REPORT TO THE ADMINISTRATOR

of the

UNITED NATIONS DEVELOPMENT PROGRAMME (UNDP)

GLOBAL RESEARCH

FINAL REPORT

RESEARCH ON TROPICAL WHEAT IMPROVEMENT (GLO/82/007)

Carried out by:

THE INTERNATIONAL MAIZE AND WHEAT IMPROVEMENT CENTER (CIMMYT). Mexico

Covering the period July 1, 1982 to June 30, 1987
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GLOSSARY OF ACRONYMS
I. INTRODUCTION

A. GENERAL BACKGROUND

1. In recent years, wheat consumption in developing countries has been on the rise. Population growth, urbanization, rising incomes, bread subsidies, and food aid have contributed to escalating demand. During the 1970s, consumption was increasing at an annual rate of 5.4 percent. By 1980, 65 developing countries were consuming over 100,000 tons (t) of wheat annually. While China, India, Pakistan, Turkey and Argentina are self-sufficient, all other developing countries must import wheat to satisfy consumer demand. Most of this grain is purchased from developed countries which produce about two-thirds of the world’s supply and, between 1979 and 1981, accounted for 95 percent of total exports.

2. In the tropical belt, the area contained within the tropic of Cancer (23.5° N) and the tropic of Capricorn (23.5° S), dependence on imports is particularly high largely due to climatic conditions which pose constraints to the production of wheat – a temperate and subtropical crop. While 45 tropical countries consumed more than 100,000 t of wheat each year between 1981 and 1985, less than a fourth of these produced an equivalent amount. Most of this wheat is grown in the tropical areas of India, Sudan, Yemen Democratic Republic, the Andean Region, and Eastern and Southern Africa at higher elevations. The area contributes less than 2 percent to developing world production. More than 85 percent of the 22 million t of wheat consumed in the tropical zone each year must be imported. This dependence on foreign suppliers, chiefly industrialized nations, places a heavy burden on the already fragile economies of the tropical countries leaving them vulnerable to external political pressures.

3. This situation prompted a number of countries to look for ways to increase domestic production. Cameroon, the Dominican Republic, Paraguay, Thailand, the Philippines, Indonesia and Madagascar are just some of the countries which initiated or stepped up wheat production programmes. In other developing nations, situated adjacent to or within tropical areas where wheat is commonly grown at higher latitudes and/or elevations (i.e. Brazil, Bangladesh, Ethiopia, Nigeria, Somalia), production increases are being sought by exploiting land in the lower-lying, warmer areas. The technology needed to increase production in the tropics involves the development of germplasm and crop management practices suited to the wheat growing season which is the coolest period of the year. Research focusing on wheat for the warmer, marginal areas provides a potential solution to the precarious circumstances faced by developing countries dependent on imports.

B. CIMMYT

4. To increase their capacity to produce wheat, many of these countries turned to the International Maize and Wheat Improvement Centre (CIMMYT), renowned for its success in dramatically increasing wheat production throughout much of the developing world. In the early 1960s, plant breeders working in CIMMYT’s host country, Mexico, developed the first high-yielding dwarf varieties. These were transferred to spring wheat fields worldwide resulting in a fourfold increase in production in India and Pakistan. Improved crop management practices, similarly helped Turkey achieve self-sufficiency. More recently, the Center has been

\[1\] The Spanish language acronym for Centro Internacional de Mejoramiento de Maiz y Trigo.
extending its research into nontraditional areas with continued success. In Bangladesh, a most notable example, wheat production increased from 218,000 t in 1976 to almost 1.5 million t in 1985 through the introduction of high-yielding, early-maturing and heat tolerant varieties. Today, CIMMYT germplasm is grown on more than half of the 88 million hectares (ha) planted to bread wheat in the developing world.

5. The Centre was established in 1943 under an agreement between the Mexican Ministry of Agriculture and the Rockefeller Foundation for the purpose of improving Mexican agriculture. In 1966, the Centre became known as CIMMYT and began international operations as a civil association under Mexican law.

6. CIMMYT is one of the 13 international agricultural research centers (IARCs) belonging to the Consultative Group on International Agricultural Research (CGIAR) established in 1971 under the sponsorship of the World Bank (IBRD), the Food and Agriculture Organization (FAO) of the United Nations, and UNDP. The CGIAR receives contributions from its original sponsors, the Ford and Rockefeller Foundations, more than 40 governments, private organizations and regional development banks. It, in turn, provides support to its member organizations - each of which is mandated to study particular commodities, farming systems or ecological zones. Within this network of research institutes devoted to the improvement of agriculture in the developing world, CIMMYT is charged with the responsibility for conducting research and training, and providing assistance to national programmes in the production of wheat, maize, and triticale.

7. CIMMYT pursues its goal of improving small grain cereal production in the following ways:

- Breeding germplasm suited to the various ecological conditions (mega-environments) encountered in developing countries focussing on increasing yield potential, improving nutritional and industrial quality, and building up resistance to diseases, insects and environmental stresses;
- Developing crop management techniques to maximize the productivity of newly developed germplasm;
- Conducting studies to identify social, cultural and economic factors that condition farmers' acceptance of improved seed and production practices, and to design appropriate farming systems technology;
- Building up national programmes through collaborative research activities, and by providing training in Mexico and in developing countries to promising agricultural technicians and scientists; and
- Conducting workshops and seminars, and publishing materials to exchange information with developing-country scientists, technicians, and extension specialists.

C. THE ROLE OF UNDP

8. UNDP substantially strengthened the capacity of IARCs to conduct innovative research aimed at tackling the more difficult agricultural development problems, particularly those which
national programmes are unable to resolve themselves. The Governing Council's concern with the application of basic and applied research for social and economic development led to its decision, in 1969, to support the work of research institutions worldwide in implementing new technologies. Moreover, the Council authorized the Administrator to waive counterpart contributions from governments requesting assistance on such projects. These actions paved the way for UNDP's direct involvement in agricultural research. Since funding its first project in 1970, Global One, to improve the protein quality of maize, UNDP, through its Division for Global and Interregional Projects (DGIP), generated support for its research initiatives from various donors in excess of 17 times the original contribution. This backing enables the international scientific community to work together in seeking solutions to age-old agronomic and animal husbandry problems, and to disseminate new technologies over a wide spectrum of developing countries.

D. PREPARATORY ASSISTANCE

9. UNDP responded to CIMMYT's request for financing research on the development of wheats for warmer, marginal areas with a 12-month preparatory assistance grant beginning in July 1981 in the amount of $125,000. The objectives of this preparatory phase were to:

- Identify and assemble the presently available germplasm of wheat and related species possessing agronomic characteristics desirable for marginal tropical areas;
- Begin intensive screening of this material for the desired traits;
- Establish special segregating populations to facilitate this screening; and
- Disseminate advanced generation materials with special traits adapted to warmer environments.

10. Each of these objectives were met. Preliminary intensive screening of CIMMYT germplasm resulted in the identification of approximately 210 lines possessing some resistance to Helminthosporium sativum (spot blotch). In addition, lines with observed resistance to Fusarium graminearum (scab) were obtained from China and Brazil in 1981. These lines were crossed with the best Mexican wheats to combine scab resistance into better agronomic types. CIMMYT also created artificial scab epidemics on bread wheat, durum wheat and triticale. Based on this work, CIMMYT identified approximately 60 bread wheat lines and 30 triticale lines showing some degree of resistance to scab. These 90 lines were sent to China and Brazil for additional testing to establish correlations of resistance across the three areas.

E. PROJECT OBJECTIVES AND COMPONENTS

11. In July 1982, UNDP continued to support CIMMYT's research with a grant of $2,500,000 for a period of five years. The overall goal of Research on Tropical Wheat Improvement (GLO/82/007) was to develop high-yielding, semi-dwarf wheats that would perform well in the warmer areas of the world. It should be stressed that these areas are not the very hot, humid tropics, but rather tropical areas which have a sufficiently cool growing season to successfully produce wheat where currently no crops are grown. As such, the project's aim was to promote wheat as a supplementary crop rather than a substitute for traditional crops.

12. The warmer areas are classified into two mega-environments with separate breeding objectives established for each (Appendix A, Table 1). These are:
• Mega-environment A - warmer, dry areas such as the Sudan, Northern Thailand and Nigeria where irrigation is commonly practiced and the only major disease problem is *Puccinia recondita* (leaf rust); and

• Mega-environment B - warmer, humid areas such as the Philippines, Brazil, Paraguay, Bangladesh and Zambia where wheat is mostly rainfed and the high humidity causes numerous diseases which include spot blotch and scab.

13. All of the wheats bred for these warmer areas require heat tolerance and good agronomic characteristics (e.g. lodging resistance). The warmer, humid environments also require germplasm resistant to diseases which are not commonly found in traditional areas. Within these mega-environments, however, the variations in soils, cropping systems, climate, moisture availability, latitude and level of mechanization call for the selection of germplasm with specific characteristics. For example, in some rainfed areas where moisture availability is low, tolerance to drought must be incorporated into germplasm. Where acid soils pose a constraint to wheat production, breeding for tolerance to aluminum toxicity is needed. Early-maturing varieties also may be required to fit into certain crop rotation schemes or to avoid excessively high temperatures and drought conditions encountered during the early and/or latter periods of the growing season.

14. To improve wheat production in the warmer mega-environments, CIMMYT breeders focussed on developing germplasm with the following characteristics:

- Good agronomic traits for high yield;
- Tolerance to abiotic stresses such as drought, heat and aluminum toxicity; and
- Resistance to biotic stresses such as spot blotch, scab, and leaf rust.

Sources of genetic variability, and availability of screening methods are presented in Appendix A, Table 2.

15. This breeding effort required a coordinated approach among the CIMMYT base and outreach programmes, and national cooperators. During the first phase of the project, the work was carried out at CIMMYT’s Mexican research stations and in Southeast Asia, sub-Saharan Africa, and South America. A breeder and agronomist were posted to each region with UNDP funds supporting the work of the breeders in Southeast Asia and South America. CIMMYT core funds were used for agronomic research in the three regions and for breeding activities in Mexico and sub-Saharan Africa. Specific project activities included:

- Identifying germplasm with characteristics suited to warmer, marginal areas;
- Making crosses and advancing segregating generations at CIMMYT’s Mexican research stations;
- Cooperating with advanced national programmes through shuttle breeding projects to improve germplasm for specific characters;
- Distributing segregating materials and screening nurseries containing advanced lines to national cooperators worldwide;
Evaluating the performance of project materials under target-country conditions, analysing the data and reporting the results to CIMMYT's base programme and to national cooperators;

Developing crop management practices to improve the productivity of germplasm;

Conducting in-service and in-country training programmes for qualified agricultural researchers from tropical countries;

Conducting workshops and conferences to exchange information and experiences with researchers and scientists concerned with wheat production for the warmer areas; and

Purchasing research equipment for use by national programmes.

While UNDP funds supported training activities, workshops and conferences, equipment purchases and much of the breeding component including shuttle breeding, approximately 10 percent of CIMMYT's wheat programme core budget supplemented the remaining activities. CIMMYT's substantial contribution to the project reflects the view that research on wheats for the warmer, nontraditional environments will have spin-off benefits for ongoing germplasm improvement work in traditional areas. For example, leaf rust, scab, drought, heat and soil toxicities are constraints common to wheat production in both warmer and traditional areas as are many of the problems associated with rice-wheat rotations. Since such environmental pressures are more severe in the warmer areas, it is expected that the technology issuing from the research conducted in these previously unexplored high stress environments may be applied with greater success in regions where similar stress conditions are less severe.

