

# Wheats for More Tropical Environments

**A Proceedings of the International Symposium**

September 24-28, 1984 Mexico, D. F.

Sponsored by: The United Nations Development Programme and CIMMYT



The International Maize and Wheat Improvement Center (CIMMYT) is an internationally funded, nonprofit scientific research and training organization. Headquartered in Mexico, CIMMYT is engaged in a worldwide research program for maize, wheat and triticale, with emphasis on food production in developing countries. CIMMYT is one of 13 nonprofit international agricultural research and training centers supported by the Consultative Group for International Agricultural Research (CGIAR). The CGIAR is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR consists of 40 donor countries, international and regional organizations, and private foundations.

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**Reynaldo L. Villareal**  
**Symposium Organizer**

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## Preface

The international workshop on Wheats for More Tropical Environments was held in Mexico City September 24-28, 1984. This was the first attempt to bring together wheat scientists from all over the world to search for solutions to the problems which face farmers in more tropical areas who seek to grow wheat outside of its traditional environments.

As a result of growing urban populations and rising incomes in the tropics, bread is becoming a staple food for more and more people. For many developing nations, this has led to an increased dependency on wheat imports and the accompanying foreign exchange drain.

In answer to a request by the CGIAR to look for ways to decrease this dependency, CIMMYT, with the assistance of the United Nations Development Programme (UNDP), has begun emphasizing the development of wheats adapted to the stress conditions of the more tropical environments.

It is hoped that this workshop will lead to an increased participation in collaborative research efforts on the part of wheat scientists from many countries so that, by working together, one more battle may be won in the war on hunger.

**Reynaldo L. Villareal**  
**Arthur R. Klatt**  
Technical Editors

# 2

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## Welcome to the Symposium on Wheats for More Tropical Environments

**R.D. Havener, Director General,  
CIMMYT, Mexico**

It is my privilege to welcome you to this, the first symposium which CIMMYT is holding to focus on the problems related to increasing the production of wheat in more tropical and nontraditional production environments. I would like to thank both Rey Villareal, chairman of the symposium, and Art Klatt on behalf of CIMMYT. Before introducing our keynote speaker, let me share a few thoughts with you to set a framework for what I hope you will be talking about during the balance of this conference.

CIMMYT, whose headquarters is at El Batán, about 45 km from Mexico City, is the hub of an international network of which many of you are partners. CIMMYT itself is a very small organization. Within our wheat, maize, economics and support programs, even the largest programs, wheat and maize, each have only about 35 scientists working on a global basis. Only by acting as the hub of an international network can we accomplish very much.

CIMMYT is a part of an international organization of agricultural research centers supported by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is composed of a group of approximately 40 donors that support these centers located across the tropical and subtropical world. Included are CIAT and CIP in Latin America, IFPRI in Washington, D.C., USA, and ISNAR, the

International Service for National Agricultural Research in the Netherlands. IBPGR, the gene board, is located at FAO headquarters in Rome. Other crop and livestock centers in Africa include WARDA, the West Africa Rice Development Association, IITA, the International Institute of Tropical Agriculture in Nigeria, and ILCA and ILRAD, the livestock centers in Ethiopia and Kenya in East Africa. ICARDA, in the Middle East, works with dryland farming systems for the semi-arid regions having a Mediterranean-type climate, and ICRISAT is in India, which has similar climatic zones, but with summer rainfall patterns and tropical climates. Then there is IRRI, the International Rice Research Institute in the Philippines. These 13 centers comprise the international network supported by the CGIAR.

The peasant farm family about which we will be talking a great deal in the next few days is the target group for us, the international centers; they are however, not our client group. You, the national agricultural research programs, the national agricultural universities, those national institutions working for the welfare of developing-country farm families, are in fact our client group, the ones with whom we work. You, in turn, work with the farmers who actually produce the crops around the world.

Here at CIMMYT, we work principally on five experiment stations, Poza Rica on the coast at 60 meters of elevation in the hot, humid tropics, Tlaltizpan, a mid-elevation station at 1000 m elevation, El Batán at 2250 m elevation,

Toluca, a high-elevation station at 2650 m and Ciudad Obregon (CIANO) in the Sonora desert at 40 m. CIANO is owned and operated principally by the government of Mexico, which has allocated to CIMMYT 175 hectares of land in an irrigated valley for a cooperative wheat-improvement program. Within these stations we can typify most of the agroclimatic zones in which wheat and maize are grown around the world.

CIMMYT's products are germplasm, research procedures, trained personnel, information and consulting services. We have global testing networks of which you are a part or, at least, now a subpart dealing with the tropical germplasm of the wheat program. International testing is important for germplasm development, and it is important in the mechanism of germplasm distribution to our collaborators around the globe. Dealing with both wheat and maize are approximately 125 national governments in the germplasm-exchange program.

At CIMMYT, we have had in-service trainees or visiting scientists from virtually every country in the world where wheat and maize are important crops. In this hemisphere, we have regional programs in Mexico, Central America and the Caribbean, and the Andean Region and Southern Cone of South America. We work in West and North Africa, in the areas that are now classified as East and southern Africa and in the ICARDA zone of northern Africa and the Middle East. We also have programs in South and Southeast Asia. In each of those locations, we have regional offices and/or regional staff posted to serve the national programs. They conduct workshops, circulate regional nurseries, exchange research data, expand training opportunities, support on-farm research activities and, we hope, improve consulting services.

Depending on the needs of particular countries, we now have assigned staff with special-project funding in Haiti, Peru, Ghana, Bangladesh, Pakistan and Turkey, working in national wheat or maize improvement programs. Under consideration are national programs with extra-core special project funding in Ethiopia and Kenya.

How are we doing? When one looks at wheat production on a global basis, the answer is pretty well. Comparing the 1979-81 period to 1969-71, the worldwide annual rate of increase in wheat yield has been 3.4%; the annual increase in total production has been 4.8%. Looking at selected individual countries, the growth in wheat production and yield has been quite spectacular; here in Mexico there has been a compound growth rate approaching 5% annually during the past 20 years. There have been peaks and valleys, depending on government policies, availability of water and seasonal variations, but the trend continues to go up. In 1983-84, it is predicted that it will go even higher.

In India, an average of 10.5 million tons of wheat were harvested from 1961 to 1965. For 1984, the harvest is reported to be in the neighborhood of 45 million tons. There is a similar story in Pakistan and also in Turkey. In Turkey, the increase in production has come about as a result of improved farming practices and farming systems rather than through the use of improved genetic materials; it has been based largely on better dryland farming practices, especially on the Anatolian plateau.

In Argentina, there have been ups and downs, principally depending on government pricing policies, but the upward trend in production has been very strong and there is every reason to believe that, in the next few years, it will increase even more rapidly.

The real success story in wheat has been in Bangladesh. It has gone from a small wheat-production area in 1961-65 to a production of over one million tons today. This has occurred with technology that was co-generated by CIMMYT and the Government of India, and imported into Bangladesh and applied to the fields of former rice producers. It is a story of an extraordinary take-off in wheat production.

There are, however, problem areas in the world where wheat production has not increased. These areas are mainly in the Middle East and Africa, where there has been a downward trend in per capita production.

CIMMYT wheats are now planted on approximately 40 million hectares in developing countries and another 10 million in developed countries. When we say CIMMYT, we are referring to this network of some 2,500 scientists scattered around the world. These 50 million hectares may have already expanded to 60 or even 65 million; at the moment we are trying to get new figures on the area under wheat crops that bear CIMMYT germplasm. Ten million tons of grain may be added to the world's food supply annually, just from the effect of these varieties.

Looking briefly at maize, there has been a similar success story in the 1969-71 to 1979-81 period. There have been significant increases in yield during the decade. The developed countries had made big increases during the 1959-61 to 1969-71 decade but, with the developing countries catching up, an even more surprising percentage increase in total production took place this last decade.

We reckon that some 3 million hectares of land are now under improved maize varieties coming out of the CIMMYT network, with some 90 million dollars in value added each year. But, here again, there are regional discrepancies. While Latin America had an increase in production of 2.4% annually during the last decade, Africa has not kept pace with the rate of population growth. The increase in the Middle East has been greater than the rate of population growth, and Asia has made some real gains in per capita availability of maize.

Much of CIMMYT's effort continues to be on improving the genetic yield potential, but even more effort is now going into increasing yield dependability under environmental stress conditions. That is why you are here this week. We are trying to close the gap between potential yields and those on farmers' fields. This is the reason that the emphasis on on-farm research and production agronomy has become a much more substantial part of our program in the last few years.

The biggest problem we face is population growth, with which you are familiar. When I was born, the population of the world was less than 2 billion people. If I live my three score and seven years, the population by the end of my life time will exceed 6.5 billion. This is what can happen to the population of the world within the space of one man's life. This is the challenge that faces us in the years ahead, and this is where our opportunity lies.

