large number of training materials with the desired balance of theory and practice.

A questioning mind is an essential trait of a competent agronomist. One important objective of the course, therefore, was to develop the ability of trainees to question what they see and hear. Trainees were encouraged to question all phases of research. For example:

- Were existing recommendations appropriate in terms of agronomic principles and socioeconomic circumstances of the farmers?

- Were comments and observations made on crop growth in the field (by either trainers or fellow participants) correct?

- Did the trainee really believe the instructor when he said the problem was N and not disease?"

The instructors commitment to both posing and receiving questions, no matter how basic, encouraged participants to explore more thoroughly areas about which they were uncertain or wished to acquire greater competence.

The basis of good agronomy and good research is not just an understanding of the principles of crop response, but also the ability to observe features of crop growth that may indicate production problems or present opportunities to enhance crop performance. An important aspect of the course was therefore teaching participants to observe patterns and changes in plant growth caused by either experimental treatments, natural imbalances and/or changes due to growth and development. One method found to be effective in this was to give trainees the field plan for a single replication in a field trial. Trainees were then asked to identify the experimental treatments in the remaining replications. This also encouraged trainees to interpret their observations in the field as shown in the following example: "I have observed stunted and chlorotic plants. Based on the pattern of the symptoms, I can eliminate many of the possible causes such as N deficiency and conclude that this is probably due to herbicide damage." At each field visit, trainees were also required to explain observations of crop performance in on-farm trials.

Identifying and prioritizing production problems through field surveys that involve crop observation are essential skills for research scientists. To develop these abilities, trainees were asked to diagnose the major limitations to production in commercial farmers' fields based on crop observations. By combining this information with a knowledge of the farmers' production practices and socioeconomic circumstances, trainees can prioritize and propose or design appropriate technologies for testing.

Courses conducted in Mexico for participants from up to 20 different countries (and thus more than 20 different environments) did not address all of the specific problems that trainees faced in their home countries. The approach, therefore, was to present general principles, backed up by exercises using specific examples. The principles approach to instruction showed to have a greater long-term impact than instruction in facts alone (Cardwell 1985). The trainees learned principles involved in conducting a CMR program in one or two agro-ecological environments within Mexico. Based on this experience, they were then encouraged to apply these principles to their own countries. This process was expedited towards the end of the course, when trainees present a research project for their home countries based on agronomic and socioeconomic problems that they know exist.

Course Logistics

The structure of CIMMYT CMR courses was traditionally based on the crop life cycle. Consequently, both maize and wheat courses were historically 5 to 7.5 months long, allowing course participants to observe the full crop growth cycle and participate both in the activities required to grow the crop and those involved in a CMR program. These activities included the following:

- Planning and discussion of proposed trials (based on secondary data and field observations).

- Visits to and evaluation of proposed on-station and on-farm sites.

- Treatment preparation (e.g., germination tests, fertilizer weighing, etc.).

- Trial planting (including trial layout, land preparation, and field plan preparation).

- Experiment management (e.g., herbicide application, cutting alleys, etc.).

- Data collection from both trials and farmers' fields (e.g., disease scores, weed populations, nutritional deficiencies, etc.). Discussions with farmers.

- Trial harvest.

- Trial analysis (agronomic, statistical and economic), interpretation, and presentation.

- Planning of subsequent trials and formulation of recommendations.

Depending on factors such as climatic conditions, course timing, and the number of trials, the actual amount of time spent on each activity varied from year to year.

Originally, the CMR courses were always conducted in the order of topics given above. The sequence of these activities can, however, be rearranged. For example, in later years, the maize training courses began in the middle of the growing cycle. Participants visited the trials, collected data, and harvested. Then, after interpreting the results, they planned and conducted the planting and maintenance stages of the succeeding set of trials. This structure allowed greater emphasis to be placed on the analysis, interpretation, and planning phases. In addition, these changes allowed a decrease in course length, while maintaining course content. Although course activities were reorganized, the objectives and curricula remained basically the same.

Usually, from 10 to 30 trials were planted for each course, most of them in farmers' fields. The objective of these experiments was to expose trainees to a range of trial types and designs and to provide results for analysis. Therefore, the selection of trials may not have been the same as that used in a typical on-farm research program, where a specific sequence of experimentation was often followed. The trial selections represented a deliberate mixture designed to identify and quantify problems, develop solutions, and test technologies (i.e. "exploratory," "levels," and "verification" trials).

Senior CIMMYT staff made a large investment of time in CMR courses. Typically, classes involved 6-7 hours per day of contact time, while field activities involve 6-10 hours/day. Consequently, a typical week involved between 30-40 hours of contact time with senior staff.

Conclusion

The CIMMYT CMR courses attempted to teach agronomists from developing countries how to:

- Grow a crop of wheat or maize.
- Diagnose agronomic and socioeconomic constraints to crop production based on field observations and farmer surveys.
- Design experiments to solve priority problems, which within an overall research strategy, focuses on farmers' circumstances.
- Conduct experiments both in farmers' fields and on research stations.
- Analyze experiments in agronomic, statistical, and economic terms.
- Formulate recommendations, and design subsequent trials based on the results.

The special strength of the course that developed over its 20-year run is considered to have been its focus on the crop and on farmers' actual conditions, as well as its combination of theory and practice.

Acknowledgments

Many individuals contributed to the development of the CIMMYT CMR courses. Senior staff who spent more than 2 years in the CMR training programs include: J. Barnett, H. Hepworth, E.B. Knapp, F. Kocher, J. Lindt, P. Marco, H. Nasr, and J. Woolley.