II. PROGRESS OF GERmplASM DEVELOPMENT

A. SHUTTLE BREEDING AND INTERNATIONAL TESTING

CIMMYT's past achievements in germplasm development can largely be attributed to the shuttle breeding approach. As the name suggests, shuttle breeding involves making a cross and selecting subsequent segregating (heterozygous) generations at different locations (often in different countries) each season until the characters stabilize and a pure (homozygous) line is developed. The process takes approximately 6 to 8 generations after a cross is made. Each generation is screened under artificial or natural stress conditions. The best materials are selected, based on agronomic performance and tolerance to stresses. From these, the next generations are planted and similarly screened at other locations and under different conditions. As the germplasm is advanced through repeated screening and selection at various latitudes, altitudes and environmental pressures, widely adapted lines with resistance to diseases, tolerance to abiotic stresses, and high yield potential are developed.

Shuttle breeding and testing within Mexico is done at nine test sites. During the summer, the progeny of crosses are screened for resistance to stripe rust and leaf rust, Septoria tritici (leaf blotch), scab, Barley Yellow Dwarf Virus (BYDV) and bacterial infections in Toluca and Tepatitlan; leaf rust and stem rust resistance in El Batan; drought tolerance in Huamantla; and resistance to leaf blotch in Patzcuaro. Plants that perform well under these conditions are selected and, during the winter cycle, the next generation is screened for heat and drought tolerance, and leaf rust and stem rust resistance at the low altitude, Yaqui Valley experiment station in Cd. Obregon. Other locations used during the winter cycle are: Poza Rica (spot...
blotch resistance and heat tolerance); Los Mochis (leaf rust resistance and heat tolerance); and Rio Bravo (leaf rust resistance). Two crop cycles per year reduce by one half the time needed to develop an advanced line from 6-8 years to 3-4 years. Moreover, the differences in latitude (especially in lower latitudes) among the research stations automatically ensure selection for daylength insensitivity – a key characteristic for widely adapted germplasm.

19. Germplasm for warmer areas is screened in Mexico under the appropriate stress conditions. For stresses and diseases not common in Mexico, environments outside of the country are used. A shuttle breeding programme was established between Mexico and Brazil to develop germplasm tolerant to aluminum toxicity, and resistant to spot blotch and other leaf spotting diseases. Germplasm was shuttled between Mexico and China to improve materials for resistance to scab. Partnerships were established with Paraguay and Nepal to breed lines for heat tolerance and spot blotch resistance. In addition, a cooperative programme to develop germplasm for drought conditions is currently being negotiated with Argentina.

20. To identify parental material with genetic characteristics suited to the warmer areas, lines and varieties were assembled into separate screening nurseries (i.e. Helminthosporium, scab, heat, drought and aluminum) and evaluated on the basis of a single trait. Between 1982 and 1987, 1000 sets of various nurseries were sent to 50 tropical countries (Appendix B, Table 1). More than 2000 lines were tested during the project period. Once the performance of individual traits was evaluated in international trials, outstanding lines were crossed to combine characters and improve disease resistance and stress tolerance. The segregating populations were advanced in Mexico and in cooperating countries. The F2 and F4 materials also were distributed to 38 tropical countries for local selection (Appendix B, Table 2).

21. In 1987, the initiation of the Warmer Areas Wheat Screening Nursery (WAWSN), which contained 143 lines with resistance to spot blotch, rust and scab, tolerance to heat, and high yields, marked the beginning of testing germplasm for multiple traits. The advanced lines emerging from crosses and those identified as having several characteristics suited to warmer areas were entered into the WAWSN and distributed to 48 locations in 25 countries in Africa, Asia and Latin America.

22. The Drought Screening Nursery (DSN), which meets the needs of all drought stressed areas as well as those in the warm and dry mega-environment, was sent to 38 countries in the tropics. Lines included in the DSN combine drought tolerance, leaf rust resistance, and yield performance.

23. Two regional nurseries – the Hot Climate Wheat Screening Nursery (HCWSN), assembled in Thailand, and the Southern Cone Screening Nursery (LACOS) – were distributed to target areas in the tropics and subtropics. The HCWSN, primarily made up of wheat germplasm indigenous to Asia, was initiated in 1984 as a cooperative effort to exchange locally developed varieties among the region's national agricultural research systems (NARSs). In 1986, the HCWSN was released for testing in Africa and Latin America. LACOS was initially assembled in Chile, but now is assembled in Paraguay and distributed to all cooperators in Latin America.

\[^2\text{F refers to filial generation. Thus, F2 and F4 indicate the second and fourth filial generations respectively.}\]
\[^3\text{The Spanish language acronym for Vivero de Lineas Avanzadas de Cono Sur.}\]
24. In countries where acid soils pose an added constraint to wheat production, the Acid Soil Tolerance Screening Nursery (ASTSN) provides national cooperators with germplasm which incorporates aluminum tolerance, rust resistance, improved phosphorus uptake efficiency, and better agronomic type. Some of the lines entering the ASTSN also possess tolerance to heat and drought, and resistance to spot blotch and scab. This nursery grew out of the Aluminum Screening Nursery (ALSN) which was the product of a 13-year joint breeding programme with Brazil to improve the yield potential of aluminum tolerant varieties. In 1987, as the availability of lines possessing multiple traits suited to acid soil conditions increased, the ALSN was renamed the ASTSN to more accurately reflect the agricultural environment it serves.

B. YIELD AND ADAPTABILITY

25. Most of CIMMYT’s germplasm contains the Rht1 and/or Rht2 dwarfing genes which reduce plant height and increase tillering capacity. When first exploited by the breeding programme, these genes resulted in the development of the high yielding varieties (HYVs) which sparked the “green revolution” in the late 1960s. Another milestone in yield potential was reached in the early 1980s as a result of a cross, made in 1973, which combined a winter wheat, Kavkaz, from the USSR with spring wheats originating from Mexico and India. The subsequent change in genetic composition boosted the yield potential of the selected progeny by 10 percent over that of other widely adapted HYVs. Veery ‘S’, the name given to these lines by CIMMYT breeders, rapidly gained acceptance in diverse production environments. Since 1981, 13 developing countries, including 5 in tropical climates, released Veery sister lines. The Veerys currently are grown on over 4 million ha in the developing world.

26. The popularity of CIMMYT’s germplasm stems from breeding for wide adaptation. Wide adaptation represents high and stable yield response across locations and years within a given mega-environment, and is a function of resistance to biotic and abiotic stresses. Spacial and temporal stability can only be achieved if a cultivar is sufficiently resistant to the diseases, and tolerant to the abiotic stresses it encounters over a range of locations and growing seasons. Moreover, good phenotypical traits (i.e. strong and stiff straw, shorter plant type, larger grain size) must be present to ensure high yields when conditions permit.

27. Varieties and lines are annually evaluated for yield potential, adaptation and specific traits through the International Spring Wheat Yield Nursery (ISWYN) and the Elite Selection Wheat Yield Trial (ESWYT). The ESWYT’s and ISWYN’s serve the same purpose, however, the ESWYT’s primarily contain CIMMYT germplasm while the ISWYN’s also include cultivars originating from national programmes. Yield trials differ from screening nurseries in that they provide a more accurate measure of yield potential. Experimental design to measure yield involves replicating plots as compared to screening nurseries which are single plot trials.

28. Many of CIMMYT’s lines are performing well in the warmer areas. In the twenty-second ISWYN (1985-86), one of these, Ciano 79, proved to be widely adapted to the warmer areas which include Burma, Indonesia, Thailand, Bolivia, Brazil and Sudan. This line showed slightly higher yields (2187 kg/ha) than the local checks (2172 kg/ha) across all locations. Genaro 81

4The short arm of the 1B chromosome in bread wheat was replaced by that of the 1R chromosome of rye.
(2689 kg/ha) and OCEPAR 8 (2816 kg/ha), a Brazilian/CIMMYT cultivar, were widely adapted to the drought afflicted areas yielding higher than the local checks (2674 kg/ha). Genaro 81 also exhibited greater resistance to lodging than the local lines. On a site-by-site basis, the number of lines out of the 50 tested which exceeded the yields of local varieties in selected tropical countries were: 26 in Bangladesh; 24 in Burma; 23 in Malawi; 21 in Thailand; 11 in Bolivia; 8 in Nigeria; 7 in Sudan; and 3 in Indonesia. A list of the highest yielding lines as a percent of the local checks is provided in Appendix B, Table 3.

29. The yield performance of the lines included in the seventh ESWYT, distributed in 1985-86, equalled or exceeded the yield of the local checks by up to 285 percent in selected tropical countries (Appendix B, Table 4). In trials conducted in Bolivia, Brazil, Burma, Costa Rica, Nigeria, Sudan, Tanzania and Thailand, between 8 and 22 out of 30 lines developed by CIMMYT yielded more than the local checks. The average of the highest yielding line (Her/Sap'S'/Vee=TUI'S')⁵ across all tropical locations was 0.5 t/ha higher than the average yield of the local checks. Six of these lines also showed a high level of resistance to rust diseases.

30. The foregoing results illustrate the performance of the widely adapted HYVs in warmer climates. To further improve the germplasm for the marginal areas of the tropics and subtropics, genes from stress tolerant and disease resistant lines are introduced into the HYVs while high yield potential, wide adaptability and good agronomic traits are maintained.

C. HEAT TOLERANCE

31. Heat stress reduces yield potential by accelerating the development process thereby impeding a plant's ability to assimilate an adequate amount of growth resources as it speeds through its life cycle. If the supply of water, nutrients and radiation is not proportional to the rate of growth, the phenotypical traits which determine yield potential are stunted. Plants flower early and display fewer spikes and grains with smaller, shriveled kernels and premature leaf senescence leading to a reduction in head fertility, and grain and test weight. Heat stress is particularly damaging during germination, at the end of tillering, and after flowering. The fate of wheat production in both the dry and humid tropics hinges, to a great extent, on sufficiently minimizing the consequences of thermal stress.

32. Supplying the required inputs at critical growth stages is one way of curtailing the effects of heat on yields, and crop management research can play a key role in this regard. Logic, however, would obviate a technology that relied on costly inputs alone to enhance production. The need for inputs is reduced by exploiting the vast pool of genetic resources which, over time, has proved to be a sound means of achieving and sustaining gains in crop productivity.

33. Heat tolerance is heritable. In the hot tropical climates of India, a number of varieties originating from CIMMYT's nurseries (i.e. Kalyansona, Sonalika) are reportedly showing normal plant development with a yield potential comparable to those in other parts of the country. For many decades crop researchers have been developing heat tolerant wheat varieties without

⁵A code used by CIMMYT breeders to indicate the pedigree and the crossing method used. Advanced lines deemed to be high performers are later identified by a name. CIMMYT's current bread wheat nomenclature employs names of land birds only. Varietal names are given to CIMMYT lines by national programmes upon release in their respective countries. Hence, a single line may be known by many names.
fully understanding the complex physiologic relationships and the interaction between environment and genotype. In recent years, however, interest in stress tolerance physiology and genetics has been gaining momentum. Information generated from research is leading toward greater efficiencies in plant selection for heat tolerance. Nonetheless, the breadth of knowledge remains narrow. There are no simple screening methods, and combining genes for heat tolerance and high yields is a complex undertaking necessitating numerous crosses and years of multilocalational testing.

34. With the aid of UNDP, CIMMYT’s wheat programme has been able to target heat tolerance as a breeding objective, and systematically mobilize the independent activities of national cooperators worldwide into an efficient, collective effort to hasten progress. Beginning with its own germplasm collection and that gathered over the years from national programmes, CIMMYT selected known heat tolerant varieties, placed these into a specialized screening nursery, and sent them to hot spots around the globe for evaluation. In collaboration with breeding programmes in Paraguay, Nepal and Thailand, CIMMYT identified heat tolerant material to cross with the HYVs emerging from the stress and disease screening nurseries to develop germplasm for the dry and humid mega-environments. In addition, the establishment of regional posts in the tropical climates enabled close coordination with national programmes. The new focus on wheat breeding for warmer climates was the chief reason for moving the regional staff in South America from Chile to Paraguay.