In Bangladesh, many farmers' fields previously produced less than one-half ton of dryland rice per hectare per year in rotation with the main rice crop. In 1984, that same land produced in the neighborhood of 2.5 tons of wheat under similar conditions and with similar irrigation schedules. This type of progress gives us hope for being able to meet the needs of the population challenge.

In a recent publication, Derek Byerlee reported that, in 1981-82, worldwide wheat imports exceeded 100 million tons for the first time. That is an immense amount of wheat being traded to feed the world's people. Perhaps more disturbingly, 61 million of those 100 million tons were going from developed countries to developing countries; much of it was going to the recently emerging developing-country market economies to sustain domestic food supplies. Twenty years ago most of the trade was between developed countries, from the United States and Canada to Europe and Russia. Now 27 developing countries, many of whom are represented here today, are importing more than 500,000 tons of wheat per year to sustain domestic food supplies; 17 of those 27 are importing more than a million tons.

An increasing dependency on staple foods from abroad is a serious economic and political problem for many developing countries. In recognizing that problem several years ago, the Technical Advisory Committee of the

CGIAR asked CIMMYT to put more emphasis on developing wheats for more tropical environments. CIMMYT management, then as now, agreed that this was an important challenge. It would, however, be a long-term project, and progress would be slow. It is easier to increase production in good production environments than it is in poor production environments, and there was still an immense challenge for increasing yields in the better environments. Therefore, CIMMYT was not sure how much of its resources should be diverted toward the more tropical, more difficult production environments. We suggested that, if the CGIAR could provide extra-core special project funding, CIMMYT would be pleased to accept the challenge and coordinate the efforts to develop wheats better adapted to more tropical environments.

In the CGIAR system, there was a good friend representing an organization who came forward quickly and said, "Accept that challenge. Let us fund it." That person is with us today, and he is your next speaker. Let me present to you William Mashler of the United Nations Development Programme.

## **Keynote Address: Wheats for More Tropical Environments**

**W.T. Mashler, Senior Director, Division for Global and Interregional Projects, United Nations Development Programme**

It is always a great pleasure for me to be at CIMMYT, as UNDP and CIMMYT have had a long-standing relationship of a special nature with each other. When Bob Havener and Arthur Klatt kindly invited me to come to this conference on tropical wheat, I readily accepted the invitation. While I have been asked to be a keynote speaker at this conference, which is strictly devoted to research on tropical wheat, I would also like to give you an overview of UNDP's global agricultural research and related activities, including support to research on tropical wheat. To begin with, I would like to provide a brief historical perspective of the Global and Interregional Programme which I have directed since its inception in 1971.

The visit of Paul Hoffman, the first Administrator of UNDP, to the International Rice Research Institute in the Philippines in 1969, and our subsequent contacts with CIMMYT, led to the genesis of UNDP's Division for Global and Interregional Projects (DGIP). The idea was that UNDP, as the world's most broadly based partnership for technical cooperation, had both the opportunity and the obligation to increase its involvement in development efforts with potentially world-wide impact. In January 1970, UNDP's Governing Council approved support for "Global One," an international effort to develop high-protein varieties of maize, a food crop important in the diets of millions of persons throughout the world. With this project, UNDP embarked upon a new form of development support: basic scientific research aimed at finding new

solutions for old problems, in this case, improved nutrition. This began our long-standing and fruitful cooperation with CIMMYT, which in effect helped create the concept of UNDP's global research, the results of which could be spread to a wide spectrum of developing countries. Some years have passed since "Global One" began full-scale operations and, during this time, UNDP's Global Program has grown into a worldwide collaborative research effort of the highest scientific quality. A complementary program of inter-regional activities is designed to spread research results and to assist developing countries in other areas requiring international cooperation. Today, the combined program spans five areas of critical importance to developing countries:

- Food and agriculture
- Health, including drinking water and sanitation
- International economic relations and economic cooperation among developing countries
- Energy
- Human resources

More than 100 developing countries are participating in projects currently under implementation in these various sectors.

Two basic convictions underlie all of the Global/Interregional Programme's activities. The first is that every serious development must be accompanied by a constant search for new knowledge and new approaches which strike not only at the symptoms but at the causes of underdevelopment. The second is that many problems faced by developing countries can be dealt with effectively only within a framework of

global cooperation that permits a pooling and exchange of knowledge, skills and experience. Over the years, the Global and Interregional Programme has proved to be a highly useful vehicle for promoting such cooperation, both among developing countries themselves, and between UNDP, other international donors and recipient countries. The Programme's "multiplier effect" has been substantial. Between 1971 and 1982, for example, US\$ 104.2 million of UNDP's global and interregional funds have helped to generate, and have been pooled with, an additional US\$ 1,816.3 million mobilized from other sources in support of common efforts. This represents an amount nearly 17½ times larger than the catalytic UNDP contribution.

Another great strength of the Programme has been the opportunity it has provided for UNDP to pioneer and innovate. Respecting always the importance of close consultation with governments, United Nations agencies, foundations and others capable of giving advice in formulating the Programme and developing individual projects, we have been able to embark upon a number of promising new approaches to problems which have historically plagued mankind. And thus, with a bit of imagination, careful planning and tight management and monitoring, the program has, in many cases, helped to convert promise into reality.

As in so many worthwhile endeavors, resources are at best low and one is led to question how hunger can be attacked with hunger. Yet somehow we have managed, and I hope that in the years ahead the level of resources at UNDP's disposal will permit not only a continuation of UNDP global and interregional activities, but their expansion. Few other activities supported by international systems of

assistance have been more responsive to the call of the Preamble of the Charter of the United Nations to "employ international machinery for the promotion of the economic and social advancement of all peoples."

There are two features of UNDP's global activities which set them apart from the typical UNDP-supported project. The first is that they are research-oriented activities which involve a complex and long-term process including:

- Fundamental research;
- Field testing or clinical trials;
- Further research to adapt results to diverse conditions prevailing in different countries and regions of the world;
- Training of large numbers of national scientists and technicians in the application of results, and
- Strengthening agricultural and health services to achieve effective delivery.

By its nature, this is a process which requires sustained long-term support at a minimum level over a 10 to 15-year period in many cases and, frequently, longer. I have stressed this point repeatedly over the years, and I do so again today.

I also stated earlier that another unique feature of the global activities is that they represent a collaborative effort supported jointly by UNDP and a large number of other donors, as well as developing countries themselves. To mobilize the needed resources, UNDP has helped promote and has played a key role with other organizations, both within and without the United Nations system, in building up several major consortia which now provide hundreds of millions of dollars annually for agricultural and health research. The most prominent example is the Consultative Group on International Agricultural Research (CGIAR), of which UNDP is a co-sponsor, together with FAO and the World Bank. In most

cases, UNDP resources from the global projects play an important catalytic role in attracting collateral support from other donors. What is remarkable is the fact that these supporting organizations are ones which generally like to see minimum risk and maximum safety in investment. They have learned quickly and with unmatched enthusiasm that risks taken, as they must be in scientific research, can pay handsome dividends, particularly when the investments are made in institutions of excellence such as the IARCs. Equally remarkable here is another fact; the actors and personalities who created the system are for the most part gone, but those who are now representing their donor organizations are no less supportive of the system than were their predecessors. Speaking of networking in the area of scientific research, we have scored success also in achieving what hopefully will be a long-term network of donor support.

I mentioned that the main emphasis in the global program is placed on agricultural research, which represents 72% of the program's resources; health research has claimed 24% of the available resources. The program in agriculture consists of:

- Development of improved varieties of important food crops such as rice, wheat (adapted to tropical climates), maize, sorghum, millet, cassava, sweet potato and potato, combining higher yields with resistance to pests and diseases, at selected IARCs;
- Enhancement of the nutritional quality of maize through increasing its protein content, at CIMMYT;
- Multilocation testing of different strains of rice to adapt them to various agroecological conditions, including drought, cold, adverse soil conditions, pests and diseases as part of a global network of rice testing programs, at IRRI;
- Research on enhancement of biological nitrogen fixation by free-living bacteria, azolla and blue-green algae in association with paddy soils, and also fixation-associated food legumes such as cowpeas and soybeans, at IRRI, IITA and ICARDA;
- Improvement of efficiency of soil-water use by food crops under arid conditions, at ICARDA;
- Intensification of research on the development of pest management techniques through biological methods of control as an alternative to expensive, toxic and environmentally unsafe chemical pesticides, at ICIPE;
- Continuation of basic research to develop effective and economically viable measures to control trypanosomiasis and other diseases which seriously limit livestock production, at ILRAD;
- Research and training in fertilizer technology and utilization to conduct studies on the efficiency of nitrogen and phosphorus fertilizers under different soil conditions, and a program to train developing-country personnel in fertilizer production, distribution, marketing and utilization, at IFDC;
- Intensification of current agroeconomic research in East Africa and its extension into Asia through on-farm trials and farm level surveys to facilitate the adoption of improved technology by farmers, at CIMMYT, and
- Research on food systems being conducted by IFPRI in association with the United Nations Research Institute for Social Development and the United Nations University.