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6.1.2 Assessing a research training course for wheat crop management

R. T. Raab and M. A. Bell*

ABSTRACT

The aim of the CIMMYT (International Maize and Wheat Improvement Center) Wheat Crop Management Research course is to teach young scientists from developing countries the skills required to conduct farmer-focused agronomic research through practical experience in both on-station and on-farm experimentation. In an effort to assess and document immediate training impact and to ensure that the required skills are included in the course curriculum, trainees are asked to complete pre- and postcourse questionnaires. These questionnaires give trainees an opportunity to evaluate and influence course content and also to demonstrate their competence in the skills included in the curriculum. The self assessments of competence were compared with an objective assessment of both practical and theoretical competence. The results indicate that changes in competence, as measured by self assessment, must be interpreted more as a measure of a change in group confidence and competence rather than as a true measure of individual competence and improvement. This method's application and validity and its use in assessing curriculum content and documenting change in competence and confidence are discussed.

THE International Maize and Wheat Improvement Center (CIMMYT) is a nonprofit agricultural research institution dedicated to supporting and complementing the agricultural research systems of developing countries. Training is a major activity at CIMMYT. The principal objective of the Center's various training programs is to increase the professional expertise of agricultural research personnel in developing countries. The training philosophy of all CIMMYT courses emphasizes the practical application of skills.

The wheat (*Triticum* spp.) production agronomy course was initiated in 1971 due to a perceived need for scientists in lesser developed countries (LDCs) capable of developing agronomic recommendations within national programs. Up until mid-1989, this program has provided training to >300 young production researchers from approximately 60 developing countries. The goal of this course is to produce practical agronomists who can take leadership roles in their national crop management research programs. CIMMYT trainers and agronomists consider that an effective crop research program is composed of

1. Diagnosing production problems (both agronomic and socio-economic)
2. Proposing or generating appropriate technologies to solve those problems
3. Verifying technologies
4. Recommending technologies found to be effective and appropriate

The course attempts to teach participants skills needed to conduct such a program. The course is evaluated annually to monitor changes in training needs and modify course curriculum, and to document training program impact.

By the routine assessment of topic importance, an attempt is made to keep abreast of the changing needs of our diverse clients. Rapid advances in technology can make it difficult for the professional to keep abreast of change (Lindsay et al., 1977). This situation is true to some degree for the crop management researchers from developing countries who participate in the wheat crop management research course. Trainee opinions are solicited in each training course to monitor evolving needs and provide information for increasing or decreasing emphasis on a particular topic or other modifications in the course curriculum or delivery. Also, both national program personnel and CIMMYT staff based in developing countries are questioned as to the skills they consider essential for an effective production researcher.

There are several ways to measure the competence of course participants, including grading written assignments and exams, informal observation, self-assessment, and/or practical assessment. Although these methods are used to some degree, experience has shown that some are more useful and/or efficient than others as tools for assessing and documenting immediate impact of this type of training.

The traditional assessment scheme based on written answers to a range of questions has generally been inadequate for assessing trainee competence in CIMMYT courses; in the field, course participants regularly fail to demonstrate practical competence in a skill that they apparently know in theory. This situation is not unique to the CIMMYT wheat crop management course. Evidence suggests that other centers also routinely receive trainees unable to demonstrate competence in important skills (Arnon, 1981).

Informal observation of the trainees as they do the tasks associated with an effective crop management research program has also proven to be a less than ideal evaluation method for two reasons. First, it is difficult to assess with equity the performance of some 20 trainees across a range of skills amidst all the activities that occur

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in the field (particularly as the assessors themselves are usually busy with the trainees in the field). With informal observation, generally only the less enthusiastic workers are clearly identified, and cultural differences among trainees can further confound the assessors perception. Additionally, such subjective measures are of limited value in providing documentation of impact.

Self assessment, although relatively easy to conduct, has the potential problem of personal bias in the perception of an individual's own skills. Practical assessment, in contrast, gives a more accurate measure of the individual's competence but can be time consuming and thus impractical to implement.

This article presents the experiences and results of efforts by CIMMYT instructors to modify course content in response to participants' needs and to document and assess trainee competence.

MATERIALS AND METHODS

Self Assessment

Since 1983, all trainees complete both a pre- and postcourse questionnaire. The precourse questionnaire is handed out during the first week of the course. This questionnaire, in addition to asking for information that can be used to better identify the training audience, lists approximately 50 of the major topics to be covered during the course and asks respondents to rate the importance of each topic (Table 1). Respondents also rate their competence in each skill. Figure 1 shows a sample form with a subset of the topics included. A separate section gives trainees the opportunity to indicate both listed and unlisted topics that they are especially interested in learning.

The postcourse questionnaire, given during the last week of the course, gives trainees the opportunity to reevaluate the importance of, and their perceived ability to demonstrate competence in, the same topics as presented in the precourse questionnaire. This questionnaire also gives respondents an opportunity to make constructive suggestions about course organization and management.

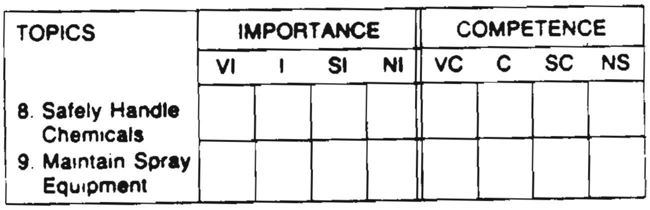
Practical Assessment

In 1987, trainees were assessed by instructors at the end of the course for their practical competence in the following skills:

1. Evaluating soil physical characteristics
2. Evaluating soil chemical characteristics
3. Selecting experimental and nonexperimental variables
4. Calibrating a sprayer
5. Handling chemicals safely
6. Interpreting pesticide and fertilizer label information
7. Taking a soil sample
8. Identifying wheat developmental stages
9. Handling machinery safely
10. Identifying machinery parts and functions
11. Identifying wheat diseases

Table 1. List of 54 topics included in the CIMMYT wheat crop management research training course.