35. Proximity to the warmer areas imparted a greater understanding of agroecological conditions. Drawing on this information and that of previous stress tolerance research, CIMMYT designed methodologies for heat tolerance breeding. Since heat tolerance is required in germplasm for all warmer conditions, a number of approaches were adopted. In the Yaqui Valley experiment station in Mexico, representative of irrigated desert conditions, heat screening is done in conjunction with drought tolerance and rust resistance. The Poza Rica research station, a humid tropical location, serves as the heat and spot blotch screening site. Trials in Southeast Asia are conducted on bunded land where heat stress occurs in early growth, and on irrigated paddy land for late heat tolerance during the grain filling stage. The hot spots in South America are Santa Cruz, Bolivia; Palotina, Brazil; Volendam/Caacupe, Paraguay; and, at higher altitudes during the summer, the mesothermic valleys of Bolivia and Cordillerita region of Paraguay. In these areas, screening for heat and drought tolerance is done simultaneously. Selection is based on phenotypical traits and yield. The criteria used to identify heat tolerant plants under each of the above conditions are listed in Appendix B, Table 5.

36. Annual distribution of the Heat Tolerance Screening Nursery (HTSN) began in 1983. More than 300 lines were sent to 37 locations. Widely adapted lines are those most frequently selected for further testing in a given year by cooperators at different locations. In the third HTSN (1985-86), 22 lines were selected for further evaluation by one-fourth to one-half of the cooperators from the 28 locations reporting results. The average yields of these lines over 9 of the heat stressed sites of the tropics ranged from 1545 kg/ha to 3159 kg/ha (Appendix B, Table 6). Moreover, 4 of these were among the 8 highest performing lines selected for a second time in 1986-87 in the hot spots of South America indicating temporal as well as spacial stability.

37. In addition to the selections made from the HTSN, the lines from the specialized screen-
ing nurseries and yield trials, which were selected by cooperators in hot climates, necessarily possess some tolerance to heat.

D. DROUGHT TOLERANCE

38. The winter season in the tropics is primarily drought stressed. As the summer rains subside, traditional crops such as rice, maize, cotton and soybean are harvested leaving the land fallow during the dry winters. The wheat plant's ability to use water efficiently is precisely what makes it a viable off-season crop for some of these marginal areas where low moisture availability precludes a second growing season. Despite its comparatively moisture efficient constitution, wheat is, nevertheless, affected by drought – a wide-spread condition that limits wheat production on over 15 million ha of the developing world's bread wheat fields including major areas in Turkey, India, China, Argentina, North Africa and the Middle East. Drought not only affects the semi-arid regions and tropical environments, but is a common occurrence in traditional wheat-growing climates.

39. Over the years, a number of CIMMYT's widely adapted lines performed well in the dry mega-environment. In the low-yielding, disease-free drought locations of the fourth (1967-68) and sixth (1969-70) ISWYNs, the yields of two varieties, Siete Cerros 66 and Inia 66, averaged 30 percent more than the mean yield of the 50 entries included in the trials. When compared to the traditional, tall cultivars bred for specific adaptation to drought conditions in India, Pakistan and Australia, Siete Cerros 66 had higher yields in most locations indicating greater stability and wider adaptation. Siete Cerros 66 performs well in the hot and dry mega-environment. The variety has gained acceptance in the tropical countries of West Africa (i.e. Nigeria, Mali, Niger, Chad, Senegal and Burkina Faso) where the winters are typified by high temperatures and low rainfall.

40. In the 1970s, the bread wheat programme produced another group of lines adapted to drought conditions. Two of these, Jupateco 73 and Pavon 76, yielded from 5 to 45 percent more than Siete Cerros 66 in the drought stressed locations of the tenth (1973-74) and thirteenth (1976-77) ISWYNs. Between 1973 and 1983, these lines were released for use in the low moisture areas of Mexico, Algeria, Peru, Bolivia, Brazil, Chile, Pakistan and Australia.

41. Improvements continued into the 1980s with the release of the Veery 'S' lines which inherited the superior drought and heat tolerance, and foliar disease resistance of their winter wheat parent, and the high yield potential, broad adaptation, strong straw, and rust resistance of their spring wheat parentage. One of these, Seri 82, performed as well as or better than Siete Cerros 66 in 19 out of 20 low-yielding drought sites, and better than Pavon 76 in high-yielding locations (20th ISWYN - 1983-84). This demonstrates a higher level of input efficiency (ability to maximize use of available nutrients and moisture) relative to Siete Cerros 66, and greater input responsiveness (ability to increase yields relative to increases in moisture and nutrients) compared to Pavon 76. In the twenty-second ISWYN, the top yielding Veery 'S' lines were judged among the highest in terms of input responsiveness.

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At the start of the UNDP project, CIMMYT innovated a breeding methodology to increase the yield potential of drought tolerant lines. The objective is to develop germplasm which is input efficient and input responsive - essential traits for the dry mega-environment. Traditional, tall cultivars indigenous to the dry areas are crossed with the bread wheat programme's best high yielding lines. By alternating the segregating generations from irrigated to reduced water environments, lines can be selected on the basis of yield performance under optimum and low moisture conditions.

The first 52 lines were developed, using this methodology. Several years of international testing will be needed to evaluate their performance.

Promising drought tolerant lines for use as parental material in crosses or for direct release by national programmes were identified each year through the DSN. Twenty-seven of the 41 cooperators receiving the fourth DSN (1985-86) identified 12 lines for further evaluation. Across all 41 locations, these lines yielded from 2140 kg/ha to 2996 kg/ha (Appendix B, Table 7). In addition to these, the regional tropical programme in South America selected 37 lines for a second year for their outstanding tolerance to the dry and hot conditions of Chaco, Paraguay where drought stress is most severe during the latter stages of plant development. The lines will be tested for a third time in Chaco, Paraguay; Santa Cruze, Bolivia; and Marcos Juarez, Argentina.

**E. ALUMINUM TOLERANCE**

Acid soils, which contain toxic levels of aluminum and manganese, are deficient in essential nutrients, and have low levels of pH and fertility, severely limit wheat production. The major limiting factor is the presence of aluminum which inhibits root growth by preventing cell division. Plants are unable to make use of the available soil nutrients and moisture. The problem merits serious attention as approximately 1 billion ha in the tropics and subtropics are acidic.

Brazilian wheat researchers have been working with CIMMYT to improve aluminum tolerant wheat varieties for Brazil where approximately 70 percent of the land under wheat cultivation is acidic. CIMMYT's high yielding, semidwarf wheats were crossed with Brazil's aluminum tolerant lines. The progeny were alternately screened in Brazil for tolerance to acid soils and resistance to local diseases, and in Mexico for good agronomic performance and resistance to rust. Laboratory screening procedures were also used to identify aluminum resistant seedlings.

The shuttle breeding programme resulted in significant achievements in germplasm development for acid soil conditions. From 1984 to 1987, 10 cultivars possessing an acceptable level of aluminum, heat and drought tolerance, greater phosphorus uptake efficiency, and resistance to spot blotch, scab, powdery mildew, and rust, were recommended for commercial production in Brazil (Appendix B, Table 8). These varieties, which yield at least 25 percent more than traditional Brazilian wheats in acid soils, and have a yield potential of 6-7 t/ha under optimum conditions at the Yaqui Valley experiment station, contributed to the nation's rapid production increases. Between 1981 and 1986, Brazil nearly doubled its production from 2.6 million metric tons (mmt) to 5.4 mmt through the use of improved varieties and crop management practices,
and an area expansion in wheat production of close to 1 million ha. Average yields rose by 66 percent to 1.4 t/ha.⁷

48. Building upon the achievements of the past and the strength of the cooperative relationship with Brazil, CIMMYT expanded the utility of the high yielding, aluminum tolerant lines into the warm mega-environments. Countries with acid soils such as Madagascar, Zambia, Rwanda, Cameroon and Ecuador are benefitting from the germplasm. Between 1982 and 1986, 208 ALSNs were distributed to 10 Asian, 12 African and 12 Latin American countries. In 1987, the multi-trait germplasm included in the new ASTSN was received by 20 tropical countries. In the last ALSN (1985-86), 24 out of 65 lines showed a high level of tolerance to aluminum. Mean yields across 11 sites ranged from 2379 kg/ha to 3291 kg/ha (Appendix B, Table 9).

49. Because of the earlier work to incorporate disease resistance into Brazilian germplasm, many lines were readily available for testing and use in warm and humid acid soil areas worldwide at the start of the project. Much of the scab and spot blotch resistant germplasm used in the project originated from Brazil. Ten of the 19 top performing scab resistant lines listed in Appendix B, Table 11, and 4 of the 25 spot blotch resistant lines in Appendix B, Table 10 are derived from Brazilian/CIMMYT crosses.

F. SPOT BLOTCH RESISTANCE

50. The warm, humid mega-environment poses the greatest challenge to wheat production. In addition to heat tolerance and high yield potential, germplasm must possess resistance to the endemic diseases. The rice-wheat rotations further demand early to medium maturing varieties which are tolerant to waterlogging and resistant to lodging. Combining all of the required traits into one genotype is a complex task largely due to the prevalence of diseases. The most pernicious of these is spot blotch caused by the facultative pathogen, Helminthosporium sativum.

51. *H. sativum* favours warm, humid climates attacking wheat at various stages of development. Black point develops on infected seeds, lesions appear on seedlings, leaves display symptoms of spotting, roots and crowns rot, and grains shrivel. Yield losses are absolute if the pathogen permeates the roots and crowns before or during seed formation. Another species, *H. tritici repentis*, was found chiefly in cooler traditional climates and, thus, was not a focus of disease resistance breeding for the warmer areas.

52. The many races of *H. sativum* make it difficult to develop materials that are resistant over a range of locations. To further complicate breeding efforts, resistance to the pathogen is governed by minor genes. This slows the process of accumulating sufficient resistance. Moreover, *H. sativum* has a wide range of hosts such as rice, which intensifies disease pressure in crop rotations, and is capable of surviving as a saprophyte on dead plant tissue and in soil debris.

53. Breeding for spot blotch resistance is a new area of investigation which began at CIMMYT in 1981. An interdiciplinary team of breeders, pathologists and agronomists work together to control the disease’s effects on wheat. Laboratory and greenhouse techniques were established

to identify resistant grains and seedlings, and to develop inoculum for artificial epidemics. During the project period, approximately 480 lines with some resistance were identified and tested in Poza Rica, Mexico and internationally through the Helminthosporium Resistance Screening Nursery (HRSN). The most resistant materials were found in Brazil and the Yangtze River Basin of China. The best of these were combined with HYVs and other materials to enhance yield potential and resistance. In 1985, 15 lines were developed showing good agronomic characteristics and substantial resistance to spot blotch. Another 24 resistant and moderately resistant varieties and lines were identified in 1986 (Appendix B, Table 10). With the use of fungicides, such as propiconazole and fentinacetate-maneb, these lines were found to be sufficiently free of the disease.

A number of resistant materials were released in Brazil, Bolivia and Zambia. In Zambia, where acid soils are an additional constraint, the more recently developed Brazilian/CIMMYT lines crossed with local materials yielded up to 3.2 t/ha in national trials compared to the local variety which yielded 1.8 t/ha. Two CIMMYT lines, Bobwhite'S' and Kyz/K4500 L.A.4, are reportedly showing resistance to spot blotch in the high stress area of Santa Cruz, Bolivia.

The wide crosses programme made substantial gains in combining spot blotch resistant genes from alien grass species, belonging to the genera Agropyron, Aegilops, Elymus and Hynaldia, with wheat. By 1985, the programme produced 10 resistant lines. More recently, interspecific crosses with T. turgidum and T. tauschii resulted in the development of 4 resistant synthetics. The materials, which are low yielding, will be combined with HYVs in the bread wheat programme. About five years will be needed to produce advanced lines.