Recognizing the importance of closer links between our global research projects and national programs, we have made a special effort to expand, to the extent possible from available resources, the scope of our projects to strengthen national capabilities through increased training opportunities, conferences, workshops and, in certain cases, small grants to selected national institutions to undertake collaborative research. The International Rice Testing and Improvement Programme and the West African Sorghum and Millet Improvement Programme being supported by UNDP are excellent examples of such collaborative programs designed to strengthen links with national institutions. Expanded training of nationals of developing countries continues to be a vital and integral part of all of our current and future projects. However, it is obvious that, in view of the financial limits of our Global Programme, a much larger effort has to be made by donor agencies and developing countries themselves to mobilize adequate resources to strengthen national institutions, so as to ensure sustained agricultural production in developing countries to meet the needs of a growing population.

In all of our projects with the IARCs, we have, from the beginning, encouraged inter-institutional cooperation in pertinent fields, including close linkages with related disciplines. For example, ever since we became involved with CIMMYT on research to improve the quality of protein in maize, I have been emphasizing to crop-oriented IARCs the importance of developing closer interaction between nutritional and crop sciences, so that an understanding can be reached on the parameters for nutritional improvement of food crops. I am indeed glad that we played a role in bringing together concerned IARCs at the recent nutrition workshop at ILCA, supported by UNDP, which was the culmination of an effort which I started years ago.

Although the IARCs were created as individual entities, it was always the intent of the founder of the CGIAR system that they interact with each other within a system of centers. As the IARCs have grown and matured, we can now see how they fit into the system, respond to each other's needs as well as to those of national programs, and thus are forging important links and networks whose effectiveness will increasingly benefit the objectives of our joint aims. This issue needs to be pursued vigilantly and new opportunities recognized and seized. As an example, I point to the study of the integration of IARC activities in southern Africa (Southern Africa Development Coordination Conference, SADCC), which was initiated at my suggestion at the last meeting of the CGIAR in 1984. Other examples of intercenter cooperation are the recent agreement between CIMMYT and IITA on maize research in Africa, collaborative arrangements between ICARDA and CIMMYT and joint endeavors between CIAT, CIP and IITA. There are many others, including the joint rice-wheat integrated production trials initiated by IRRI and CIMMYT.

Going back to our association with CIMMYT, it is a matter of great satisfaction to us that UNDP's sustained assistance to research at CIMMYT has contributed to a major breakthrough in the development of the high-quality protein maize. This is indeed a spectacular achievement in research on plant breeding and genetics involving a crop which constitutes the staple diet of millions of people in the world. A stage has been reached where efforts should be made to encourage countries to adopt the nutritionally rich maize on a large scale, although it is recognized that in several countries an active promotional campaign is needed to familiarize farmers and senior

government officials with the potential benefits of the new maize. We are pleased to extend continued UNDP assistance to research and training in maize improvement for an additional period of five years, beginning in January 1985. The project recently approved by our Council presents a new image involving three program thrusts, international testing, training and nutritional studies. CIMMYT will be able to sustain and expand its international maize testing and to transfer to developing-country farmers improved maize varieties, combining higher yield and nutritional quality. Over 50% of the funds requested from UNDP will be spent on training developing-country scientists at various levels in all aspects of maize improvement. The nutritional studies envisaged in the project will be an essential complementary activity to be implemented by the Instituto de Investigación Nutricional (IIN) in Peru, under subcontractual arrangements with CIMMYT.

Now I wish to make a few remarks on our support to research on wheat adapted to tropical environments. I shall confine myself to some general observations, as all the technical aspects will be covered in depth at this conference. The considerable vision and forethought displayed in our global program is attested to by the fact that I have been extremely receptive to new ideas and have readily responded with funds, from whatever resources were available, for new research initiatives which have the potential to produce promising results. Our support to CIMMYT's program to develop wheat varieties adapted to tropical environments is a striking example. Wheat accounts for more than one-quarter of total world grain production,

and is a staple food for one-third of the world's population. Originating in the subtropical and temperate climates of the Middle East, over the centuries wheat spread into temperate northern climates. There, cultivators and scientists greatly improved its yield potential, the breadth of its adaptation and its resistance to the pests and diseases most devastating in those environments. In the early 1960s, CIMMYT developed the first high-yielding dwarf wheats, which dramatically increased yields throughout the world.

Bob Havener and his associates believed that wheat could play a much more important role in tropical countries, if resistance to a variety of fungus diseases and insect pests could be overcome. It has considerable tolerance to drought, is a high-yielding crop of short duration and provides high quality food which is readily accepted. I agreed to advance some funds for further preparatory work. CIMMYT has already started to cross wheat with related tropical grass species to see if their insect and disease resistance can be transferred, as well as some of their tolerance to tropical soils.

Developing countries throughout much of the tropics are also becoming increasingly dependent upon wheat as a relatively low-cost source of food for their urban poor and landless populations. Some wheat is home grown in the tropics and subtropics during the drier, cooler seasons, but yields are relatively low, due to the generally short growing seasons. The crop also suffers much damage from insects and diseases, since little research has been done to develop resistance to tropical pests and diseases. Tropical countries must, therefore, import wheat to satisfy domestic demand, using up scarce foreign exchange.

With UNDP assistance, CIMMYT expanded this research to:

- Identify and assemble available germplasm of wheat and related species possessing agronomic characteristics desirable for warmer, subtropical areas;
- Intensively screen these materials for desired traits;
- Establish special advanced generation nurseries to facilitate screening, and
- Arrange locations for testing advanced materials.

In 1982, UNDP agreed to support a five-year project with a contribution of US\$ 2.5 million to enable CIMMYT to further expand research to develop high-yielding, disease-resistant, semidwarf wheats that would perform well in the warmer, subtropical areas of the world. At that time, three-fourths of all wheat grown in developing countries were varieties developed or improved at CIMMYT. In addition to breeding and testing, the project involves training and conferences for the exchange of information and experience. Personnel from developing countries are being trained in the development of new varieties, agronomic research and disease methodology. Regional workshops and conferences are bringing CIMMYT and developing-country scientists together to focus on research progress and problems. The project will also enable CIMMYT to provide basic research equipment which is lacking in many countries. It is extremely gratifying to note that the results obtained to date are encouraging and it can be hoped that, in the not too distant future, several varieties adapted to tropical environments will be available for production programs.

Another example of my encouragement and support to new research ideas is the program on wide crosses in wheat and maize. I have been fascinated by the idea of transferring genes into or among crops for greater disease resistance, tolerance to environmental stresses, such as drought, salinity, acidity and aluminum toxicity, and higher protein quality. I am confident that an intensification of research in this area, with support from the donor community, will produce useful and applied results in the foreseeable future. I am indeed glad to have been able to provide modest financial support from UNDP, since additional assistance will be forthcoming from other donors. Understandably, this program may present a higher risk than conventional breeding programs, as there is no guarantee that it will be successful as a source of genes for the germplasm development and breeding programs. However, in my years of experience in development projects, I have never hesitated to take a risk or gamble as long as I am assured of the scientific quality of the programs and that they will be implemented by first-class scientists from reputable institutions. Ultimately risk is what science is all about; if we do not take risks, nothing will happen.

Now I wish to make some concluding remarks about the great many efforts being made in international agricultural research. The vision which led to the establishment of the original IARCs and, subsequently, to the creation of the Consultative Group was a significant, if not the most important, step in the direction of filling a tremendous void which had impeded international agricultural development. What started as an intended first step cannot be regarded as the fulfillment of the vision; it was merely the first step. We here, and others elsewhere, who are parties to this most essential endeavor,

must realize that the centers have been cast in a role much greater than research on crops, cropping and farming systems. They should, in my view, become the catalysts and diagnostic tools in anticipating the concomitant needs that must be addressed in the years and generations ahead, so that the dynamics generated at the time of their creation do not falter or stagnate. With every step, with every solution found to problems, with every bit of new knowledge acquired, there arise new issues in a changing and growing world. The centers are uniquely positioned now to play this role, and they are able to anticipate in scientific and technical terms the projected needs and demands which go beyond their original mandates. They are, therefore, in a position to create awareness among those in the political sphere of their responsibility to help their constituents reap the full benefits of properly applied scientific opportunities.

In short, vision, opportunities and responsible interaction will ultimately create the climate for enlightened decisions to be made. This will take courage and persuasion.

Food, health, water and energy are essential to sustain life on our planet. They have a fundamental impact on the human condition, and will ultimately determine whether human beings can function to the optimum level of their capacity. This is the

crucial element in development, and must be the foremost concern, as I am sure it is, of each and every government. Over the last 14 years, I never permitted this important consideration to be lost in our support of what I believe to be the cornerstone of development and the right of every human being.