No.	Topics
1.	Evaluate a suitable seedbed.
2.	Seed by hand and machine.
3.	Apply fertilizer by hand and machine.
4.	Calibrate a sprayer.
5.	Propose appropriate methods of pest control.
6.	Interpret pesticide and fertilizer label information.
7.	Evaluate chemical and fertilizer storage conditions.
8.	Safely handle chemicals.
9.	Maintain spray equipment.
10.	Predict evapotranspiration.
11.	Predict soil moisture deficit.
12.	Schedule irrigation (timing and amount).
13.	Develop research objectives and priorities.
14.	Select experimental and nonexperimental variables.
15.	Record data in field books.
16.	Harvest and prepare plot samples for analysis.
17.	Produce a crop of wheat.
18.	Layout and plant field trials.
19.	Explain farmer adoption behavior of technology.
20.	Select research sites.
21.	Conduct a farmer survey.
22.	Identify wheat developmental stages.
23.	Interpret climatic data as regards crop development.
24.	Evaluate stand establishment.
25.	Score wheat diseases.
26.	Identify wheat diseases.
27.	Recall sources of inoculum and control methods of diseases.
28.	Evaluate soil physical characteristics.
29.	Evaluate soil chemical properties.
30.	Test seed viability.
31.	Do chemical calculations (e.g., fertilizer and herbicide).
32.	Take a soil sample.
33.	Evaluate yield loss due to pests.
34.	Interpret soil analyses data.
35.	Measure water infiltration rates into soil.
36.	Calculate yield components.
37.	Explain the effect of tillage practices on soil characteristics.
38.	Identify problem soils and water.
39.	Diagnose field problems.
40.	Present a field day or oral presentation.
41.	Describe soil conservation practices.
42.	Perform economic analysis (partial budget and net benefit analysis).
43.	Perform agronomic analysis.
44.	Perform statistical analysis.
45.	Make recommendations from experimental results.
46.	Multiply and store seed.
47.	Describe the different phases of on-farm research.
48.	Identify plant macronutrient deficiency symptoms.
49.	Identify different farmer groups.
50.	Use a computer.
51.	Define the objectives of integrated pest management.
52.	Evaluate factors affecting sustainability.
53.	Define the role of extension in agricultural development.
54.	Use field equipment safely.



TOPICS	IMPORTANCE				COMPETENCE			
	VI	I	SI	NI	VC	C	SC	NS
8. Safely Handle Chemicals								
9. Maintain Spray Equipment								

Fig. 1. Example of the types of questions and format used to rate both pre- and postcourse importance and competence (VI = very important, I = important, SI = somewhat important, NI = not important, VC = very competent, C = competent, SC = somewhat competent, NC = not competent).

Trainees were rated on their ability to demonstrate competence in each skill based on predefined criteria. For example, after taking a soil sample, trainees were rated on identification of homogeneous sampling units, removal of surface litter from sample, number of subsamples collected in relation to sample unit size, depth of sampling, and correct labeling of the sample.

In 1988, trainees were assessed with a precourse test in Skills 4, 5, 6, 8, 9, and 10, and postcourse test in Skills 1 through 10. The whole range of skills was not assessed precourse because experience has shown that only a limited number of trainees have experience in the first three skills.

Analysis

Because most of the data collected is ordinal, the Wilcoxon Rank Sum Test was chosen as the most appropriate test of significant differences between rating scores. This procedure tests for differences between the medians of two populations. The Spearman Rank correlation was also employed to examine the strength of relationships between various measures.

RESULTS AND DISCUSSION

The two major aspects of course evaluation are (i) assessing the relevance and importance of the course material to the trainees and their home-country situations, and (ii) measuring the impact of training on the competence of the trainees. The discussion has thus been divided to consider these two issues separately.

Assessing Course Content

Trainee perceptions of the importance of various course topics were measured for 4 yr. Results have shown that all of the topics are rated from important to very important, both at the beginning and at the end of the course. Results for 1988 (Fig. 2), showing a mean difference of only 0.14 between the pre- and postcourse assessment, are typical of the response levels shown in other years. The interesting factor in these illustrations is the similarity between the pre- and postcourse importance ratings. The trainees seem to begin the course with a concept of what they consider important and complete the course holding essentially the same perceptions of individual topic importance.

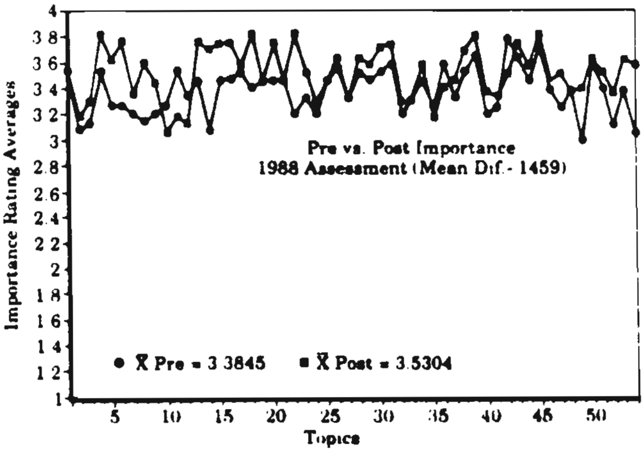


Fig. 2. Trainee importance ratings of listed topics rated pre- and postcourse for 1988 (1 = not important, 2 = somewhat important, 3 = important, 4 = very important).

Table 2. Results of the Wilcoxon rank sum test for differences between pre- and postcourse self assessments of competence over skills in 1987 and 1988.

	Precourse		Postcourse		
Year	Mean†	Median	Mean†	Median	*W*
1987 (*n* = 50 topics)	2.249 (0.4179)	2.240	3.088 (0.3340)	3.200	1423.5**
1988 (*n* = 54 topics)	2.250 (0.2474)	2.300	2.99 (0.2315)	3.000	1506.5**

** Significant at $P < 0.01$.

† Mean score range: 1 = not competent, 4 = very competent.