In 1987, with a special grant from the Federal Republic of Germany (FRG), CIMMYT signed a cooperative agreement with the University of Gettingen in the FRG, the University of Tel Aviv in Israel, and the Instituto Agronomico do Parana (IAPAR) in Brazil to carry out basic and strategic research on spot blotch epidemiology, genetics of resistance, and race analysis and selection through toxins. The project was initiated to supplement the research funded by UNDP.

G. SCAB RESISTANCE

Unlike H. sativum, Fusarium graminearum thrives in a wide range of production environments causing scab disease in humid tropical, subtropical and temperate climates. As a saprophyte, it survives on dead plant tissue surfacing on crops which grow under persistently cloudy and rainy conditions. Shrivelled kernels and floret abortion are the main symptoms of the pathogens presence. Beyond the damage it causes to crops, F. graminearum produces mycotoxins which are poisonous to humans and animals.

The highest incidence of the disease is found in China, Brazil, Paraguay, Bolivia, Uruguay, Argentina, Zambia, Ethiopia, South Korea, Japan, the United States of America and Canada. A 1985 scab epidemic in Argentina caused crop production to plummet by 30 percent. In China, 6.7 million ha are regularly plagued by the disease. Losses of up to 40 percent were...
59. International testing to identify resistant materials began in 1982. Most of the lines resistant to scab in Mexico succumbed to the disease under severe epidemics in China. Those which performed well were entered into the Scab Resistance Screening Nursery (SRSN) along with germplasm collected from China and Brazil. From 1984 to 1987, 20 tropical countries evaluated the lines. During the 1985-86 growing season, 19 of the 53 varieties and lines included in the SRSN showed high to moderate resistance over 11 locations reporting results. Eleven of these lines were also resistant to leaf rust (Appendix B, Table 11).

60. Each year the top performing lines from the SRSN were crossed with HYVs and other resistant materials, and the progeny advanced in Mexico and China. Nineteen countries in the warmer areas also received the F2 and F4 segregating populations for local selection and use in their breeding programmes. In the 1988-89 growing season, the advanced lines of the initial Chinese/Mexican crosses will be sent to China for evaluation. International testing will begin the following year. In 1987, the high stress areas of South America were included as screening sites for the segregating generations of the more recent Chinese/Mexican crosses.

H. LEAF RUST RESISTANCE

61. Rust diseases, detected by the characteristic orange-red to dark brown pustules forming on the above-ground portions of plants infected by the *Puccinia* species, have long been the target of resistance breeding. The rusts are found in nearly all production environments as are the many sources of genetic resistance to the diseases. The lack of a pandemic rust outbreak since the introduction of the semi-dwarf varieties in the late 1960s attests to the successful incorporation of genetic resistance into CIMMYT’s widely adapted HYVs. Despite these earlier gains, resistance to the rusts remains a central breeding objective due to mutation which causes resistance to break down.

62. Leaf rust, caused by *P. recondita*, is the most common form of the disease in the warmer areas. Stable resistance has been achieved by combining the non-specific resistance of the Lr13 gene complex found in the South American variety, Frontana, with additional sources of resistance taken from the Americas, North Africa, India, the Iberian Peninsula and the Middle East.

63. Monitoring the performance of germplasm is essential to maintain leaf rust resistance. All of CIMMYT’s screening nurseries and yield trials are evaluated for this characteristic. The results of international testing in 1985-86 indicated that nearly one-third of the lines tested were highly resistant to leaf rust. As new virulences are encountered, the abundance of genetic resources available for controlling the disease will ensure sustainability.

I. COMBINED TRAITS

64. Germplasm possessing multiple traits suited to the warmer areas has been developed and/or identified during the first phase of the project. Of the crosses included in the specialized screening nurseries during 1985-86, 7 were identified as top performers for two or more traits. In
South America, 10 lines showed superior performance for a range of characteristics (Appendix B, Table 12). In addition, the varieties listed in Appendix B, Table 8 possess multiple traits with varying levels of resistance to diseases and tolerance to abiotic stresses. Lines such as these are being evaluated in the 1987-88 season through the WAWSN, DSN and ASTSN. Future nursery entries will consist of the material which has been combined and is currently at various stages of development.

III. ASSISTANCE TO NATIONAL PROGRAMMES

65. As the pressure to reduce their dependence on wheat imports mounted, tropical countries increasingly turned to CIMMYT for assistance. For example, between 1967 and 1977, only 11 of the 357 participants attending CIMMYT's in-service wheat training courses came from tropical countries. During the subsequent 5-year period, this figure increased to 50 out of a total of 259.

66. In 1982, UNDP funding made it possible for CIMMYT to expand the services offered to tropical countries interested in producing wheat. In addition to training at headquarters, CIMMYT conducted in-country seminars, conferences and short-courses, provided consultancy services, and supplied national cooperators with germplasm and research equipment. Moreover, by decentralizing many of the project's activities through regional staff assignments and shuttle breeding arrangements cooperators played a key role in the process of generating new technology, and agricultural researchers working in nontraditional production environments gained valuable experience in cultivating wheat.

67. Diffusing the new technologies developed for warmer areas requires a cadre of national researchers skilled in the production of a nontraditional crop. CIMMYT's in-service wheat training includes courses on wheat production and improvement, cereal technology and experiment station management. During the project period, CIMMYT trained 271 developing-country researchers. Nearly a quarter of these came from tropical countries (Bhutan, Bolivia, Burma, Cameroon, the Dominican Republic, Chad, Guatemala, Indonesia, Madagascar, Mali, Nigeria, Paraguay, the Philippines, Senegal, Sudan, Tanzania, Thailand and Vietnam). The 52 trainees sponsored by UNDP are listed in Appendix C, Table 1. CIMMYT core funds and other sources of assistance were used to sponsor the remaining 219 trainees. UNDP also funded the visits of approximately 20 developing-country scientists to Mexico for periods of 2 to 4 weeks.

68. Women represented 10 percent of all wheat trainees for the period 1983 to 1987 as compared to 5 percent before 1983. The increase is largely due to the influx of women participants from the tropical countries of Southeast Asia. Eleven of the 26 women trained at CIMMYT headquarters during the project period were from Thailand (6), the Philippines (4) and Indonesia (1).

69. CIMMYT's regional staff conducted 9 short-courses in Thailand, Indonesia, the Philippines, Brazil and Paraguay. More than 150 breeders, agronomists, pathologists, field technicians, and station managers from university and government research institutes attended the 2- to 10-day courses. Subjects covered crop management research, disease scoring methodology, data collection and reporting, farm machinery operation and experiment station management (Appendix C, Table 2).
Conferences served as an important means of exchanging information on current developments in wheat research for the warmer, marginal environments. UNDP sponsored two international conferences – Wheats for More Tropical Environments (Mexico, 1984) and Wheat Production Constraints in Tropical Environments (Thailand, 1987) – which brought together scientists from 28 nations. Topics dealt with wheat production in selected tropical countries and in more traditional areas which share similar constraints; the current status of agronomic and breeding research on disease resistance and stress tolerance for rice-wheat rotations, acid soils, and rainfed and irrigated areas; a discussion of the progress achieved; future research needs; and socioeconomic considerations. The proceedings of the conferences were published and widely distributed. National cooperators, and bilateral and international donors sponsored an additional 22 conferences, workshops, seminars and professional meetings (Appendix C, Table 3).

IV. PROGRESS OF WHEAT PRODUCTION IN WARMER AREAS

Although sustainable wheat production systems in warmer climates have yet to be achieved, current technologies are already obtaining yields on the order of 3 t/ha. In some cases, as in the rice-wheat rotations of Southeast Asia, yields of up to 5 t/ha have been recorded under experimental conditions. This is encouraging wheat cultivation in nontraditional, warmer areas. Within the last 6 years, 57 countries produced wheat, either experimentally or commercially, in the tropical zone below 1500 masl – an area estimated to be between 3 and 5 million ha. Some of the cultivars recently released for commercial production in the warmer areas are listed by country in Appendix D, Table 1.

Despite the availability of technology and the growing efforts to improve germplasm and crop management practices for the marginal lands, the gap between wheat production and consumption is widening. Nearly 90 percent of the increase in consumption in the tropical zone over the past two decades was supplied by imports. Factors such as government policies (ie. bread subsidies, food aid, exchange rates) perpetuate this trend by providing wheat products at low consumer prices thus fueling demand and discouraging local competition. Domestic production is further hampered by the lack of adequate research, extension services, farm labour, machinery and inputs.

The escalating cost of wheat imports is, nonetheless, compelling many countries to find solutions to these economic, institutional and climatic constraints in order to increase their level of self-sufficiency. The following is an overview of recent developments in wheat production in some warmer areas. Supplementary data on area under cultivation, production, consumption, imports and self-sufficiency by country are provided in Appendix D, Tables 2 and 3.

A. SUB-SAHARAN AFRICA

African countries are cultivating wheat under a wide range of conditions – from the traditional highland production systems of East Africa to Somalia’s low altitude, very hot and humid areas. Sudan, Zimbabwe, Ethiopia, Kenya and Tanzania account for most of the roughly 1 million ha currently under production. This area, however, represents only a fraction of Africa’s productive potential. According to FAO agroclimatic assessments, approximately 38 million ha, mainly in the highlands, are suitable for wheat production. Since much of this area is dominated by crops such as barley, teff, potatoes, plantain, sorghum and cassava, countries in the region
are looking toward the lower-lying, marginal lands to provide their future needs.

Sub-Saharan Africa's largest wheat producer, Ethiopia, accounts for close to half of the region's output of almost 1.5 million t. Yet, with a 47 percent increase in consumption over a period of only 5 years, Ethiopia would have to produce nearly as much as the entire region in order to reach self-sufficiency. The nation's surge in demand is reflected in average annual imports which increased by 148 percent between 1979-81 and 1984-86. Currently, the amount of wheat imported (636,000 t/year) roughly equals the amount produced (683,000 t/year) as compared to 40 percent of domestic production between 1979 and 1981.

Three hundred kilometers east of Addis Ababa in a low altitude (700 masl), very hot and dry agroclimatic zone, researchers are investigating the potential of double cropping irrigated wheat with cotton. Three early-maturing, CIMMYT cultivars yielding 5.5 to 6 t/ha under experimental conditions were selected for planting on a 500 ha pilot production area. Sowing in late October is done to ensure grain filling during December/January when temperatures are lowest, thus, minimizing heat stress and, as a pest control measure, allowing for a 60-day vegetation-free fallow period preceding the cotton crop. Additional crop management practices include: a seed rate of 125 kg/ha; an application of 100 kg/ha of urea; 7 irrigations; and manual weeding. Weeds, and soil salinity due to poor drainage systems are the major constraints in this environment. If properly managed, the proposed 175,000 ha could expand Ethiopia's production area by 30 percent.

Zambia has long been interested in growing wheat under rainfed conditions as an alternative to its costly irrigated production systems. However, attempts to produce rainfed wheat in the nation's warm and humid areas during the late 1950s and, again, in the mid 1970s were thwarted by disease outbreaks and soil acidity. The disease resistant and acid soil tolerant lines needed in this marginal environment did not exist.

In 1979, with germplasm emanating from CIMMYT's shuttle breeding programme with Brazil, Zambian researchers, once again, began exploring the potential of producing rainfed wheat. Crosses made with local varieties resulted in the development of earlier maturing, higher yielding cultivars with acceptable levels of tolerance to aluminum toxicity and resistance to spot blotch, scab and leaf rust. Commercial production began in the 1983-84 growing season with the first varietal release for the humid areas, Whydah, yielding an average of 2.5 t/ha. Zambia now has an active rainfed wheat research programme which closely cooperates with CIMMYT. With its lines yielding up to 3 t/ha, Zambia is increasingly receiving requests for germplasm from neighboring countries which indicates a growing regional interest in warmer area, rainfed wheat production.