We, in the donor community who have supported your work, are truly grateful to you who are in the midst of a great enterprise that has produced much and holds forth the promise of exciting new ventures for the improvement of the condition of mankind. When we look around us and see how much time, money and effort is spent on so much that is unproductive, wasteful and discouraging, we can only marvel at how much is being achieved with so little here in the interest of so many. Too few in our world know, much less appreciate, the splendid achievements of these international enterprises which transcend political borders, differences and conflicts. In international research, political chasms have to be bridged by the scientific fraternity. It is initiative and commitment which are indispensable.

It seems to me that individual people are more important than institutions, which are the servants of people. Selfish objectives must be sublimated in the interests of vast numbers of people living in poverty and looking for hope. We can take great pride in our joint endeavor, which is an essential ingredient for the improvement of the quality of their lives. Indeed, it points the way towards eliminating intolerable inequities and laying the foundations for peace.

## **Introduction to the Symposium on Wheat for More Tropical Environments**

**A.R. Klatt, Associate Director, Wheat Program, CIMMYT, Mexico**

It is my pleasure, on behalf of the organizing committee and the CIMMYT Wheat Program, to welcome you to Mexico and to this Symposium on Wheats for More Tropical Environments. We hope your stay in Mexico and your participation in this symposium will prove to be both interesting and rewarding.

Mr. Mashler has just shared with us his insights into the problems associated with introducing wheat as a commercial crop in more tropical areas. The constraints are obviously numerous and complex, and will require a concerted and coordinated research effort to resolve. I want to emphasize the need for a coordinated approach to this research endeavor and note that, while we have a basic understanding of the directions in which this research should move, at this time we have few answers to the numerous perplexing problems before us.

### **Reasons for the Symposium**

Many people have asked why a symposium on wheats for more tropical environments is being held now, given the limited information and research results currently in hand. Research on tropical wheat does constitute a recent initiative, and it would be premature to draw extensive conclusions from data now available. Nevertheless, there is much to be gained at this time from a symposium such as this. If a truly coordinated approach to research is to be implemented, it is essential that an exchange of ideas among involved scientists occur early in the process. This forum has been created in an effort to encourage and facilitate the interaction of wheat researchers who

have worked in the target environments of the world, as well as those who are just beginning their research. We are confident that this interaction will lead to a mutually beneficial sharing of ideas and specific information relative to the development of better-adapted wheats.

It is also hoped that, as we identify the major constraints to the cultivation of wheat in more tropical areas, we can come to some agreement as to their relative importance. By collectively assigning priorities to various research activities, we should be able to work together in a more coordinated and cooperative manner, thus facilitating the resolution of the most pressing problems. The papers presented here will describe the research currently underway, much of which is focused on problem identification and definition. A better understanding of the scope of these current research activities, in the context of our common objectives, will greatly help us in establishing priorities for future research.

### **Some Key Definitions**

Before proceeding any further, it is important to clarify what is meant by the terms "tropical wheat" and "wheats for the more tropical environments." The use of the term "tropical wheat" does not mean that wheats for hot, humid, rain forest environments are under development. Wheat is a temperate crop, and it may not even be possible to develop germplasm that will survive in rain forest environments. "Tropical wheat" is merely an easy way of referring to "wheats for the more tropical environments." That is, we at CIMMYT

and many of our cooperators around the world are attempting to identify wheats that can be grown successfully in the warmer areas of the world where wheat is not a traditional crop.

Tropical wheat environments include most of the areas lying between the Tropic of Cancer (23° north) and the Tropic of Capricorn (23° south), plus adjacent areas with tropical or subtropical conditions. Within this area of the world, there appear to be two basic types of environments in which wheat can be grown. One is characterized by warm temperatures, generally sunny days and low relative humidity compared to the norm for the tropics. Under these conditions, disease resistance will not be a major consideration, but varieties with heat tolerance and adapted to a rather short growing season will be necessary. The other major wheat environment is typified by warm temperatures and higher relative humidity. A number of wheat diseases, many of which are not common to traditional, temperate, wheat-growing areas, will be prevalent under these conditions. For wheat to be successfully grown, better resistance to these diseases must be incorporated.

### **CIMMYT's Interest in Tropical Wheats**

CIMMYT's research mandate calls for the rapid and continuous development of improved germplasm, primarily for use in the developing world. Approximately one billion people live in the tropical countries of the developing world and, while wheat is currently a minor crop in the tropics, its consumption is increasing rapidly, especially in the urban areas. As of mid-1983, about 85% of the wheat consumed in tropical nations was being imported, and these countries accounted for about 20% of the total world wheat trade.

Rapidly expanding consumption of wheat in the countries of the tropics is resulting in an increasing dependence on imports. In many instances, these imports represent a large drain on foreign exchange. Many governments now believe it would be better to conduct the research necessary to develop wheats for their specific conditions, in order to be able to grow at least a portion of their wheat requirements.

The development of wheats adapted to the short, cool season in these more tropical countries would also allow for crop intensification. Rice is currently the predominant crop, and is generally grown during the summer monsoon. A second crop is seldom grown in the winter season, except in those areas where irrigation is available. With its lower moisture requirements compared to rice, and with its adaptation to cooler temperatures, wheat has potential as an alternate crop for the winter season. In many instances, a crop of wheat could be grown on residual moisture or with limited irrigation, and recent research has indicated that reasonable yields can be achieved under these conditions. By introducing a second crop into the cropping cycle, the total domestic production of food grains could be significantly increased.

### **General Production Constraints**

There are many production constraints that must be resolved before wheat can be introduced successfully into these environments. Resolving these problems would benefit more than the tropical countries alone; wheat production in many of the traditional wheat-growing areas would also be enhanced. Among the areas requiring research are the following:

#### **Heat tolerance**

Germplasm with better tolerance to higher temperatures is absolutely necessary for many areas. Greater heat tolerance during the juvenile growth stage and also during the flowering and

grain-filling stages are required. Screening efforts are underway to identify germplasm of this type. Its development would benefit tropical wheat areas, as well as many traditional wheat-producing areas, such as Bangladesh, northeast India, southern Pakistan, South China, the Cerrados of Brazil and other subtropical areas.

#### **Better disease resistance**

As mentioned earlier, diseases will be a problem primarily in the more humid regions. Leaf rust, stem rust, *helminthosporium*, *fusarium*, root rots and possibly barley yellow dwarf are the diseases that will most likely be important. Good resistance to leaf rust and stem rust are available in existing germplasm. Intensive efforts, frequently in cooperation with national programs around the world, are now underway to identify sources of resistance to *Helminthosporium* and *Fusarium* species. A cooperative program has been initiated with China to identify wheats with better resistance to *fusarium* head scab, and a similar cooperative effort is being pursued with Brazil to identify better resistance to *Helminthosporium* species. These efforts, in combination with others, should give us wheats with much improved levels of resistance within the next five years.

It is probable that root rots will cause severe losses in certain environments within the tropics. We know very little about the array of organisms that cause root rots; this topic will be further discussed during the symposium.

Barley yellow dwarf is a problem in many environments of the world, not just in the tropics. CIMMYT, in cooperation with many national programs, has undertaken an international effort to develop germplasm with better barley yellow dwarf resistance. Once resistance is identified, it will only be necessary to transfer it into adapted wheats.

#### **Agronomic practices**

In many tropical countries, little research has as yet been conducted on the agronomic practices required to successfully grow wheat. In the near future, we must elucidate the various agronomic practices that will be required to successfully cultivate wheat in the diverse environmental conditions of the tropics. Paramount among these practices will be proper dates of seeding, weed control, fertilization and, of course, proper soil management.

The majority of the soils in the tropics are paddy soils with a high clay content and, generally, a hard pan which helps to retain moisture during the growing of the rice crop. We know little about growing wheat on these soils, but the problems associated with the cultivation of wheat under these circumstances are many. It is quite likely that wheat will be first grown under upland conditions in the tropics, since more research information is available for these conditions. The various problems related to agronomy will be covered in much more detail during the symposium.

#### **Conclusions**

In closing, let me repeat that the purpose of this symposium is not to resolve the various constraints to introducing wheat into the tropics. Rather, our main objective is to bring together wheat researchers from around the world in an effort to facilitate the exchange of ideas and information. We are striving for a collective awareness and common understanding of the major problems before us. In striving for this common ground, the stage will be set for the kind of cooperative global effort needed to successfully develop wheats for more tropical environments.

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## Country Reports

### Selecting and Introducing Wheats for the Environments of the Tropics

C.E. Mann, Wheat Program, CIMMYT, Bangkok, Thailand

#### Abstract

*The estimated wheat area in the tropics, i.e., between 23°N and 23°S latitudes, is 3 to 4 million hectares. The potential exists for the expansion of this area as a result of research. A survey of climatic conditions and wheat yield levels from 28 experiment stations in 15 countries between 1 and 39° N and S latitudes shows only a moderate association between climate and yield. Average minimum temperature for the month after flowering has the highest correlation with yield ( $r = -.51$ ), indicating that other more controllable factors, such as crop management and germplasm, have considerable influence on yield. Important research objectives for tropical wheat are presented in this paper, and the importance of strong national programs is stressed.*

The purpose of this overview of tropical wheat is to establish a frame of reference for the country reports. After discussing the present wheat production situation in the tropics and the interests of national programs in pursuing wheat research, a tentative list of production constraints which are common to many places in the tropics will be presented. This is done mainly from the author's experience; the country reports may either substantiate this list or emphasize other factors, some of which may be general problems applicable to the tropics, and others, problems specific to certain tropical environments.