Responses to the open-ended question that asks for other topics the trainees would like included are also examined. To date, however, no one individual topic has been suggested by a significant number of trainees. Such results suggest that the trainees consider the course adequate to teach the skills needed to conduct agronomic research. One example of change, however, in response to national program needs is the addition of computer classes.

Assessing Competence

A comparison of 1987 and 1988 pre- and postcourse mean competency rating over all topics, using the Wilcoxon Rank Sum test (Table 2), indicates that the differences between pre- and postcourse self assessment of competency scores in both years were highly significant. Figure 3 shows the perceived change in competence for the 50 skills for 1988.

This procedure is thought to be a valid indicator in evaluating and documenting change for two reasons. First changes in self assessment of competence are considered

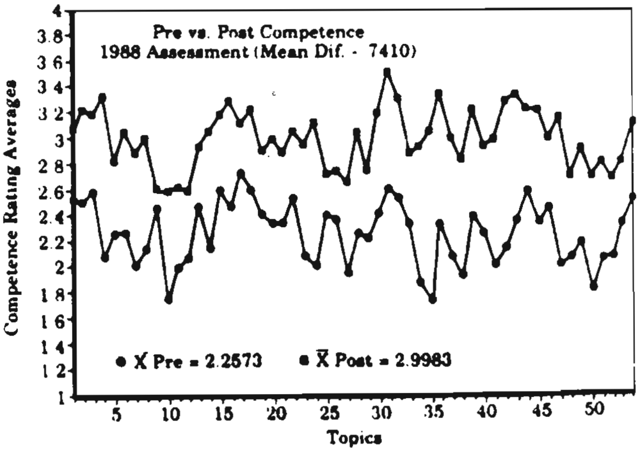


Fig. 3. Trainee competence ratings for listed topics rated pre- and postcourse for 1988 (1 = not competent, 2 = somewhat competent, 3 = competent, 4 = very competent).

to be an indication of change in confidence. Although improvements in trainee competence are of interest, changes in affective domain learning (i.e., learning involving attitudes, feelings, and values, Bloom et al., 1956) are also very important. The importance of instruction on attitudinal or affective behavior is widely acknowledged, but it is often overlooked from a measurement standpoint (Wentling, 1980). An attempt should be made to weigh attitudinal qualities important to the competent performance of cognitive objectives.

The importance of attitudinal change is supported by comments made by CIMMYT staff stationed in the countries from which course trainees originate, and also by the results of follow-up studies conducted by researchers investigating impact of similar production courses. CIMMYT staff members repeatedly state that perhaps one of the most important improvements observed in returned trainees is their increased motivation to do field tasks and their enthusiasm for their work. Change of this type appears to be lasting as shown by a follow-up study involving alumni of the International Center for Tropical Agriculture (CIAT) production course (Byrnes, 1974).

It is maintained that increased motivation and enthusiasm of trainees is due, to a large degree, to the increased self-confidence of trainees (i.e., the confidence they gain from conducting practical research and from using the associated skills). The self assessment scheme appears to be one way to measure this change, because differences between pre- and postcourse self assessments of competence can be interpreted, in part, as changes in trainee confidence to do the tasks related to an effective crop management research program.

A second reason for employing the self assessment method is the belief that self-evaluation of competence measured at the beginning and end of the course can act as a "proxy variable" (Williamson et al., 1982), which provides an easily measured indication of actual improvement. Although the ideal form of assessment would clearly involve the practical assessment of trainee competence over the range of skills taught, carrying out this task presents serious logistical and manpower problems. For example, adequate demonstration of competence by just one trainee in a single skill, such as diagnosing field problems, could take several hours, not including transportation to and from a representative site and the time needed to identify suitable fields. When one considers that a comprehensive pre- or postcourse practical assessment would entail empirically assessing the competence of approximately 20 to 30 individuals over some 50 skills, it becomes obvious why such an assessment scheme has not been adopted. Given this situation, it is clear that an earier and cheaper measurement of trainee competence is desirable.

The inclusion of both a pre- and postcourse limited practical assessment in 1988 allowed for the first time a direct assessment of changes in trainee competence. It also provided course evaluators with an indication of the accuracy of the proxy variable obtained through the pre- and postcourse self assessment method. Although imperfect, it was felt that such an assessment would give a somewhat more standardized measure of change in trainee competency. Figure 4 illustrates the increase in trainee competence as measured by the limited pre- and postcourse practical assessment over four key skills.

Table 3. Results of the Wilcoxon rank sum test for differences between trainee and trainer assessment of pre- and postcourse competence and percent change in competence. Data from 1988. Maximum competence score possible = 100%.

	Trainee assessment		Trainer assessment			
	Mean	Median	Mean	Median	W	P
Precourse	54.78 (19.94)	56.20	55.58 (16.61)	50.00	174	0.9591
Postcourse	79.30 (12.59)	81.20	88.58 (9.16)	89.50	139	0.0649
% change	65.14 (71.78)	44.48	69.05 (38.47)	79.00	156.5	0.3428

Table 4. Results of Spearman rank correlation between trainee and trainer assessments of pre- and postcourse competence and percent change in competence over four skills.

Comparison	Correlation
Trainer vs. trainee precourse assessments	−0.127
Trainer vs. trainee postcourse assessments	−0.196
Trainer vs. trainee assessments of change	0.092

A comparison of results obtained through the two assessment schemes, both the self and the limited practical, indicates that the proxy measure of competence obtained through self assessment seems to provide an accurate measurement of group competence and change. Table 3 presents the results of a comparison between group self assessment scores with group practical assessment scores using the Wilcoxon rank sum test. These and subsequent comparisons are made for the averages of four major skills that could be sensibly assessed pre- and postcourse. It can be seen that no significant differences are observed. This relationship holds true for both pre- and postcourse scores and also for percent change.