The potential now exists for Zambia to achieve self-sufficiency and, at the same time, economize on its domestic production. In order to accomplish this, however, the country would need to expand rainfed production over more than 50,000 ha. As the total area under wheat production currently stands at approximately 5,000 ha, Zambia still has far to go. While germplasm improvements for disease resistance, stress tolerance and agronomic traits continue, crop management research is dealing with the problems posed by acid soils which often demand high inputs of fertilizer and lime amendments.
B. SOUTHEAST ASIA

80. In Thailand, the Philippines, Indonesia, Sri Lanka and Vietnam, research is aimed at cultivating wheat during the dry season. Thailand, the host country for CIMMYT's regional staff, has the most active national wheat research programme. The Department of Agriculture's experiment stations at Fang, Samoeng and Chiang Rai, and Kasetsart University at Farm Suwan, Pak Chong are crossing lines of wheat and triticale selected from nurseries distributed by CIMMYT. In addition, Chiang Mai University uses CIMMYT's lines in experiment station and on-farm yield trials.

81. The two cropping systems most suitable for wheat production are:

- Rainfed areas where wheat is grown on residual moisture usually following maize in the uplands, and following rice in low to medium altitudes; and
- Irrigated lowland paddies after rice when irrigation water is insufficient to support a second rice crop.

82. Relative humidity and temperature are high throughout the crop cycle. Wheat, thus, requires early heat tolerance for better tillering and larger heads, late heat tolerance for delayed planting, drought tolerance, and resistance to spot blotch, scab and leaf rust. Varieties must be able to withstand lodging and waterlogging, and mature early to allow timely sowing of the rainy season crop.

83. Cultural practices are used to further reduce the effects of environmental stresses and diseases on yields. The objective in rainfed areas is to conserve soil moisture. The date of sowing, and rate and depth of seed placement are methods used to maximize the use of residual moisture. Techniques such as minimum or zero tillage and straw mulching reduce soil moisture evaporation. On heavy, lowland, irrigated soils, waterlogging is controlled by preparing wider seed beds, and monitoring the frequency and timing of irrigations. Agronomic methods of controlling diseases include restricting the use of nitrogen to avoid excessive vegetative growth, and wider row spacing.

84. The use of improved varieties and crop management practices are resulting in substantial gains in yield potential. In 1967, Thailand produced 300 t of wheat on 911 ha. By 1983, 150 ha yielded 150 t of wheat. Currently, Thailand has the potential of producing an average of 3 t/ha.

C. SOUTH AMERICA

85. The ability to overcome environmental limitations and achieve self-sufficiency in wheat production was most dramatically demonstrated by Paraguay in 1986.

86. Located in a warm and humid climate, where diseases pose the main threat to wheat, Paraguay was wholly dependent on imports. In 1967, in an attempt to reduce dependence on foreign suppliers, the government initiated the national wheat programme which, in its first

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9Thailand and the CG Centers. Study Paper Number 16, CGIAR.
year, produced 9,100 t of wheat on 8,300 ha. Within 4 years, area expanded to 51,500 ha and production grew to 54,800 t. In 1972, however, a severe disease epidemic destroyed 70 percent of the crop. Though Paraguay began receiving germplasm from CIMMYT the following year, the lines were not sufficiently resistant to diseases, and during the subsequent 8 years yields averaged only 925 kg/ha.

87. During the 1970s and early 1980s, efforts to improve production continued. In 1978, Paraguay joined with Argentina, Brazil, Uruguay, Chile and Bolivia to form the Southern Cone Cooperative Agricultural Research Programme (PROCISUR).\footnote{The Spanish language acronym for Programa Cooperativo de Investigacion Agricola para la Region Sur.} Regional germplasm exchanges were accelerated through the Programme’s LACOS nursery which was coordinated by CIMMYT’s regional staff. Additional germplasm was received through CIMMYT’s specialized screening nurseries which included cultivars emerging from the shuttle programme with Brazil. With access to disease resistant and regionally adapted varieties, in 1986 Paraguay was able to increase average yields to 1519 kg/ha over 153,700 ha and, thus, meet its consumption requirements. Today, Paraguay participates in the UNDP project as a shuttle breeding partner to improve germplasm for resistance to spot blotch and tolerance to heat.

88. Undoubtedly, favourable climatic conditions in 1986 played a large role in Paraguay’s production achievements. The warmer areas of South America suffer from unstable weather patterns. High minimum temperatures and evapotranspiration rates, heavy cloud cover and drought during pre- and post-anthesis reduce yield potential. Diseases due to high temperatures and humidity are major constraints in Paraguay, Northern Brazil and Southern Bolivia while drought, heat and occasional disease problems occur in Northern Argentina. Additional limitations include acid soils in Brazil, and unpredictable frosts which may occur during the flowering stage in Northern Argentina and Brazil, and Paraguay.

89. Germplasm for these warmer areas requires resistance to spot blotch, scab, leaf rust and bacterial infections, and tolerance to heat, frost, drought and aluminum toxicity. Agronomic research is focussing on developing appropriate water, soil and fertility management practices to overcome the problems associated with acid soils, drought and heat.

V. FUTURE OUTLOOK

90. The first phase of the UNDP project consolidated the efforts of a global community of researchers concerned with wheat production for warmer, marginal environments. Genetic sources of resistance to diseases and tolerance to abiotic stresses were identified. Materials were crossed to enhance single traits, and combined for use in target mega-environments. Many of the lines distributed through CIMMYT’s nursery system performed better than local varieties, and some were put into commercial production. Agronomists developed techniques to adapt wheat to new environments. National cooperators in the warmer areas gained experience with a nontraditional crop while advanced programmes contributed expertise and resources to generate appropriate technology. Formerly non-productive, warmer, marginal lands are now producing up to 3 t/ha.
91. Experience to date indicates that wheat production in the warmer, marginal environments is likely to improve and stabilize as research intensifies. Breeders and pathologists need to continue improving germplasm for resistance to diseases – the most serious threat to wheat in warm, humid environments. The work of agronomists is indispensable in determining the causes and consequences of environmental stresses, and in reducing their effects. Moreover, adequately trained extension agents are needed to disseminate the new technologies.

92. CIMMYT continues to assist national cooperators in their efforts to develop and increase wheat production in warmer climates. The objectives of breeders, agronomists and pathologists are more clearly defined as a result of the first five years of research. Progress is being made toward alleviating the constraints identified when research first began. Additional limitations, which were discovered during the course of the project, need to be addressed through interdisciplinary and global cooperation. Some of these problems include Sclerotium rolsii (a root and crown disease), bacterial infections, waterlogging and soil salinity resulting from poorly maintained irrigation systems. CIMMYT's research is proceeding as follows:

93. Germplasm Improvement. Plant breeding is an ongoing process. Lines, once improved, are used as parents to produce higher performing varieties which again are crossed to add or strengthen the desired characteristics in the resultant progeny. The process of breeding wheats for warmer areas began by identifying the highest performing lines for a given trait. This process was completed at the end of Phase I. Each year crosses were made and segregating generations were advanced. The homozygous progeny of crosses made during the initial years of the project began emerging in 1987 and are entering international trials. Crossing germplasm to develop genotypes with multiple characteristics suited to warmer mega-environments is continuing.

94. Gene transfers from alien grass species to develop lines for resistance to spot blotch and scab, and tolerance to abiotic stresses is continuing. The spot blotch resistant synthetics produced during Phase I will be crossed with HYVs and included in shuttle breeding programmes with Brazil, Paraguay and Nepal.

95. Shuttle breeding with advanced national programmes will be taken a step further as the advanced NARS assume a greater role in assisting less developed cooperators sharing similar environments.

96. Pathology. Collaborative pathological research, such as that established with Brazil, the Federal Republic of Germany and Israel in 1987, will be undertaken with advanced national programmes focussing on the epidemiology, host resistance and pathogenicity spectrum of the most serious diseases occurring in warmer areas.

97. Crop Management Research. Agronomists are making significant contributions to wheat production in warmer areas. This fact was highlighted during the first phase of the project. Soil preparation, fertilizer use and water management require further research with special attention to sustainability in rice-wheat rotations and acid soil environments. Agronomists are working on the following:

• Determining the causes of why wheat growing in tropical climates does not respond as
well to fertilizer applications as wheat growing in temperate climates.

- Determining the effects of micronutrient (i.e. Boron) deficiencies on yield.
- Seed bed preparation for wheat in rice paddies.
- Minimizing the effects of soil pathogens in rice-wheat rotations.
- Zero tillage to conserve moisture, shorten the interval between crop rotations, and keep organic matter in the soil.
- Maximizing the use of residual moisture in soils.
- Developing appropriate irrigation management technologies to maximize available water supplies and reduce soil salinity due to poor drainage.
- Determining why heat reduces tillering, and whether seed bed modification can reduce this effect.

Finally, to speed the transfer of technology to warmer areas and strengthen national programmes in countries where wheat is a new crop, assistance is being provided through in-service and in-country training, conferences, workshops, seminars, consultancies and germplasm distribution.
APPENDIX A. TABLES TO SECTION I.

Table 1
Potential Beneficiaries of Wheat Germplasm for the Warmer Areas

<table>
<thead>
<tr>
<th>MEGA-ENVIRONMENT A</th>
<th>MEGA-ENVIRONMENT B</th>
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<tbody>
<tr>
<td>High temperature, low humidity, short crop season, few disease problems.</td>
<td>High temperature and humidity, short crop season, significant disease problems.</td>
</tr>
<tr>
<td>Argentina (northern)</td>
<td>Bangladesh</td>
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<td>Burkina Faso</td>
<td>Bolivia (lowland)</td>
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<tr>
<td>Chad</td>
<td>Brazil (Cerrados)</td>
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<td>Burundi</td>
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<td>India (central)</td>
<td>Cameroon (central)</td>
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<td>Mali (central)</td>
<td>China (south coastal)</td>
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<td>Mauritania (southern)</td>
<td>Colombia (llano)</td>
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<td>Congo</td>
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<td>Guyana</td>
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<td>India (eastern)</td>
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<td>Mozambique</td>
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<td></td>
<td>Nepal (plains)</td>
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Table 2
Genetic Variability and Screening Methods for Characteristics Required in Wheats for Mega-environments A & B

<table>
<thead>
<tr>
<th>CHARACTERISTICS</th>
<th>GENETIC VARIABILITY</th>
<th>SCREENING METHOD</th>
<th>RELIABILITY OF SCREENING METHOD</th>
</tr>
</thead>
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<td>AGRONOMIC</td>
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<td></td>
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<tr>
<td>Stable, High Yield</td>
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<td>o</td>
<td>3</td>
</tr>
<tr>
<td>Grain Quality</td>
<td>++</td>
<td>o</td>
<td>3</td>
</tr>
<tr>
<td>Sprouting Resistance</td>
<td>+</td>
<td>o</td>
<td>3</td>
</tr>
<tr>
<td>Early Vegetative Vigor</td>
<td>++</td>
<td>o</td>
<td>2</td>
</tr>
<tr>
<td>Early Maturity</td>
<td>++</td>
<td>o</td>
<td>3</td>
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<tr>
<td>Lodging Resistance</td>
<td>++</td>
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+ Variability o Method available 1 = Poor
++ Great variability - Method needs refinement 2 = Fair
5 = Good
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**Wheat Screening Nurseries Delivered to Countries in Warmer Areas 1982 To 1987**

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1. Combined traits for Mega-environment A.
2. Combined traits for Mega-environment B.
3. Combined traits for acid soils.
4. Germplasm indigenous to Asian tropics.
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Segregating Populations Delivered to Countries in Warmer Areas, 1982 to 1987