#### The Wheat Situation in Tropical Countries

The word "tropics" as used here refers to the area between the tropics of Cancer and Capricorn, that is, between 23°N and 23°S latitude. There are 85 countries that have 20,000 or more square kilometers of territory within the tropics. Of these, some have no interest in wheat production, and some have no arable land in their tropical zones. Eliminating these, there are still 57

countries which have grown wheat in the tropics at some time during the last three years, either experimentally or commercially (Table 1).

Among those countries that lie entirely within the tropics, or which grow the majority of their wheat in the tropics, 566,000 hectares of wheat were grown; nearly half of this amount was in the Sudan. A more meaningful figure is reached by also including those countries that, although the majority of their wheat is grown outside the tropics, have substantial wheat areas within their tropical zones as well. This allows the inclusion of the vast areas of peninsular India and southern China, the wheat-growing area in northern Brazil, and smaller portions of other countries, such as the lowlands of Bolivia and southern Bangladesh. This figure is estimated at between 3 and 4 million hectares, with more than half of the total in India. Clearly, wheat is not a completely new crop in the tropics. Table 1 indicates the growing interest in expanding wheat production into tropical areas; a number of countries which grow no wheat commercially are, nevertheless, beginning to do some research on wheat.

Table 1. Countries growing wheat in the tropics and areas of production, 1981

Country	Area <sup>a/</sup> (000 ha)	Country	Area <sup>a/</sup> (000 ha)
<b>America</b>		<b>Africa (con'd)</b>	
Mexico	(861)	Tanzania	(50)
Guatemala	(64)	Rwanda	(4)
Honduras	1	Burundi	(6)
Nicaragua		Angola	(16)
Costa Rica		Zambia	(3)
Dominican Republic		Malawi	1
Colombia	(39)	Mozambique	3
Venezuela	(2)	Madagascar	
Guyana		Zimbabwe	41
Brazil	(1,921)	Namibia	1
Peru	(100)	Botswana	3
Ecuador	(37)		
Bolivia	(77)	<b>Asia</b>	
Paraguay	(70)	Saudi Arabia	85
<b>Africa</b>		Yemen, Arab Rep	66
Mauritania		Yemen, PDR	10
Mali	2	Oman	0.3
Niger	2	Fed. of Arab Emirates	0.4
Chad	3	India	(22,104)
Sudan	240	Sri Lanka	
Ethiopia	(523)	Bangladesh	(591)
Senegal		Burma	88
Upper Volta		Thailand	
Ghana		Vietnam	
Nigeria	13	China	(29,201)
Cameroon	2	Taiwan	
Somalia	4	Philippines	
Zaire	(5)	Malaysia	
Uganda	(4)	Indonesia	
Kenya	(120)	<b>Australia</b>	<b>(12,041)</b>

<sup>a/</sup> Numbers in brackets indicate that the majority of the wheat area is outside the tropics or above 1500 m altitude

Source: FAO Production Yearbook (4)

The need for research on wheat production in the tropics is reinforced by the fact that seven of the eight countries which increased wheat production by more than 5% annually between 1961-65 and 1981-82 (2) are located completely or partially within the tropics: Sudan, Tanzania, Zimbabwe, Yemen, Bangladesh, Brazil and Paraguay.

It is not possible to give a precise estimate of the extent of the tropical area in which wheat can be grown, either immediately or after a reasonable amount of research in agronomic practices and variety development. However, three major areas offer potentially millions of hectares of wheat land, if research can help to solve the following management problems:

- Cerrado lands—The Cerrados are characterized by tree-bush-grass ecosystems and occur in Brazil between 5 and 20°S latitude and 45 and 60°W longitude. Twelve million hectares in this area are estimated as being suitable for wheat. The soils are red-yellow and dark red latosols; they are very deep and have a high clay content, low natural fertility and high aluminum saturation (3). Similar conditions can be found on other continents, although not in such a large single block.
- Rice paddies—Millions of hectares of land throughout Asia lie idle during the dry season, because there is not enough water for a second rice crop. Although these lands appear promising, no attempt will be made here to estimate the size of the area, since there has been little research on the interactions between such factors as water retention capacity, depth of soil above the plow pan and drainage.
- Lands that could become available as a result of better plant protection—This protection against nontraditional wheat diseases could come about either through chemical or genetic means, and would immediately open new areas where wheat could compete with other crops. It would also make irrigation and land-clearing projects more feasible.

Can the limits to expanding wheat production be described *a priori*? It does not appear that production is limited by mere geographic location, since triticale grows well at sea level in Jaffna in northern Sri Lanka and wheat grows reasonably well at sea level at Mojosari, East Java. The correlation between latitude and yield of the best five varieties at each site of the 18th ISWYN (1), after deleting all tropical sites above 1500 meters and Harare, Zimbabwe, is only .341; a parabola does not give a better fit. The latitude of the 55 stations of the nursery ranges from 12 to 60°, and yield, from 1.3 to 8.6 t/ha. As nothing can be determined from these figures, other factors must have considerable influence.

In order to determine whether meteorological data can help to define tropical limits for wheat, the form presented here as Figure 1 was sent to about 40 experiment stations around the world where wheat was known to have been grown. Most of them are in the tropics below 1500 meters, and some are in traditional wheat-growing areas outside the tropics. About half of them answered in time to present the data here. Some did not have all the data requested, and some sent data from additional stations in their country. Therefore, the results include data for relative humidity and average monthly maximum and minimum temperatures from 28 stations (Table 2).

Month of sowing and month after flowering were chosen for calculations because these are critical growth stages in the tropics, representing, respectively, plant establishment, grain filling and possible disease development.

Linear correlations between yield and weather data are given in Table 3. Only the correlation with average minimum temperature at month of sowing is highly significant, and its coefficient of determination is only 26%. This is not high enough to use as a basis for estimating yield potential in a certain

area. Calculating the multiple correlation of these six characters with yield accounts for 47% of the yield variation; the four significantly correlated characters account for 43%. This tends to confirm a hypothesis based on the experience of tropical wheat scientists, that yield levels are not dependent on maximum temperatures and are only marginally influenced by minimum temperatures.

Caution must be used in generalizing from these findings, and further data will have to be considered to improve

**Climatological Data During Wheat Growing Season**

**Name of station:**

**Town:**

**Province:**

**Country:**

**Latitude:**

**degrees**

**minutes**

**Elevation:**

**m**

month							
monthly average maximum temperature							
monthly average minimum temperature							
rainfall (mm)							
relative humidity (o/o)							
hours of sunshine							
potential evaporation (open pan evaporation)							

normal sowing time of wheat. . . . .
normal harvesting time of wheat. . . . .
yield level = average yield of five best lines of advanced yield trial: . . . . .

**Figure 1. Form sent to experiment stations for gathering meteorological data, 1984**

accuracy. However, it can be concluded that yield is not severely limited by latitude or climatic conditions. With more data, the correlation coefficient can be expected to be even closer to zero; some of the stations close to the equator were only in their second or third year of growing wheat, and their yields can be expected to rise with more experience in crop management.

Thus, a strong plea is made here for adaptive research in every tropical area where wheat is considered a potential crop. To further illustrate this need, the yield of some well-known varieties can be compared between tropical and traditional areas (Table 4). The varieties

Ures, Pavon and Nacozari are well above average in traditional wheat locations, such as Ciudad Obregon, Mexico, and Faisalabad, Pakistan; they are below or only slightly above average in tropical areas. UP262 performs in the opposite manner, and Sonalika and Quimori are erratic in performance.