Self assessment does not, however, appear to be an accurate assessment of an individual's relative competence in a skill. The results of self (trainee-assessed) were poorly correlated with practical (trainer-assessed) evalu-

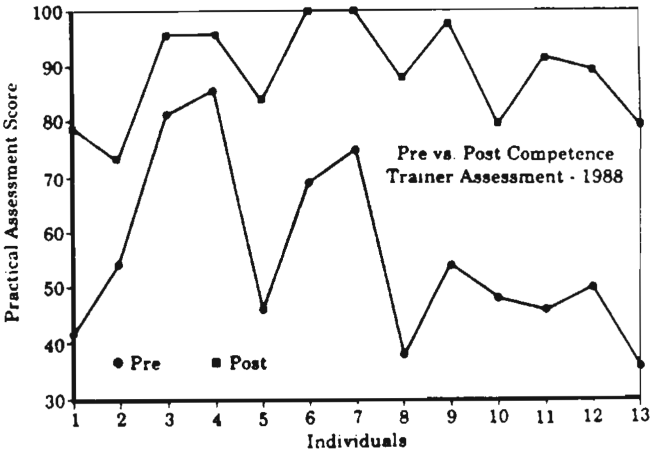


Fig. 4. Pre- and postcourse results of practical assessments of competence of four skills for 13 individuals.

ations of an individual's competence over selected skill areas for the pre- and post assessments, and for the percent change in performance during the course (Table 4).

If the two assessments were in agreement (i.e., a trainee tested as highly competent in the practical assessment also assessed him or herself as highly competent, and the trainee who lacked the required skill rated him or herself lowly) then a straight line relationship would exist between trainer and trainee assessment, and the resultant correlation would be close to one. Interestingly, the correlation was significant at the 7% level for the postcourse assessment (Table 3); this possibly indicated that by the end of the course, the trainee had a better understanding of what was required by the trainers in terms of being considered competent in a certain skill.

It is obvious that there exists very little agreement between competence assessments measured by instructors, compared with self ratings by the individuals. This would indicate that trainees do not rate themselves relative to other trainees or to the competency expected from the instructor; they come with their own perceptions of what constitutes an acceptable level of competence.

CONCLUSIONS

The use of a pre- and postcourse questionnaire to monitor changing needs and to measure impact, despite the shortcomings discussed, appears to be an efficient and valuable method of course evaluation. Information collected through such a procedure has been, and will continue to be, used as a basis for modifying or validating course content and for documenting and measuring changes in group competence and confidence. With such information available for 5 yr, differences in ratings across years serve to alert instructors that something was done better or worse in a particular course; course organization can then be adjusted accordingly. Such modifications will lead to better, more effective training.

Based on the evaluation results of one group, it appears that self evaluation is of little value for assessing an individual's relative competence or change in competence. It appears that trainees do not rate themselves relative to other course participants or to a standard of competence as defined by the training officer. This situation could possibly be addressed through more effective communication between trainer and trainee as to the standards by which trainees' competence will be evaluated.

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ANNEX 1.
MEGA-ENVIRONMENTS IN WHEAT BREEDING

Adapted from CIMMYT Wheat Breeders Conference, April 3-5, 1989, Ciudad Obregon, Sonora, Mexico.

Introduction

CIMMYT's strategic plan defines a mega-environment (ME) as a broad, not necessarily contiguous area, usually international and frequently transcontinental, defined by similar biotic and abiotic stresses, cropping system requirements, consumer preferences, and for convenience, by volume of production of the relevant crop. Germplasm products generated for a given ME are useful throughout it, accommodating major stresses, but perhaps not all the significant secondary stresses.

Before the nomenclature of an ME came into use, CIMMYT's wheat breeding program used the term "agro-ecological zone" to define and focus objectively its goals. Almost all of the current MEs, to which different breeding strategies are devoted, have been picked up over the last 44 years as the program evolved into its various facets.

CIMMYT currently deals with seven MEs for wheat--six are distinct agro-ecologies for spring wheats and one is for facultative and winter wheats. Presently, all the MEs are based on moisture availability, soil type, temperature regime, and, consequent to these, disease spectrums and abiotic stresses in each. These MEs are numbered 1 through 7, chronologically as CIMMYT became involved with them.

ME1--Irrigated (low rainfall), temperate

ME1 represents irrigated areas associated with very low rainfall. The representative areas are the Yaqui Valley in Mexico, the Indus Valley in Pakistan, the Gangetic Valley in India, and the Nile Valley in Egypt. The wheat growing period is associated with a temperate climate, however, sudden rises in temperature after flowering are common occurrences.

Efforts to breed wheat in ME1 started in 1944 on a regional basis at first. The shuttle breeding concept was first applied to this ME and now some of the more highly developed breeding programs are devoted to this favored environment.

The dwarfing genes Rht1 and Rht2 were first deployed in this environment, which resulted in doubling and tripling of yield potential and production. The three rusts are major disease constraints; nonetheless, the stem and leaf rust problems have been solved to a large extent. No stem rust epidemic has occurred in the last 30 years; leaf rust resistance has stabilized during the last 10 years. Breeders at CIMMYT and national programs have deployed maintenance breeding to both of these diseases and are looking for better sources of stripe rust resistance. Due to a lack of proper drainage, certain areas of ME1, such as the Mexicali Valley in Mexico and the Indus Valley, are suffering salinity problems.

Current breeding strategy involves a continuous search for high yield potential, lodging resistance, better industrial quality characters, maintenance of dwarfing genes Rht1 and Rht2, and durable resistance to the rusts. Since ME1 encompasses many millions of hectares spread primarily over Asia and Africa from 20° S to 35° N latitude, it is obvious that pathogenic variation is large within the same rust group and temperature fluctuations are moderate.

The future focus of ME1 will still be yield potential, as the payoff can be large if more controlled agronomic practices are used, Maintenance breeding for the rusts should have a significant resource allocation. The salinity problem needs to be addressed through genetics. Aphids seem to be a growing problem in this ME. Spring x winter crosses will play an important role in ME1 in the continuous search for genetic variability. Spring bread wheat and, to lesser extent, spring durum wheat are important in ME1 (Table 1).