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<td>2</td>
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<td>1</td>
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<td>2</td>
<td>2</td>
<td>9</td>
</tr>
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<td>Brazil</td>
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<td>2</td>
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<tr>
<td>Ecuador</td>
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<td></td>
<td>1</td>
<td>1</td>
<td>3</td>
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<tr>
<td>Guatemala</td>
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<td></td>
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<tr>
<td>Guyana</td>
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<td></td>
<td></td>
<td>1</td>
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<tr>
<td>Mexico</td>
<td>4</td>
<td></td>
<td></td>
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<td>Paraguay</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>7</td>
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<td>Uruguay</td>
<td>1</td>
<td></td>
<td></td>
<td>3</td>
<td>1</td>
<td>6</td>
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<tr>
<td>Venezuela</td>
<td>2</td>
<td>1</td>
<td></td>
<td>1</td>
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<td>5</td>
</tr>
<tr>
<td>MIDDLE EAST</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Yemen Rep.</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>90</td>
<td>27</td>
<td>22</td>
<td>86</td>
<td>31</td>
<td>23</td>
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</table>
Table 3
Highest Yielding Varieties and Lines Compared to Local Checks in Warmer Areas as Reported in the 22nd ISWY, 1985-86

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>LATITUDE</th>
<th>MASL</th>
<th>VARIETY OR LINE</th>
<th>ORIGIN</th>
<th>YIELD (kg/ha)</th>
<th>PERCENT OF LOCAL CHECK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangladesh</td>
<td>23.46° N</td>
<td>8</td>
<td>Buck Patacon</td>
<td>Argentina</td>
<td>3160</td>
<td>2118</td>
</tr>
<tr>
<td>Bolivia</td>
<td>17.14° S</td>
<td>320</td>
<td>UP 262</td>
<td>India</td>
<td>594</td>
<td>426</td>
</tr>
<tr>
<td>Brazil</td>
<td>19.30° S</td>
<td>386</td>
<td>ICTA Sara</td>
<td>Guatemala</td>
<td>3333</td>
<td>2361</td>
</tr>
<tr>
<td>Burma</td>
<td>23.22° S</td>
<td>585</td>
<td>NS 51.28</td>
<td>Yugoslavia</td>
<td>4067</td>
<td>2483</td>
</tr>
<tr>
<td>Indonesia</td>
<td>15.35° S</td>
<td>1000</td>
<td>LU 262</td>
<td>Pakistan</td>
<td>4543</td>
<td>3078</td>
</tr>
<tr>
<td>Bolivia</td>
<td>23.02° N</td>
<td>120</td>
<td>Bij&quot;S&quot;/Jup</td>
<td>Mexico</td>
<td>2626</td>
<td>1973</td>
</tr>
<tr>
<td>Indonesia</td>
<td>7.20° S</td>
<td>545</td>
<td>LU 265</td>
<td>Pakistan</td>
<td>2422</td>
<td>2222</td>
</tr>
<tr>
<td>Malawi</td>
<td>14.24° S</td>
<td>1590</td>
<td>Alamos 83(TCL)</td>
<td>Mexico</td>
<td>3345</td>
<td>2167</td>
</tr>
<tr>
<td>Nigeria</td>
<td>12.00° N</td>
<td>470</td>
<td>Nacosari 76</td>
<td>Mexico</td>
<td>4660</td>
<td>4050</td>
</tr>
<tr>
<td>Sudan</td>
<td>14.24° N</td>
<td>411</td>
<td>Anza</td>
<td>USA</td>
<td>1222</td>
<td>1049</td>
</tr>
<tr>
<td>Tanzania</td>
<td>4.30° S</td>
<td>1788</td>
<td>Punjab 81</td>
<td>Pakistan</td>
<td>2862</td>
<td>1747</td>
</tr>
<tr>
<td>Thailand</td>
<td>18.47° N</td>
<td>314</td>
<td>Genaro 81</td>
<td>Mexico</td>
<td>1347</td>
<td>360</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>19.37° N</td>
<td>430</td>
<td>Bij&quot;S&quot;/Jup</td>
<td>Mexico</td>
<td>2654</td>
<td>2639</td>
</tr>
</tbody>
</table>

1. Meters Above Sea Level
2. / indicates simple cross (variety A x variety B).

Table 4
Highest Yielding Varieties and Lines with CIMMYT Germplasm Compared to Local Checks in Warmer Areas as Reported in the 7th ESWY, 1985-86

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>LATITUDE</th>
<th>MASL</th>
<th>VARIETY OR LINE*</th>
<th>YIELD (kg/ha)</th>
<th>PERCENT OF LOCAL CHECK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolivia</td>
<td>17.14° S</td>
<td>320</td>
<td>Nac/Vec&quot;S&quot;/Vec&quot;A&quot;/Vec&quot;B&quot;</td>
<td>744</td>
<td>259</td>
</tr>
<tr>
<td>Brazil</td>
<td>18.39° S</td>
<td>386</td>
<td>Pfau</td>
<td>2879</td>
<td>2625</td>
</tr>
<tr>
<td>Brazil</td>
<td>15.35° S</td>
<td>1000</td>
<td>Her/Sap&quot;S&quot;/Vee</td>
<td>3627</td>
<td>2793</td>
</tr>
<tr>
<td>Brazil</td>
<td>23.22° S</td>
<td>586</td>
<td>Her/Sap&quot;S&quot;/Vee</td>
<td>6650</td>
<td>5583</td>
</tr>
<tr>
<td>Brazil</td>
<td>24.17° S</td>
<td>300</td>
<td>Vec &quot;S&quot;</td>
<td>3886</td>
<td>3874</td>
</tr>
<tr>
<td>Burma</td>
<td>23.02° N</td>
<td>120</td>
<td>Vec &quot;S&quot;</td>
<td>2500</td>
<td>2228</td>
</tr>
<tr>
<td>Costa Rica</td>
<td>10.15° N</td>
<td>1680</td>
<td>Nd/Vg9114//Kal/Vec/S By5/Yeco</td>
<td>5137</td>
<td>3832</td>
</tr>
<tr>
<td>Indonesia</td>
<td>7.20° S</td>
<td>545</td>
<td>Buc/Pvn</td>
<td>2624</td>
<td>2511</td>
</tr>
<tr>
<td>Nigeria</td>
<td>12.00° N</td>
<td>470</td>
<td>Vec &quot;S&quot;</td>
<td>5750</td>
<td>3800</td>
</tr>
<tr>
<td>Sudan</td>
<td>14.24° N</td>
<td>411</td>
<td>Guasave 81</td>
<td>1938</td>
<td>1333</td>
</tr>
<tr>
<td>Tanzania</td>
<td>8.55° S</td>
<td>1800</td>
<td>Vec &quot;S&quot;</td>
<td>4554</td>
<td>2014</td>
</tr>
<tr>
<td>Thailand</td>
<td>18.17° N</td>
<td>820</td>
<td>Seri 82</td>
<td>4975</td>
<td>4070</td>
</tr>
<tr>
<td>Thailand</td>
<td>14.40° N</td>
<td>300</td>
<td>Buc/Bij</td>
<td>472</td>
<td>429</td>
</tr>
</tbody>
</table>

* // indicates top cross in P1 followed by the variety it was crossed with (variety A x variety B // variety C).

Table 5
Heat Tolerance Selection Criteria by Location

<table>
<thead>
<tr>
<th>MEXICO</th>
<th>SOUTHERN CONE OF SOUTH AMERICA</th>
<th>SOUTHEAST ASIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Leaf area duration after anthesis</td>
<td>1. Prolonged early vegetative vigor</td>
<td>1. Number of heads per square meter</td>
</tr>
<tr>
<td>2. High tillering capacity</td>
<td>2. High tillering capacity</td>
<td>2. Number of grains per head</td>
</tr>
<tr>
<td>5. Test weight</td>
<td>5. Non-shrivelled kernels</td>
<td></td>
</tr>
<tr>
<td>6. Yield</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 6
Top Performing Lines in the 3rd HTSN (1985-86) Based on Frequency of Selection by Cooperators with Corresponding Leaf Rust Score and Yield

<table>
<thead>
<tr>
<th>VARIETY OR LINE1</th>
<th>FREQUENCY OF SELECTION (%)</th>
<th>MEAN SCORE LEAF RUST2</th>
<th>MEAN YIELD3 (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Locations Reporting</td>
<td>28</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>Kauz'S'</td>
<td>46.4</td>
<td>17.8</td>
<td>2446</td>
</tr>
<tr>
<td>MtI'S'/Buc'S'</td>
<td>39.3</td>
<td>7.7</td>
<td>2495</td>
</tr>
<tr>
<td>Cc/2*Tob//MN72131</td>
<td>32.1</td>
<td>0.8</td>
<td>1545</td>
</tr>
<tr>
<td>L2286/1406.101//Buc'S'/3/Vpm/Mos83.1.4.8//Nac</td>
<td>32.1</td>
<td>5.2</td>
<td>2221</td>
</tr>
<tr>
<td>Pvn'S'/Prl'S'</td>
<td>32.1</td>
<td>16.3</td>
<td>2540</td>
</tr>
<tr>
<td>Psn'S'/Bow'S'</td>
<td>32.1</td>
<td>26.5</td>
<td>1780</td>
</tr>
<tr>
<td>Inia/A.distichum//Inia/3/Vee'S'</td>
<td>32.1</td>
<td>22.6</td>
<td>2347</td>
</tr>
<tr>
<td>Inia/A.distichum//Inia/3/Vee'S'</td>
<td>32.1</td>
<td>23.3</td>
<td>3159</td>
</tr>
<tr>
<td>PAT10/Ald'S'//PEL72300/3/Pvn'S'</td>
<td>28.6</td>
<td>25.2</td>
<td>2230</td>
</tr>
<tr>
<td>Psn'S'/Buc'S'</td>
<td>28.6</td>
<td>36.0</td>
<td>2681</td>
</tr>
<tr>
<td>M rng/Buc'S'//B lo'S'/P sn'S'</td>
<td>28.6</td>
<td>1.0</td>
<td>2392</td>
</tr>
<tr>
<td>Vee#7'S'</td>
<td>25.0</td>
<td>19.9</td>
<td>2626</td>
</tr>
<tr>
<td>Vee#7'S'</td>
<td>25.0</td>
<td>25.5</td>
<td>2419</td>
</tr>
<tr>
<td>Cc/2*Tob//MN72131</td>
<td>25.0</td>
<td>17.2</td>
<td>1642</td>
</tr>
<tr>
<td>Cc/2*Tob//MN72131</td>
<td>25.0</td>
<td>3.6</td>
<td>1602</td>
</tr>
<tr>
<td>Buc'S'/Pvn'S'</td>
<td>25.0</td>
<td>1.0</td>
<td>2077</td>
</tr>
<tr>
<td>R37/Ghl211//Kal/Bb/3/Klt'S'</td>
<td>25.0</td>
<td>12.0</td>
<td>2081</td>
</tr>
<tr>
<td>Pvn'S'/Prl'S'</td>
<td>25.0</td>
<td>13.5</td>
<td>2640</td>
</tr>
<tr>
<td>Kauz'S'</td>
<td>25.0</td>
<td>21.0</td>
<td>2207</td>
</tr>
<tr>
<td>Trt'S'/Gh'S'</td>
<td>25.0</td>
<td>13.0</td>
<td>1919</td>
</tr>
<tr>
<td>Gz156/Nac//Ps n'S'/Ures</td>
<td>25.0</td>
<td>7.7</td>
<td>2139</td>
</tr>
</tbody>
</table>

1. / indicates simple cross (variety A x variety B).
2. // indicates top cross in F1 followed by the variety it was crossed with (variety A x variety B // variety C).
3. /number/ indicates the F generation in which a cross was made.
4. * indicates backcross.
6. Less than 5 is highly resistant; between 5 and 7 is moderately resistant; more than 7 is susceptible.
7. Yield data are estimates based on unreplicated small plots.
### Table 7

Top Performing Lines in the 4th DSN (1985-86) Based on Frequency of Selection by Cooperators with Corresponding Leaf Rust Score and Yield