Earliness is another unpredictable character as varieties are moved to the tropics. While Pavon is five days later in flowering than Nacozari at Ciudad Obregon, they are equal in maturity at Faisalabad; Pavon is 27 days later than Nacozari at Chiang Mai, Thailand, and nine and eight days later at Villa Guede, Senegal, and Campinas, Brazil, respectively. UP262 is even earlier in the tropics than in traditional areas, a

**Table 2. Location of experiment stations replying to request for meteorological data, 1984**

Country and station	Elevation (m)	Latitude (°N or S)	Country and station	Elevation (m)	Latitude (°N or S)
Argentina			Indonesia		
La Dulce	72	38	Kuningan	545	7
Brazil			Mojosari	30	8
Brasilia	1000	16	Margahayu	1250	7
Londrina	566	23	Sukarami	928	1
Burma			Philippines		
Yezin	97	20	Los Baños	22	14
Lashio		23	Sudan		
Taunggyi	1439	21	Wad Medani	411	14
Monywa		22	Thailand		
Sagaing	70	22	Chiang Mai	314	19
Mandalay	74	22	USA		
Bangladesh			Yuma, Arizona	100	33
Joydebpur	8	24	Woodland, California	21	39
Jessore	8	23	Yemen, PDR		
Ishurdi	7	24	Seiyun	700	16
China			Zambia		
Nanjing	12	32	Chilanga	1213	16
Costa Rica			Zimbabwe		
San Josecito	840	10	Harare	1496	18
India			Chiredzi	429	21
Indore	557	22			

**Table 3. Correlation coefficients between yield and climatological parameters, 28 locations in 15 countries, 1984**

Parameter	Range	Correlation coefficient with yield
Yield	800-10,100 kg/ha	--
Average minimum temperature		
Month of sowing	3.7-23.6°C	-.40*
Month after flowering	8.7-20.8°C	-.51**
Average maximum temperature		
Month of sowing	12.0-36.1°C	-.16
Month after flowering	14.8-32.4°C	-.33
Average relative humidity		
Month of sowing	37-86%	-.45*
Month after flowering	38-89%	-.40*

\*, \*\* Significant at the 5 and 1 % levels, respectively

**Table 4. Relative yields and days to flowering of six wheat varieties in traditional and tropical wheat-growing areas**

Location	Yield as % of location mean						Days to flowering as % of location mean					
	Naco-		Sona-		Qui-		Naco-		Sona-		Qui-	
	Ures	Pavon	zari	UP262	lika	mori	Ures	Pavon	zari	UP262	lika	mori
Traditional area												
Cd. Obregon, Mexico	120	115	114	90	104	82	107	101	96	90	82	86
Faisalabad, Pakistan	108	112	127	92	95	101	105	97	97	93	87	89
Tropical area												
Chiang Mai, Thailand	70	96	96	144	83	180	117	110	83	87	80	81
Villa Guede, Senegal	96	101	87	105	87	81	113	98	89	89	81	93
Campinas, Brazil	94	108	104	112	117	94	114	98	90	87	80	88

Source: The 18th ISWYN, CIMMYT, Mexico

fact that, together with above-average yield, makes it appropriate for tropical environments (if leaf rust is not present). Sonalika has similar maturity across environments. Quilmori again is erratic in maturity, and probably in other characters, especially those of spikes per square meter, spikelets per spike and 1000-grain weight.

Unfortunately, this could not be demonstrated using an orthogonal set of varieties and locations. The need for adaptive research, demonstrated here for germplasm, is probably equally important in other disciplines.

### **Obstacles to the Successful Introduction of Wheat into Tropical Areas**

As researchers, there is a need to categorize production problems into problems of a size that can be handled by research. It is hoped that the following breakdown will be helpful for those presenting country reports.

#### **Breeding and pathology**

Following are some problem areas in this field, together with the knowledge of the genetic variability currently available. These will be summarized in Table 5.

*Early heat tolerance*—Wheats for the tropics must be able to germinate in hot soil, tiller under high temperatures and, subsequently, head normally. Many traditional wheat lines produce only small heads in tropical environments. Genetic variability is available in germplasm with good agronomic type.

*Late heat tolerance*—The plant must have the ability to fill the grain completely under high temperatures. This tolerance is enhanced if the leaves remain green and active long enough to produce required assimilates. Genetic variability in good lines is available.

*Tolerance to late drought*—This character is necessary when wheat is grown on residual moisture. It will enhance grain-filling ability and the retention of the assimilation area. Again, genetic variability is available.

For these three characters, limited knowledge is available regarding the physiological mechanisms of tolerance and their genetic control. There is a vast area for basic research in the three characters.

**Table 5. Breeding characteristics required for tropical environments and an indication of availability of genetic variability and suitable screening methods**

Character	Genetic variability available	Screening methods available
Early heat tolerance	+	+
Late heat tolerance	+	+
Earliness	++	+
Tolerance to late drought	+	+
Tolerance to acid soils and aluminum toxicity	++	+
Resistance to:		
Leaf rust ( <i>Puccinia recondita</i> )	++	+
Leaf blotch ( <i>Helminthosporium</i> spp.)	±	±
Seedling blight ( <i>Sclerotium rolfsii</i> )	—	—
Scab	+	—
Waterlogging, aphids, stem borers	?	?

**Earliness**—Earliness is needed if the wheat plant is going to be able to fit into narrow crop rotations, escape diseases and avoid seasonal environmental stresses. A broad array of genetic variability exists. The main problem is to incorporate this character into lines which are adapted to tropical conditions.

**Tolerance to acid soils and aluminum toxicity**—Considerable research has been conducted for this character, and progress has been made mainly by combining Brazilian and Mexican materials.

**Resistance to leaf rust**—Many resistant lines are available, but resistance is not of lasting character. Changes in the rust virulence require the continuous attention of pathologists and breeders in order to have resistant lines ready for release as current varieties become susceptible. As the wheat area extends into warmer environments, there must be a constant awareness of new races of pathogens.

**Resistance to *helminthosporium***—*Helminthosporium sativum* is by far the most common species in this genus, and much less is known about it than is known about the rusts. Genetic variability for resistance exists, but no complete resistance is known. Genes for resistance from several sources, including species other than wheat, may have to be combined to achieve sufficient resistance for the tropics. Currently, the most resistant lines are not necessarily those of highest yield potential.

**Resistance to seedling blight caused by *Sclerotium rolfsii***—This fungus can be particularly devastating in poorly drained fields. Until recently, it was assumed that there was almost no genetic resistance to it, and that seed treatment or agricultural practices were

the only solutions. However, recent preliminary research in the Philippines indicates some variability for resistance (D.A. Lapis, personal communication).

**Resistance to *fusarium head scab***—This disease is not restricted to hot environments, but can be very devastating under warmer conditions. Genetic variability exists, and considerable research to pyramid genes for resistance is being conducted in China, Brazil and Mexico.

These last three diseases are typical of hot, humid conditions. Knowledge about their life cycle, host range and epidemiological behavior is limited, as are the techniques for working with them. Artificial inoculation procedures and storage and artificial multiplication of spores must be further studied before mass screening of breeding materials is possible.

**Resistance to aphids, stem borers and waterlogging**—These characters are more important in hot climates than in traditional wheat areas. Aphids can cause direct feeding damage, and also transmit virus diseases. They have preferences for certain varieties in experimental plots, but it is not known whether there is true resistance to feeding. Little is known about resistance to stem borers and tolerance to waterlogging.

This short overview reveals the existence of genetic variability for most characters. The breeder must combine these characteristics into germplasm with acceptable agronomic background, so that the farmer is assured of reasonable yields every year. It is easy to breed for a single character while neglecting the others, but such a line will never reach farmers' fields. The country reports presented here should help in the understanding of combinations of characters needed for the various environments of the tropics.

**Yield**—The last character to be mentioned here is yield. Although correlation with latitude is not high, it is certain that yield is, generally speaking, reduced in the tropics. This fact, however, must be viewed in the context of earliness or maturity. Measured in production per day, a 100-day crop of 2 t/ha in the tropics corresponds to a 150-day crop of 3 t/ha in temperate zones. In many areas, this forced maturity is a major advantage of wheat as it facilitates the growing of a second crop and sometimes even a third crop. It must also be remembered that the average yields of major wheat producers such as Australia and Argentina were 1.2 and 1.5 t/ha, respectively, for the 1979 to 1981 period (4). What is most important for small farmers is the fact that small management mistakes, which would normally cause minor yield reductions in temperate climates, can lead to complete crop failures in the tropics.

#### **Agronomy**

Agronomic knowledge about wheat grown in temperate environments needs to be rechecked under hot climate circumstances. The following agronomic factors probably do not constitute a complete list of the problems which will be encountered in the tropics.

**Weeds**—Weed species are often different in the tropics, e.g., volunteer rice in rice-wheat rotations. Higher temperatures may also cause the effects of herbicides to be different.

**Fertilizers**—Fertilization is generally needed, because tropical soils are often poor in nutrients. The short growing season but fast decomposition has to be considered in relation to basal versus split applications.

**Seed bed preparation**—Special tillage practices may be necessary for moisture conservation, because of waterlogging problems or heavy soils.

**Sowing depth**—Further investigation is needed here in relation to stand establishment and subsequent plant development.

These factors are complicated by the strong interactions between them and also by nonagronomic factors, such as variety and the socioeconomic conditions of the farmers growing the wheat.

#### **Seed production**

The production of seed must receive special attention, since the seed multiplication rate is slower under tropical conditions, because of reduced tillering and generally lower yield levels. The short growing cycle, on the other hand, permits two crops per year, if suitable areas for off-season sowing can be identified. This necessitates moving to high elevations, which are often intensively cropped with vegetables or other high-value crops, or shipping seed between countries, which can be very expensive and involve a great deal of logistical support.