ME2--High rainfall, temperate

Breeding for tolerance to *Septoria tritici*, prevalent in ME2, started in 1972. This step was taken because a majority of the germplasm products of ME1 when placed in high rainfall areas of the Mediterranean Basin was highly susceptible to septoria leaf blotch. Susceptibility was so severe that, during the late 1960s, the critics of the semidwarf wheats felt there was a positive relationship between septoria tritici blotch susceptibility and the Rht1 and Rht2 genes for semidwarfness.

High rainfall areas are prevalent in the Mediterranean countries, the Southern Cone and Andean highlands of South America, and East Africa. Small portions of these regions have acidic soils and are included in a separate mega-environment (ME3). Stem rust, leaf rust, stripe rust, septoria tritici blotch, BYDV, fusarium head scab, bacteria, and powdery mildew are present either singly or in combinations of two or three. Stripe rust and septoria tritici blotch are the most important throughout ME2. Both spring bread and durum wheats are important crops (Table 1).

ME3--Acid soils, high rainfall, temperate

Aluminum (Al) toxicity is the major constraint in acid soils--at least from the breeding point of view. Manganese (Mn) toxicity is problem to a lesser degree. In addition to the soil element problems in ME3, the disease problems are similar to those described above for ME2. This project started in 1975 as a joint venture between CIMMYT and Brazilian institutions such as EMBRAPA, FECOTRIGO, OCEPAR, and IAPAR because the CIMMYT semidwarfs were unadaptable in Brazil due to their inherent susceptibility to Al toxicity.

Soil scientists estimate that at least 1 billion ha worldwide are acidic. In addition to Brazil, CIMMYT deals with these soils in the Andean highlands, central Africa, and the Himalayas. Triticale has shown outstanding performance in this ME; bread wheat and barley are also important (Table 1).

ME4--Low rainfall

This ME is generally characterized by existence of drought during one or more stages of plant development and growth. Since CIMMYT became involved with this ME in 1975, it has identified three distinct sub-MEs:

- ME4A--Winter rain: Mediterranean type of rainfall associated with drought during the post-flowering stage. Most of the rain falls during winter months. Representative locations include Aleppo, Syria, and Settat, Morocco. The major breeding objective is drought tolerance.

- ME4B--Winter drought: Southern Cone type rainfall in which drought is associated before the onset of flowering, mostly at the tillering and bolting stages. A representative location is Marcos Juarez, Argentina. In addition to drought tolerance, breeding objectives include resistance to leaf rust, stem rust, septoria, and fusarium.

- ME4C--Mostly stored moisture: After monsoon rains, resulting in continuous drought. A representative location is Indore, India. The major breeding objective is drought tolerance.

These sub-MEs represent three broad categories of drought. Variations in precipitation distribution and amount, soil types, and temperature regimes make drought tolerance breeding extremely difficult. The CIMMYT/ICARDA program based in Aleppo is developing germplasm for the winter rain sub-ME. Spring habit bread wheat, durum wheat, and triticale are important crops in ME4 (Table 1).

ME5--High temperature

CIMMYT classified this ME in 1981 as part of a UNDP project on wheats for warmer environments where the mean temperature of the coolest months is >18°C. Two distinct sub-MEs have been identified for ME5:

- ME5A--Humid atmosphere: Resistance to helminthosporium, fusarium, leaf rust, and sprouting are major breeding objectives. Representative locations include Poza Rica, Mexico and Joydepur, Bangladesh, and parts of Thailand and Paraguay.

- ME5B--Dry atmosphere: Representative locations include Gezira, Sudan and Kano, Nigeria.

ME6--Facultative and winter wheats

This ME has been divided into four sub-MEs:

- ME6A--Moderate cold (0 to 5°C, coolest month), high rainfall or partly irrigated: Major breeding objectives are yield potential, and resistance to stripe rust, fusarium, and sprouting. Representative locations are Temuco, Chile, and large parts of China.

- ME6B--Moderate cold (0 to 5°C, coolest month), low rainfall: Major breeding objectives are drought tolerance and resistance to stripe rust and bunt. Representative locations include Diyabakir, Turkey, and Dezful, Iran.

- ME6C--Severe cold (-10 to 0°C, coolest month), high rainfall or part irrigated: Major breeding objectives are yield potential and resistance to stripe rust and leaf rust. Representative location is Beijing, China.

- ME6D--Severe cold (-10 to 0°C, coolest month), low rainfall: Major breeding objectives are drought tolerance and resistance to stripe rust and bunt. Representative locations include Ankara, Turkey, and Tabriz, Iran.

Bread wheat and durum wheat are important crops in ME6 (Table 1).

ME7--High latitude (>40o N or S)

This newest ME is characterized by severe winters and spring-sown spring wheats. A representative location is Harbin, China, an area with which CIMMYT began a shuttle breeding project in 1988. Some degree of photoperiod sensitivity is required in addition to resistance to stripe rust and leaf rust, fusarium, helminthosporium, and sprouting. Pre-anthesis drought is common, and in this respect it parallels ME4B.

Allocation Index for Bread Wheat Breeding

Table 2 provides 1984-86 statistics for the MEs listed above that were used to calculate an allocation index for CIMMYT's bread wheat breeding effort.

Table 1. Current priority setting by ME for small grain cereals.

Crop	Mega-environment						
	ME1	ME2	ME3	ME4	ME5	ME6	ME7
Spring Bread Wheat	X	X	X	X	X		X
Bread Wheat (Winter/Fac)						X	
Spring Durum Wheat	X	X		X			
Spring Triticale			X	X			
Barley (ICARDA/ CIMMYT, in Mexico)		X	X				

Table 2. Statistics of wheat mega-environments in developing countries as used by CIMMYT Wheat Program in 1989 to calculate an allocation index for bread wheat breeding effort; 1984-86 statistics.