<table>
<thead>
<tr>
<th>VARIETY OR LINE</th>
<th>CROSS CODE1 &amp; PEDIGREE2</th>
<th>FREQUENCY OF SELECTION (%)</th>
<th>MEAN SCORE LEAF RUST3</th>
<th>MEAN YIELD4 (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Locations Reporting:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Veery #5'S'</td>
<td>CM33027-F-15M-500Y-0M-110B-0Y</td>
<td>27</td>
<td></td>
<td>21</td>
</tr>
<tr>
<td>Cook/Veery'S'/Dove'S'/Veery'S'</td>
<td>CM69279-C-2Y-1M-5Y-1M-0Y</td>
<td>44.4</td>
<td>21.0</td>
<td>2911</td>
</tr>
<tr>
<td>Opata86</td>
<td>CM40038-8M-4Y-2M-1Y-2M-1Y-0B</td>
<td>40.7</td>
<td>2.3</td>
<td>2896</td>
</tr>
<tr>
<td>Myra'S'/Vul'S'</td>
<td>CM64646-2M-1Y-1M-5Y-0M</td>
<td>37.0</td>
<td>3.0</td>
<td>2140</td>
</tr>
<tr>
<td>Chil'S'</td>
<td>CM66884-D-1M-4Y-2M-1M-0Y</td>
<td>33.3</td>
<td>1.4</td>
<td>2474</td>
</tr>
<tr>
<td>Mon'S'/Imu</td>
<td>CM61942-4Y-2M-1Y-2M-1Y-0M</td>
<td>29.6</td>
<td>15.7</td>
<td>2906</td>
</tr>
<tr>
<td>R37/Ghl121//Kal/Bb/3/Klt'S'</td>
<td>CM64609-6Y-3M-2M-1M-0Y</td>
<td>29.6</td>
<td>0.8</td>
<td>2711</td>
</tr>
<tr>
<td>Buc'S'/Chrc'S'</td>
<td>CM52421-26Y-1Y-1M-3Y-1M-OY</td>
<td>25.9</td>
<td>13.0</td>
<td>2553</td>
</tr>
<tr>
<td>Plb/Peto(B)//Nac/3/</td>
<td>CM57878-03Y-04X-2X-0Z</td>
<td>25.9</td>
<td>9.6</td>
<td>2437</td>
</tr>
<tr>
<td>Pnn'S'/Buc'S'</td>
<td>CM58797-4Y-1M-2M-2M-0Y</td>
<td>25.9</td>
<td>17.6</td>
<td>2251</td>
</tr>
<tr>
<td>Mrl'S'/Buc'S'</td>
<td>CM61949-3M-4Y-1M-1M-1M-OY</td>
<td>25.9</td>
<td>1.5</td>
<td>2327</td>
</tr>
<tr>
<td>~b'S'</td>
<td>CM64340-4M-1M-2M-1M-0Y</td>
<td>25.9</td>
<td>10.2</td>
<td>2253</td>
</tr>
</tbody>
</table>

1. Cross code indicates where a cross was made. CM = CIMMYT. If a letter immediately follows the cross code, a top cross was made. This letter has a corresponding numerical value indicating which plant was selected.

2. Pedigree indicates the screening site of segregating material, the F generation, and the number of the plant selected. If a "0" precedes the letter, all plants were carried as bulk to the next generation.

B = El Batan, Mexico; M = Toluca, Mexico; X = Oaxaca, Mexico; Y = Yaqui Valley, Mexico; Z = Ceres Alta, Brazil.

3. Less than 5 is highly resistant; between 5 and 7 is moderately resistant; more than 7 is susceptible.

4. Yield data are estimates based on unreplicated small plots.

---

### Table 8

Characteristics of Some Aluminum Tolerant Varieties Released in Brazil, 1984 to 1987

<table>
<thead>
<tr>
<th>VARIETY</th>
<th>CROSS CODE1 &amp; PEDIGREE2</th>
<th>CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Alumin. Leaf Rust</td>
</tr>
<tr>
<td>OCEPAR 8</td>
<td>CM47207-6M-109PR-2T-0T</td>
<td>T</td>
</tr>
<tr>
<td>OCEPAR 9</td>
<td>CM47971-4M-109PR-2T-0T</td>
<td>M</td>
</tr>
<tr>
<td>OCEPAR 10</td>
<td>CM46991-16M-109PR-1T-0T</td>
<td>M</td>
</tr>
<tr>
<td>OCEPAR 11</td>
<td>CM46961-16M-113PR-1T-0T</td>
<td>M</td>
</tr>
<tr>
<td>OCEPAR 12</td>
<td>B13707-0A-0Z-0L-0M-0L-0P</td>
<td>T</td>
</tr>
<tr>
<td>OCEPAR 13</td>
<td>B14402-0M-1T-2T-0T</td>
<td>T</td>
</tr>
<tr>
<td>CEP 13</td>
<td>F11860-F-500-900Y-312Z-0A</td>
<td>MT</td>
</tr>
<tr>
<td>Trigo BR 14</td>
<td>(a mixture of lines)</td>
<td>MT</td>
</tr>
<tr>
<td>Trigo BR 16</td>
<td>B19789-4-508M-1Y-10F-701Y-1F-700Y</td>
<td>MT</td>
</tr>
<tr>
<td>MG 1</td>
<td>CM47207-16M-2Y-3F-704Y-7F-700Y</td>
<td>MT</td>
</tr>
</tbody>
</table>

1. Cross codes: B = Brazil; CM = CIMMYT; P = Parana.

2. Pedigrees: A = Ceres Alta, Brazil; F = Passo Fundo, Brazil; L = Londrina, Brazil; M = Toluca, Mexico; PR = Parana, Brazil; T = Caravall, Brazil; Y = Yaqui Valley, Mexico; Z = Ceres Alta, Brazil.

---

B = Early
I = Intermediate
L = Late
M = Moderate
MR = Moderately Resistant
MS = Moderately Susceptible
MT = Moderately Tolerant
R = Resistant
S = Susceptible
T = Tolerant
na = data not available
### Table 9

Top Performing Lines in the 4th ALSN (1985-1986) Based on Frequency of Selection by Cooperators with Corresponding Aluminum Tolerance Score, and Leaf Rust Score

<table>
<thead>
<tr>
<th>LINE</th>
<th>ALUMINUM MEAN SCORE</th>
<th>FREQUENCY OF SELECTION (%)</th>
<th>LEAF RUST</th>
</tr>
</thead>
<tbody>
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<td>2.8</td>
<td>25.0</td>
<td>38.9</td>
</tr>
<tr>
<td>Maya'S'/Sprw'S'/Vee#6</td>
<td>4.0</td>
<td>21.0</td>
<td>38.9</td>
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<td>16.0</td>
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<tr>
<td>Maya'S'/Sprw'S'/Vee#6</td>
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<td>38.9</td>
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<td>16.0</td>
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<td>38.9</td>
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<tr>
<td>Maya'S'/Sprw'S'/Vee#6</td>
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<td>16.0</td>
<td>38.9</td>
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<td>3.5</td>
<td>30.3</td>
<td>22.2</td>
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<td>2.8</td>
<td>25.0</td>
<td>38.9</td>
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<tr>
<td>Maya'S'/Sprw'S'/Vee#6</td>
<td>4.0</td>
<td>16.0</td>
<td>38.9</td>
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<tr>
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<td>10.3</td>
<td>27.8</td>
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<td>3.5</td>
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<td>4.0</td>
<td>16.0</td>
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<td>27.8</td>
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<td>3.5</td>
<td>30.3</td>
<td>22.2</td>
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</table>

1. A line listed more than once indicates that sister ('S') lines of the same cross were entered into the ALSN.
2. Aluminum tolerance is measured on a 0-9 scale with 0 being the most tolerant and 9 the least tolerant.
3. Less than 5 is highly resistant; between 1> and 7 is moderately resistant; more than 7 is susceptible.

### Table 10

Bread Wheat Germplasm Resistant or Moderately Resistant to Spot Blotch in Poza Rica, Mexico, 1986

<table>
<thead>
<tr>
<th>VARIETY OR LINE</th>
<th>PEDIGREE*</th>
<th>ORIGIN</th>
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<tbody>
<tr>
<td>V81623</td>
<td>CM43903</td>
<td>CIMMYT</td>
</tr>
<tr>
<td>Ningmai #4/On//Ald/Yangmai #3</td>
<td>CM43903</td>
<td>China</td>
</tr>
<tr>
<td>Shanghai #4</td>
<td>CM43903-H-4Y-1M-1Y-3Y-0B-0E</td>
<td>CIMMYT</td>
</tr>
<tr>
<td>Suzhoe #1</td>
<td>CM43903</td>
<td>CIMMYT</td>
</tr>
<tr>
<td>Suzhoe #8</td>
<td>CM43903</td>
<td>CIMMYT</td>
</tr>
<tr>
<td>Ymi #6</td>
<td>CM43903</td>
<td>CIMMYT</td>
</tr>
<tr>
<td>Lira</td>
<td>CM43903-H-4Y-1M-1Y-3Y-0B-0E</td>
<td>CIMMYT</td>
</tr>
<tr>
<td>Pri/Toni</td>
<td>CM7360-2Y-3M-4Y-1M-1Y-2M-0Y</td>
<td>CIMMYT</td>
</tr>
<tr>
<td>Cook/Vee//Dove/Vee</td>
<td>CM69279-C-2Y-1M-1Y-0Y</td>
<td>CIMMYT</td>
</tr>
<tr>
<td>MN72131</td>
<td>CM55651-4Y-1M-4Y-0M</td>
<td>USA</td>
</tr>
<tr>
<td>Bijy/Coc</td>
<td>CM40610-33M-500M-500M-500M-0M</td>
<td>CIMMYT</td>
</tr>
<tr>
<td>LAJ2514</td>
<td>CM6687-2L-9L-12L-0L</td>
<td>Brazil/CIMMYT</td>
</tr>
<tr>
<td>Trt</td>
<td>CM7890-7Y-1M-4Y-0Z-2Z-0Y</td>
<td>Brazil/CIMMYT</td>
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<tr>
<td>Ald//CNT7//PF70354//3/PAT24//Bb/Kal</td>
<td>CM53612-2MM-2MM-1MM-1MM-0MM</td>
<td>CIMMYT</td>
</tr>
<tr>
<td>BFH11407//Ald</td>
<td>CM53612-2MM-2MM-1MM-1MM-0MM</td>
<td>CIMMYT</td>
</tr>
<tr>
<td>Aldan/CNT9</td>
<td>CM53612-2MM-2MM-1MM-1MM-0MM</td>
<td>CIMMYT</td>
</tr>
<tr>
<td>Coq/P61.70/0/Cndr/3/Onl/4/Pho</td>
<td>CM48958-N-6Y-1M-2Y-6M-2Y-1Y-0Y-Pets-0Y</td>
<td>CIMMYT</td>
</tr>
<tr>
<td>MN72131</td>
<td>CM21335-C-9Y-3M-1Y-1Y-1Y-0B</td>
<td>USA</td>
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<tr>
<td>Wmr/Ptm//Coc</td>
<td>CM47943-V-5M-3Y-1M-1Y-0Y</td>
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<tr>
<td>Ald/Ptn</td>
<td>CM47943-V-5M-3Y-1M-1Y-0Y</td>
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<tr>
<td>Kea</td>
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<td>CI14227//Trnr///Mad</td>
<td>CM47943-V-5M-3Y-1M-1Y-0Y</td>
<td>CIMMYT</td>
</tr>
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</table>

* B = El Batan, Mexico; E = Ecuador; L = Londrina, Brazil; M = Toluca, Mexico; MM = Mount Makulu, Zambia; Pts = Patnauro, Mexico; Y = Yaqui Valley, Mexico; Z = Cra. Alta, Brazil.
Table 11
Top Performing Lines in the SRSN (1985-86) Based on Mean Scab Score with Corresponding Mean Leaf Rust Score