#### **Seed storage**

Storage is a big problem in the tropics, especially under hot and humid conditions. Technical solutions suitable for storage on-farm, in the village and at national levels would greatly facilitate the introduction of wheat in many areas. Grain storage is generally given high priority but, at harvest, many farmers do not know whether they will use their grain for food or for seed. Therefore, the use of chemicals for pest control must be considered carefully.

#### **Nontechnical problems**

Previously, problems specific to tropical conditions have been discussed, but the introduction of wheat into a country

requires more than technical solutions. The general aspects of introducing a new technology are thoroughly discussed in chapters 7 and 8 of *Wheat in the Third World* (5). There is a tremendous task of education and institutional change which must be accomplished. Technical personnel must be trained for experiment stations, and researchers often have to become familiar with a crop they have never worked with before. Problem-oriented research must be initiated for the specific needs of the tropics and the tropical farmer. Research findings need to be disseminated to farmers and housewives through extension and agricultural schools.

It will not always be easy to create a research budget for a new crop whose potential has not yet been proven. Credit and marketing face the same problem. However, a technology can never be developed unless there is a research budget. The importance of these nontechnical problems should not be underrated. Lack of leadership, team effort, training and institutional structure can hinder or completely stop every technical innovation achieved through research.

### Summary

The combination of strong national programs and international cooperation has demonstrated that wheat can be grown in the tropics, and that what is being attempted is not impossible. Efforts are being made to push back the limits of possible wheat-growing areas. Results to date have shown that climatic limitations are not impossible to resolve. For the research objectives for wheat in the tropics, and with the limited funds available, care must be taken to consider all aspects which can lead to the overall goal.

To guide our thinking, let us use the symbol of a net hauling in a big harvest of wheat for the benefit of all. If one thread is broken or weak, some wheat may be lost, but the other threads in the mesh can compensate for it to some extent. The whole catch may be lost, however, if there are too many holes in the net. It is the task of everyone involved in tropical wheat to identify the weak spots and get the holes closed; these may be different for each country. The following country reports should point out what is currently being done in each of the national programs and what their strengths and weaknesses are.

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## Wheat Breeding in Northeast Argentina

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The wheat-growing region of northeast Argentina is located in the provinces of Chaco and Formosa between 25° and 28°S latitudes and 58° and 62°W longitudes (Figure 1). The climate is subtropical and has an average annual rainfall of 800 mm in the west and 1,100 mm in the east, with the greater proportion falling in the spring, summer and early fall. The average temperature for January is 27.4°C, and for July, 15.5°C. Frost causes damage to wheat if it occurs late in the year, during the heading stage. In the spring, there are high temperatures; if these are accompanied by north winds, shriveling of the grain can occur.

In northeastern Argentina, wheat is grown under dryland conditions, without fertilization. Crop growth is a result of moisture accumulated in the soil before sowing, rather than of rainfall. Wheat cultivation began to expand in the region after 1962, when there were approximately 5,000 hectares; this area had increased to 82,000 hectares by 1968. This was due in part to a severe drop in the price of cotton, the principal crop of the area. This caused a diversification of agriculture, and wheat was one of the crops that replaced cotton.

After 1969, the area dedicated to wheat fluctuated greatly, as did production and yield; this was caused by weather conditions, low prices and competition



Figure 1. The wheat-growing region of northeastern Argentina

from other crops. During the period 1979 to 1983, an average of 24,000 hectares was planted to wheat in Chaco, from which 16,000 hectares yielded an average of 1,200 kg/ha (Table 1). Approximately 4,500 hectares were under wheat cultivation in the province of Formosa during the same period, with a yield similar to that of Chaco.

The marked decline in the area under wheat cultivation in the last few years has been due, in great part, to unfavorable weather conditions, such as drought in some years, excessive humidity in others and late frosts. Nevertheless, in spite of these adverse conditions, wheat remains the only winter crop which fits into the existing rotation patterns with the predominant row crops of sorghum, cotton, sunflower and soybeans. Wheat is of economic benefit to the farmers, as it brings in income at an opportune time of the year.

Wheat production in northeast Argentina is sufficient to meet the local demand of the flour milling industry in Chaco and northern Santa Fe province.

**Table 1. Wheat area and production, Chaco province, Argentina, 1979 to 1984**

Season	Area planted (ha)	Area harvested (ha)	Grain yield (kg/ha)
1979-80	14,200	11,000	1,201
1980-81	44,500	7,900	1,021
1981-82	11,600	11,100	1,562
1982-83	33,500	32,100	929
1983-84	16,600	15,650	1,295
5-year average	24,100	16,000	1,200

Source: Chaco Extension Service and Planning Office

It is also possible to export some wheat to neighboring Bolivia, Brazil and Paraguay, countries which represent important markets for Argentine products.

### **Wheat Research in Northeast Argentina**

When wheat cultivation started in the early 1960s, the commercial varieties used came from the traditional wheat-growing regions in the humid pampas. As these varieties were not ideally adapted to the conditions of the area, limited yields were obtained with considerable risk to the farmer.

In 1972, because of the need to increase wheat production, a research program was initiated to develop new varieties for the Chaco region, in coordination with the National Council for Wheat Programs. The objective of the program was to investigate the production problems caused by the extreme environmental variation in the area, such as drought, late frosts, high temperatures, low fertility and disease problems.

The specific objectives of the program were:

- Develop varieties of high yield potential and broad adaptation;
- Develop varieties of medium-to-late maturity with good agronomic type;
- Develop varieties with resistance to steA rust (*Puccinia graminis tritici*), leaf rust (*Puccinia recondita tritici*), septoria leaf blotch (*Septoria tritici*), glume blotch (*Septoria nodorum*), diseases caused by *Helminthosporium* spp., scab (*Fusarium* spp.) and powdery mildew (*Erysiphe graminis tritici*);
- Develop varieties with tolerance to shriveling, and

- Produce grain of high industrial and commercial quality for both national and international markets.

Genetic variability was introduced as a result of 200 crosses made each year in Mexico and at the Marcos Juarez Regional Experiment Station in Cordoba, using progenitors with good adaptation for northern Argentina. Individual selection from F<sub>2</sub> to F<sub>4</sub> populations for disease resistance, agronomic characters, grain type and industrial quality was conducted at the Presidencia Roque Saenz Peña Regional Experiment Station. Mass selections were made beginning with the F<sub>5</sub> populations.

Shuttle breeding of F<sub>3</sub> populations was also accomplished through the Balcarce summer nursery at the Balcarce Regional Experiment Station, Buenos Aires. The goals of this off-season nursery were:

- Develop lines with better adaptation;
- Develop lines with resistance to stem rust;
- Achieve homozygosity in fewer years;
- Evaluate advanced lines in preliminary comparative yield trials;
- Evaluate lines to be included in regional comparative trials at Saenz Peña and Colonia Benitez, as well as in various parts of the pampas region;

- Evaluate advanced international lines for good agronomic characters and disease resistance;

- Evaluate commercial bread wheat varieties through comparative yield trials at Saenz Peña, at Colonia Benitez and Las Breñas Experiment Stations in Chaco, and at El Colorado Experiment Station in Formosa, and
- Identify different biotypes (virulences) of stem and leaf rust by observing varietal differences at the various testing sites.

### Conclusions

The cultivar Chaqueño Inta was released as a result of this program; its pedigree is Son64-P4160E x CT244. It has high yield potential, intermediate-to-late maturity, good agronomic characters, disease resistance and good bread-making quality. Chaqueño Inta and Marcos Juarez Inta are the predominant cultivars grown in northeast Argentina. Other commercial varieties adapted to the region are Leones Inta, Buck Pangare, Cargill Trigal 800 and Klein Chamaco. Several advanced lines are almost ready for release and have shown increased yield potential over the best check varieties, have better disease resistance and have acceptable industrial quality (Table 2).

Potential areas for wheat cultivation in rotation with other crops have been determined, and an additional subtropical area in northeast Argentina has been found to hold promise for wheat cultivation within a soybean-wheat rotation. This is the area of Tucuman, Salta and Jujuy in Santiago del Estero province. At present, wheat is grown there on only about 20,000 hectares, but high yields have been obtained under irrigation.