Mega-environment[a]		Area % (m ha)	Production % (m t)	Per capita income $/yr[b]	Rate of progress %/yr[c]	Calculated allocation index %[d]
Temperate, wet						
ME1	Irrigated	36.1	42.7	390	1.0	44.9
ME2	High rainfall	8.5	10.4	1,220	1.0	7.3
ME3	Acid soil	1.9	1.3	1,640	1.0	0.4
Temperate, dry						
ME4A	Winter rain	6.1	2.3	1,990	0.7	1.2
ME4B	Transitional	3.6	2.1	2,110	0.7	0.5
ME4C	Residual moisture	4.9	2.5	300	0.7	1.9
Hot						
ME5A	Hot, low vpd	4.4	4.9	540	1.0	5.0
ME5B	Hot, high vpd	3.6	1.5	380	0.7	1.1
Cold-Very cold						
ME6A	Falcult., wet	6.2	9.8	350	1.3	13.4
ME6B	Falcult., dry	5.1	2.0	990	1.0	1.8
ME6C	Winter, wet	7.4	9.2	570	1.3	11.6
ME6D	Winter, dry	6.7	4.6	780	1.0	3.6
Extreme cold						
ME7	High lat.	5.5	6.8	310	1.0	6.9
Total		100 (88)	100 (191)	-	-	100

[a] See text.

[b] For allocation index weighed as follows: 0-399=3.0, 400-999=2.3, 1000-1499=1.7, 1500=1.0.

[c] Projected for 1990-99.

[d] Calculated by product of % production, and income, rate of progress, and strength of national program weights for each ME, then dividing by the total of all MEs. Strength of national program weights not shown because they vary little between weak (1.3) and strong (1.0).

Source: R.A. Fischer and S. Rajaram. 1990. Progress and Plans in Spring Wheat Breeding at CIMMYT. In: Wheat Breeding Society of Australia, 16-20 Sept. 1990.

ANNEX 2.
CURRENT PROJECTS OF THE CROP MANAGEMENT & PHYSIOLOGY SUBPROGRAM

Note: Details can be found in Fisher, R.A., and G.P. Hettel, eds. 1992. Research Project Updates and Descriptions of New Projects for the CIMMYT Wheat Program. Mexico, D.F.: CIMMYT.

Agronomic Support to Breeding (8 projects)

MPOF8501: On-farm research in the Yaqui Valley. K. Sayre, I. Ortiz-Monasterio, A. Limon, S. Rajaram, O. Abdalla, M. Camacho, and O. Moreno.

MPWC8601: Weed control practices for nurseries grown on 90-cm beds. K. Sayre and I. Ortiz-Monasterio.

MPWC8602: Improvement of weed control practices for yield trials. K. Sayre and I. Ortiz-Monasterio.

MPWC8603: Herbicide screening for phytotoxicity effects on bread wheat, durum wheat, triticale, and barley. K. Sayre, I. Ortiz-Monasterio, and respective crop leaders.

MPCR8601: El Batan station management rotation trial. K. Sayre, M. Bell, and D. Lawn.

MPPP9001: Evaluation of economic yield importance of leaf rust resistance in bread wheat. K. Sayre and R.P. Singh.

MPTP9001: Strategies on patterns and frequency of subsoiling. I. Ortiz-Monasterio and K. Sayre.

MPPP9201: Assessment of yield losses by bread wheat to foliar diseases at El Batan. K. Sayre, L. Gilchrist, R.P. Singh, S. Rajaram, and G. Saari.

Physiologic Support to Breeding (20 Projects)

MPDR8501: Use of the line source gradient irrigation system for evaluating breeding materials. K. Sayre, S. Rajaram, W. Pfeiffer, and O. Abdalla.

MPGC8601: Characterization of the agronomic performance of innovative genotypes originating in the former Germplasm Development Section. K. Sayre.

MPGN8601: Nitrogen rate x genotype of bread wheat, TCL, and durum. I. Ortiz-Monasterio, K. Sayre, and J. Peña.

MPGM8801: Characterization of crop management by genotype interactions related to contrasting morphological plant types with emphasis on weed suppression. K. Sayre and I. Ortiz-Monasterio.

MPYP8802: Assessment of genetic progress for improvement in yield potential for bread wheat, durum wheat and triticale. K. Sayre, S. Rajaram, W. Pfeiffer, and O. Abdalla (H. Vivar when barley is periodically included).

MPDR8903: Investigation of responses of CIMMYT BW germplasm to different intensities of pre- and post-anthesis drought stress and a comparison between line source and gravity irrigation methodologies. M. Reynolds and K. Sayre.

MPHT8901: International Heat Stress Genotype Experiment (IHSGE). M. Reynolds, E. Acevedo, and R.A. Fischer.

MPYP8902: Investigation of response of CIMMYT BW varieties to reduced inter-plant competition for light and soil resources. M. Reynolds, E. Acevedo, and R.A. Fischer.

MPGC9001: Selection of bread wheat genotypes for phosphorus use efficiency. I. Ortiz-Monasterio, M. van Ginkel, and K. Sayre.

MPPB9001: Physiology breeding for improved performance of durum wheat under drought stress. E. Acevedo, O. Abdalla, P. Monneveux, and M. Nachit.

MPBW9101: Identification, assessment, and verification of early generation selection criteria to increase the efficiency of selection for yield potential in ME1. E. Acevedo, P. Stefany, S. Rajaram, M. van Ginkel, J. Crossa, R.A. Fischer, and V. Calixto.

MPBW9102: Increasing drought resistance through selection for osmotic adjustment in wheat. E. Acevedo, S. Rajaram, M. van Ginkel, D. Hoisington, M. Khairallah, J. Crossa, and V. Calixto.

MPBW9201: Study of morphology and phenology of high yielding bread wheats to understanding the physiological processes associated with high yield in ME1. P. Stefany.