<table>
<thead>
<tr>
<th>VARIETY OR CROSS</th>
<th>ORIGIN</th>
<th>MEAN SCORE(^1) SCAB</th>
<th>MEAN SCORE(^2) LEAF RUST</th>
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<tbody>
<tr>
<td>No. of Locations Reporting:</td>
<td></td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>Fan#1</td>
<td>China</td>
<td>11.1</td>
<td>48.3</td>
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<tr>
<td>Shanghai 3</td>
<td>China</td>
<td>12.0</td>
<td>38.8</td>
</tr>
<tr>
<td>IAS20/H567.71/5*IAS20</td>
<td>Brazil</td>
<td>13.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Nanjing 7840</td>
<td>China</td>
<td>14.5</td>
<td>6.2</td>
</tr>
<tr>
<td>IAS20/H567.71/5*IAS20</td>
<td>Brazil</td>
<td>14.6</td>
<td>5.3</td>
</tr>
<tr>
<td>IAS20/H567.71/5*IAS20</td>
<td>Brazil</td>
<td>15.9</td>
<td>3.5</td>
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<tr>
<td>Shanghai 5</td>
<td>China</td>
<td>16.5</td>
<td>39.7</td>
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<tr>
<td>Sumai 3</td>
<td>China</td>
<td>16.7</td>
<td>11.3</td>
</tr>
<tr>
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<td>Brazil</td>
<td>17.7</td>
<td>1.8</td>
</tr>
<tr>
<td>PF74354/Ld/Ald'S'</td>
<td>Brazil/CIMMYT</td>
<td>18.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Yumi#6</td>
<td>China</td>
<td>18.6</td>
<td>36.8</td>
</tr>
<tr>
<td>Bow'S'/PF74354</td>
<td>Brazil/CIMMYT</td>
<td>18.9</td>
<td>6.5</td>
</tr>
<tr>
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<td>Brazil</td>
<td>20.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Ttr'S'/Bow'S'</td>
<td>CIMMYT</td>
<td>22.7</td>
<td>11.8</td>
</tr>
<tr>
<td>IAS20/H567.71/5*IAS20</td>
<td>Brazil</td>
<td>24.1</td>
<td>2.4</td>
</tr>
<tr>
<td>Ttr'S'/Bow'S'</td>
<td>CIMMYT</td>
<td>25.0</td>
<td>12.0</td>
</tr>
<tr>
<td>PF74354/Ld/Ald'S'</td>
<td>Brazil/CIMMYT</td>
<td>27.0</td>
<td>0.8</td>
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<tr>
<td>Suzhao F3#1</td>
<td>China</td>
<td>28.3</td>
<td>28.0</td>
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<tr>
<td>PF74354/Ld/Ald'S'</td>
<td>Brazil/CIMMYT</td>
<td>28.5</td>
<td>0.2</td>
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</table>

1. 0-20 = Resistant; 21-30 = Moderately Resistant; 31-50 = Moderately Susceptible; below 51 = Susceptible.
2. Less than 5 is highly resistant; between 5 and 7 is moderately resistant; more than 7 is susceptible.

Table 12
Overall Superior Germplasm from South America, 1987

<table>
<thead>
<tr>
<th>VARIETY OR CROSS</th>
<th>MATURITY</th>
<th>DROUGHT</th>
<th>HEAT</th>
<th>LEAF RUST</th>
<th>H. SATIVUM</th>
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<tr>
<td>Opata</td>
<td>I</td>
<td>MR</td>
<td>MR</td>
<td>R</td>
<td>MS</td>
</tr>
<tr>
<td>Chilero'S'</td>
<td>L</td>
<td>R-MR</td>
<td>MR</td>
<td>R</td>
<td>MR</td>
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<tr>
<td>Kaus</td>
<td>L</td>
<td>R-MR</td>
<td>MR</td>
<td>S</td>
<td>MR</td>
</tr>
<tr>
<td>Myna'S'/Vul'S'</td>
<td>I</td>
<td>MR</td>
<td>MR</td>
<td>MS</td>
<td>MR</td>
</tr>
<tr>
<td>Cno79/Prl'S'</td>
<td>L</td>
<td>MR</td>
<td>MR</td>
<td>MS</td>
<td>MS</td>
</tr>
<tr>
<td>Vee'S'/Bow'S'</td>
<td>L</td>
<td>MR</td>
<td>MR</td>
<td>MS</td>
<td>MS</td>
</tr>
<tr>
<td>Bau'S'</td>
<td>I</td>
<td>MS</td>
<td>MR</td>
<td>R</td>
<td>MR</td>
</tr>
<tr>
<td>Bow'S'/Prl'S'</td>
<td>L</td>
<td>MR</td>
<td>MR</td>
<td>S</td>
<td>MR</td>
</tr>
<tr>
<td>Vs73600/Mrl'S'...</td>
<td>L</td>
<td>R</td>
<td>MR</td>
<td>R</td>
<td>MR</td>
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<tr>
<td>Amd/Hn4/3/Glo...</td>
<td>L</td>
<td>MS</td>
<td>MR</td>
<td>R</td>
<td>MR</td>
</tr>
</tbody>
</table>

L = Late
I = Intermediate
MR = Moderately Resistant
MS = Moderately Susceptible
R = Resistant
S = Susceptible
# APPENDIX C. ASSISTANCE TO NATIONAL PROGRAMMES

Table 1

UNDP-Sponsored In-Service Wheat Trainees (GLO/82/007), 1983-87

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>TRAINEES (52)</th>
<th>COURSE</th>
<th>YEAR</th>
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<td>Bhutan</td>
<td>Man Bahadur Gurung</td>
<td>Production</td>
<td>1986</td>
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<tr>
<td>Burma</td>
<td>U. Aung Sein</td>
<td>Improvement</td>
<td>1987</td>
</tr>
<tr>
<td>Cameroon</td>
<td>Mohaman Bello</td>
<td>Improvement</td>
<td>1983</td>
</tr>
<tr>
<td></td>
<td>Antoine Ngiewa</td>
<td>Cereal Technology</td>
<td>1986</td>
</tr>
<tr>
<td>China</td>
<td>Huang Xiang-Gou</td>
<td>Improvement</td>
<td>1985</td>
</tr>
<tr>
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<td>Yang Bei</td>
<td>Improvement</td>
<td>1987</td>
</tr>
<tr>
<td></td>
<td>Chen Xin-Min</td>
<td>Improvement</td>
<td>1987</td>
</tr>
<tr>
<td>Guatemala</td>
<td>Hector E. Ochoa Ovalle</td>
<td>Production</td>
<td>1983</td>
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<td>Edgar A. Garcia Hernandez</td>
<td>Production</td>
<td>1984</td>
</tr>
<tr>
<td>Indonesia</td>
<td>Mochamad Noch</td>
<td>Improvement</td>
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<td>Abdul Kaher</td>
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</tr>
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<td></td>
<td>Tailama Yamin</td>
<td>Improvement</td>
<td>1986</td>
</tr>
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<td>Nasun Damhuri</td>
<td>Improvement</td>
<td>1987</td>
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<td>Korea</td>
<td>Sun Duck-Yong</td>
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<td>1983</td>
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<td>Kyong Ju Choi</td>
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<td>Rodin A. Randriantsalama</td>
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<td>Hodges M. Mlena</td>
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<td>Alejandro Gallardo Suarez</td>
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<td>Gabriel Bisi Adekanye</td>
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<td>Gandoul Ibrahim Gandoul</td>
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<td>Production</td>
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<td>Nicholas Melkhiory</td>
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<td>Thongma Manskul</td>
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<td>Somnak Kayaphad</td>
<td>Production</td>
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<td>Ta Duy Minh</td>
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### Table 2
**In-Country Short-Courses, 1984-87**

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<th>YEAR</th>
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<tr>
<td>1984</td>
<td>Thailand</td>
<td>Thai Nurseries Technical Workshop. To standardize procedures in data collection and reporting.</td>
<td>2 days</td>
<td>22</td>
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<tr>
<td>1985</td>
<td>Thailand</td>
<td>Wheat Production in the Tropics. Discussion of crop management for warmer areas. Classroom &amp; field work.</td>
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<td>40</td>
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<td>Experiment station management.</td>
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<td>Traveling seminar to 28 experiment stations and on-farm research sites in Thailand.</td>
<td>10 days</td>
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<td>1986</td>
<td>Brazil</td>
<td>Advances in Genetic Improvement of Wheat.</td>
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<td>1987</td>
<td>Indonesia</td>
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### Table 3
**Professional Meetings, Conferences and Workshops, 1984-87**

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<td>Cereal Rust Workers Meeting.</td>
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<td>Wheat Production Constraints in Tropical Environments.</td>
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### APPENDIX D. PROGRESS OF WHEAT PRODUCTION IN THE WARMER AREAS

**Table 1**  
Some Varieties Released in Warmer, Marginal Areas From 1982 to 1987

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<th>COUNTRY</th>
<th>YEAR</th>
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<td>Bobwhite</td>
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<td></td>
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<td>Veery 5</td>
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</tr>
<tr>
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<td>1982</td>
<td>Boohai</td>
<td></td>
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<td>Kalyan</td>
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<td>1985</td>
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<td>1985</td>
<td>Kinigi</td>
<td>Bb/Cno//Jar/3/Cno/7c//Cc/Tob</td>
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<td>Pai Cupesi</td>
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<td>1982</td>
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<td>Bb/Cal</td>
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<td>Kea'S'</td>
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<td>IAS564/Aldan'S'</td>
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## Table 2
Wheat Area and Production in Selected Countries
Cultivating Wheat in Warmer Areas

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<th>Country</th>
<th>% Area Warmer, Marginal*</th>
<th>Average Area (000 ha) 1979-81</th>
<th>% Change 1979-81</th>
<th>Average Production (000 tons) 1979-81</th>
<th>% Change 1979-81</th>
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* CIMMYT Estimate.

† Lowland, near tropics.
### Table 3
Wheat Consumption, Imports and Self-Sufficiency in Selected Countries Cultivating Wheat in Warmer Areas

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<tr>
<th>COUNTRY</th>
<th>AVERAGE CONSUMPTION&lt;sup&gt;1&lt;/sup&gt;</th>
<th>AVERAGE IMPORTS&lt;sup&gt;2&lt;/sup&gt;</th>
<th>SELF-SUFFICIENCY&lt;sup&gt;3&lt;/sup&gt;</th>
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<td>(000 tons) 1979-81</td>
<td>1984-86</td>
<td>% Change</td>
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1. CIMMYT Estimate: Consumption = Production + (Imports - Exports) - Stock Changes.
3. CIMMYT Estimate: Self-Sufficiency = Production/(Production + (Imports - Exports) - Stock Changes).
## GLOSSARY OF ACRONYMS

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<td>ASTSN</td>
<td>Acid Soil Screening Nursery</td>
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<tr>
<td>BYDV</td>
<td>Barley Yellow Dwarf Virus</td>
</tr>
<tr>
<td>BR</td>
<td>Brazil</td>
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<tr>
<td>CEP</td>
<td>Centro de Experimentação e Pesquisa (Experimentation and Research Centre)</td>
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<tr>
<td>CGIAR</td>
<td>Consultative Group on International Agricultural Research</td>
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<tr>
<td>CIAAB</td>
<td>Centro de Investigación Agrícola Alberto Boerger (Alberto Boerger Agricultural Research Centre)</td>
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<td>CIMMYT</td>
<td>Centro Internacional de Mejoramiento de Maíz y Trigo (International Maize and Wheat Improvement Centre)</td>
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<td>DGIP</td>
<td>Division for Global and Interregional Projects</td>
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<tr>
<td>DOA</td>
<td>Department of Agriculture</td>
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<td>Elite Selection Wheat Yield Trial</td>
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<td>Federal Republic of Germany</td>
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<td>IBRD</td>
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<td>IDB</td>
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<td>Meters Above Sea Level</td>
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