MPBW9202: Investigation of the introduction of genetic material from diploid ancestor species through new synthetics for the increase in Pmax and yield potential of bread wheat. D. Rees, E. Acevedo, A. Mujeeb-Kazi, and R.L. Villareal.

MPBW9203: Relationship between stomatal conductance of individual leaves and canopy temperatures--potential selection method for high yielding varieties. D. Rees, K. Sayre, A. Limon, E. Zeige, and E. Acevedo.

MPBW9204: Divergent selection for traits related to heat tolerance in bread wheat. M. Reynolds and M. van Ginkel.

MPGC9201: Genotypic interaction with the environment and its subsequent effect on phenotype development. P. Stefany.

MPGC9202: Increasing salinity resistance in wheat. E. Acevedo, A. Mujeeb-Kazi, S. Rajaram, H. Fraga, and I. Pargas.

MPGR9201: Investigation of Ethephon as a suitable growth regulator to reduce wheat plant height and lodging. K.D. Sayre and I. Ortiz-Monasterio.

MPWL9201: Assessment of the tolerance of cereals to variable soil waterlogging conditions. K. Sayre, M. van Ginkel, and I. Ortiz-Monasterio.

Strategic Compoment Agronomy (7 Projects)

MPGM9001: Plant canopy architecture studies with emphasis on row spacing and planting method. I. Ortiz-Monasterio, K. Sayre, and R.A. Fischer.

MPHT9001: International Heat Stress Management Experiment (IHSME). M. Reynolds, E. Acevedo, and R.A Fischer.

MPNE9001: Rates, timing, splitting, and sources of nitrogen on bread wheat yield and quality. I. Ortiz-Monasterio, K. Sayre, and J. Peña.

MPMV9001: Study to assess the sensitivity of the CERES wheat model. M. Bell.

MPMA9002: Pakistan planting date study. M. Bell and P.R. Hobbs.

MPPD9001: Planting date x density x cultivar. I. Ortiz-Monasterio and K. Sayre.

MPNE9201: Nitrogen rates and timing under different levels of initial soil nitrogen on bread wheat. I. Ortiz-Monasterio, K. Sayre, and J. Peña.

Strategic Cropping Systems Sustainability Research (7 Projects)

MPYP8701: Effect of soil management strategies on sustainability of maximum yields. K. Sayre, I. Ortiz-Monasterio, and X. Uvalle (CIANO).

MPNE8904: Use of N fixing legume species as intercrops with wheat to improve productivity and nitrogen inputs at low soil fertility. M. Reynolds and K. Sayre.

MPDD9001: On-farm research in the Yaqui Valley--diagnostic determination of yield limiting factors. A. Limon, K.D. Sayre, and I. Ortiz-Monasterio.

MPMA9001: Yield trends in the Yaqui Valley--variation due to climate and contribution due to inputs. M. Bell, R.A. Fischer, and D. Byerlee.

MPSM9001: Wheat straw management alternatives in the wheat-soybean rotation. K. Sayre, I. Ortiz Monasterio, and X. Uvalle (CIANO).

MPSM9102: Sustainable cropping in ME2: long-term rotation and tillage experiments in El Batan. R.A. Fischer, S. Roman, an V. Calixto.

MPSM9201: Sustainability implications for wheat straw management for ridge-till wheat-maize cropping system in ME1. K. Sayre, I. Ortiz-Monasterio, A. Ortega, and J. Uvalle.

ANNEX 3.
SPECIAL PROJECTS AND COLLABORATIVE PROJECTS WITH ADVANCED INSTITUTIONS, JANUARY 1993

Special Projects

- Bangladesh Wheat Project
  CIDA Project No. 170/10734 (1 Senior Scientist)
  Phase II underway

- Eastern Africa Cereals Program.
  CIDA Project No. 978/15170 (1 Senior Scientist).
  Funded.

- Wheat Production in Warmer and Stressed Environments.
  UNDP GLO /90/001 (1 Senior Scientist, 1 Associate Scientist).
  Funded.

- Sustainability of Maize-Wheat System.
  Mexican Institutes/CIMMYT (Pre-doctoral student).
  Unfunded but underway with modest core support.

- Post-doctoral fellow on rice-wheat in Nepal.
  Unfunded. (ODA-Rockefeller sustainability fellow).

Collaborative Projects with Advanced Institutions

- CERES-Wheat Simulation Model Validation in ME1.
  CIMMYT/Michigan State University (Prof. I. Ritchie,
  Prof. R. Ward, pre-doctoral student).
  Funded.

- Photosynthesis and Heat Stress.
  Colegio de Postgraduados/CIMMYT (Prof. A. Larque Saavedra,
  masters student). Very modest core funding.
  Underway.

- Modelling Wheat Sowing Date and Phenology for ME1.
  CIMMYT/University of Wageningen (Prof. R. Rabbinge,
  Dr. H. van Kenlen, predoctoral student).

- Osmotic Adjustment in Wheat as Indirect Selection for Drought Resistance.
  CIMMYT/University of Wageningen (Prof. Ian Parlevliet, predoctoral or
  postdoctoral student).
  Submitted to DGIS.

- Comparison of Wheat Genotypes in Terms of Membrane Thermostability (Mexico and Romania, Dr. Nick Saulescu).
  Funded, UNDP/core, very modest.

- Remote Sensing for Biomass and Stomatal Opening. Membrane thermostability and osmotic adjustment (UGA, Israel, CIMMYT, developing country).
  Not funded.

- Post-Doctorate from Swiss Government. (Any one of a number of projects, eg. Competitive Genotypes).
  Unfunded.

- Nitrogen Use Efficiency in ME1 (IFDC-CIMMYT-donor agency).
  Unfunded

- Drought Resistance in ME4B--Argentina type (Drs. S. Goldberg, A. Hall --Argentina; Dr. I. Ledent, Belgium).
  Unfunded.

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