**Table 2. Advanced lines selected for high grain yield and disease resistance, Presidencia Roque Saenz Peña Experiment Station, Chaco, Argentina, 1981 to 1983**

Advanced line	Grain Yield (kg/ha)	Comparison to best control (o/o)	Disease resistance score <sup>a/</sup>	
			Stem rust	Leaf rust
<b>1981 Preliminary Advanced Comparative Trials</b>				
Chaqueño Inta (control)	2787	100	50	10
LAN1 SP.	3581	128.48	10	10
LAN2 SP.	3393	121.74	10	10
LAN3 SP.	3243	116.36	5	5
<b>1982 Preliminary Advanced Comparative Trials</b>				
Chaqueño Inta (control)	1346	100	60	40
LAN1 SP.	1953	145.09	20	10
LAN2 SP.	1880	139.67	10	10
LAN3 SP.	1706	126.74	10	5
<b>1983 Production Plots</b>				
Chaqueño Inta (control)	1760	100	40	30
Marcos Juarez Inta (control)	1705	96.87	10	40
Las Rosas Inta (LAJ2056)	1785	101.42	10	20
LAJ2484	2140	121.56	20	20
LAN1 SP.	2356	133.86	10	10
<b>1982 Regional Comparative Yield Trials</b>				
Chaqueño Inta	1125	100	70	40
LAJ2028 SP.	1495	132.88	20	10
LAJ2395 SP.	1320	117.33	30	30
<b>1983 Regional Comparative Yield Trials</b>				
Chaqueño Inta (control)	1660	100	30	20
LAJ2548 SP.	2070	127.69	10	10
LAJ2082 SP.	2070	124.69	10	20
LAJ2395	1945	117.16	20	10

<sup>a/</sup> Scoring scale 0 to 100 (0-50 = moderately resistant, 51-100 = moderately susceptible)

## Wheat Research Efforts in the Abapo-Izozog Region of Bolivia

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Bolivia produces less than 20% of its wheat needs, as shown in Table 1. Mistaken production policies and consumption incentives have contributed to the increasing difference between the demand for wheat and its local production, and this unfavorable trend is continuing (Table 2).

Ninety percent of Bolivia's wheat is grown in the traditional wheat-growing areas, located mainly in narrow mountain valleys. The great variety of microclimates in these areas fall between the following values:

- Elevation, 1,500 to 3,000 meters
- Annual precipitation, 350 to 700 mm

- Mean temperature, 11 to 19°C
- Rainy season, from December to May when wheat is grown

The potential area for wheat production is about 150,000 hectares. Today, approximately 60,000 hectares are cultivated; yield is less than 1 t/ha. Greater use of inputs, such as fertilizer, herbicides, improved seed and a stable water supply, could raise yield to over 3 t/ha. The adoption of this technology, however, is far in the future because of the high costs of irrigation systems and fertilizer.

**Table 1. Wheat production and consumption in Bolivia, 1976 to 1980**

Year	Production (000 tons)	Consumption (000 tons)	Consumption locally produced (%)
1976	69.8	256.3	27
1977	48.0	283.1	17
1978	56.0	376.9	15
1979	56.2	309.1	18
1980	70.0	371.6	19

**Table 2. Annual growth rates in wheat production and consumption, Bolivia, 1950-52 to 1978-80**

Period	Production (%)	Imports (%)	Consumption (%)	Population (%)
1950-52 to 1958-60	7.87	3.64	4.89	1.91
1960-62 to 1968-70	0.28	3.88	2.72	—
1970-72 to 1978-80	2.43	2.87	3.02	2.09
1950-52 to 1978-80	2.78	4.39	4.11	1.89

If Bolivia does not radically change its food consumption patterns, the country will have to put a great deal of effort into the cultivation of wheat in nontraditional areas, now considered as marginal for wheat. These areas offer many advantages; land and water is available, climatic conditions are adequate for growing wheat and agronomic resources are available. Also, the land system lends itself to wheat cultivation.

According to precipitation regimes, these nontraditional areas can be divided into two regions:

- Chaco region:
  - 400 to 800 mm of rainfall per annum
  - 10 to 150 mm during the season for irrigated wheat
- Northern Santa Cruz region:
  - 800 to 1,700 mm of rainfall per annum
  - 200 to 450 mm during the season for rainfed wheat

Irrigation is projected for the Chaco, but has been delayed due to the high initial investment necessary. Two big schemes could irrigate 150,000 hectares with surface water. A ground-water irrigation system currently is under development for 15,000 hectares, and an additional 2,000-hectare system is also being considered for the rainfed area north of Santa Cruz. Irrigation combined with available technology would assure an average yield of 2 t/ha for the Chaco region. By 1988, it may be feasible to grow 5000 hectares of irrigated wheat in the Chaco.

Planning for the northern Santa Cruz region includes the promotion of a gradual increase in wheat area. It would be grown as a winter crop, mainly on medium to large-size farms. The five-year goal for this region is 28,000 hectares, with a yield of 1 to 2 t/ha by 1988.

Bolivia expects to be producing 80,000 tons of wheat by 1990, with a possibility of reaching 120,000 tons. These amounts represent, respectively, 17 and 26% of the estimated wheat demand for that year (470,000 tons).

### Conclusions

Hopefully, Bolivia can change its food consumption patterns to satisfy a larger part of its carbohydrate needs through the use of foods more appropriate to its environmental conditions, i.e., yucca, maize, potato and rice. In the long term, wheat production will principally be carried out in the nontraditional areas, the tropical and subtropical lowlands in the east. Therefore, research work on wheat for these nontraditional areas is of greatest importance. Tables 3 to 6 summarize wheat research being conducted at the Coronel A. Gomez Experiment Station in the Chaco region.

**Table 3. Wheat Research program, Coronel A. Gomez Experiment Station, Chaco, Bolivia, 1984**

Yield	Crop rotation suitability	Disease	Quality	Efficiency and adaptability
Breeding for:				
Plant type (1)	Earliness (1)	Rust resistance (1)	Test weight (1)	Water uptake (3)
Rust resistance (1)			Grain texture (1)	Fertilizer uptake (3)
Lodging (1)			Grain weight (2)	Drought tolerance (3)
Shattering (1)				
Clean leaves (2)				
Trials:				
Preliminary yield (1)	Seeding date (1)	Regional yield (2)		
Advanced yield (1)				
Other activities:				
		Variety exchange (1)	Milling test (3)	
		Seed increase (1)	Baking test (3)	
		Seed distribution (3)		

(1) = in progress, (2) = beginning, (3) = in planning stage

**Table 4. Soil management and improvement program, Coronel A. Gomez Experiment Station, Chaco, Bolivia, 1984**

Fertility	Physical soil characteristics		Production costs
	Compaction	Crusting	
Trials:			
Fertilizer rate (1)	Implement use (0)	Tillage system (1)	Reduced tillage (2)
Regional fertility monitoring (2)	Manure and sod buryng (1)	Sowing rate (2)	
Inoculants (2)	Tillage systems (1)	Sowing depth (3)	
Sulphur application (3)	Sand and sulphur application (3)	Sand and sulphur application (3)	
In use:			
	Sod implantation (1)		

(0) = completed, (1) = in progress, (2) = beginning, (3) = in planning stage

**Table 5. Water efficiency utilization program, Coronel A. Gomez Experiment Station, Chaco, Bolivia, 1984**

<b>Irrigation</b>	<b>Flow efficiency</b>	<b>Irrigation scheduling and efficiency</b>
<b>Trials:</b>		
Depth and frequency of irrigation (1)	Weed control in channels (3)	
Tillage system (1)		
<b>In use:</b>		
Siphon use (2)	Channel maintenance (1)	Ground water surveillance (0)
Field leveling (2)		Meteorological observation (1)
<b>Other activities:</b>		
		Water use survey (0)
		pF relations survey (3)

(0) = completed, (1) = in progress, (2) = beginning, (3) = in planning stage

**Table 6. Crop management program, Coronel A. Gomez Experiment Station, Chaco, Bolivia, 1984**

<b>Crop rotation suitability</b>	<b>Insect control</b>	<b>Weed control</b>	<b>Stand</b>	<b>Production costs</b>
<b>Trials:</b>				
Sowing date (1)	Seedbed preparation to avoid insect carry-over from cotton crop (0)	Herbicide use (3)	Sowing rate (1)	
Alternative crops (2)		Bermuda and Johnson grass control (3)	Tillage system (1)	
			Fungicide use (2)	
			Sowing depth (3)	
<b>In use:</b>				
	Insecticide use (1)	2,4-D use (1)	Appropriate seed storage (2)	Economic evaluation in larger fields (1)

(0) = completed, (1) = in progress, (2) = beginning, (3) = in planning stage

## Wheat Production in the Subtropical Areas of Santa Cruz, Bolivia

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Bolivia needs 400,000 tons of wheat per year to meet its total domestic needs. Unfortunately, present wheat production is not sufficient to satisfy this need. The subtropical areas of the country, such as the plains of Santa Cruz province, offer a possible solution in terms of prospects for wheat production expansion. This report will focus mainly on these subtropical areas of Santa Cruz.

### Wheat Production

The wheat area in northern Santa Cruz is 10,000 hectares, but estimates for potential wheat area in the region is 160,000 hectares. In general, wheat cultivation is under rainfed conditions, with limited area under irrigation. The main factors limiting production are:

- Lack of availability of seed of commercial varieties
- Lack of suitable technology for farmers
- Lack of moisture
- Presence of diseases

- Marketing, e.g., pricing restraints
- Lack of credit for farmers
- Agronomic problems such as weeds and low soil fertility

### Characteristics of the Subtropical Zone

#### Rainfall

Figure 1 shows the rainfall pattern during the normal wheat cycle. It also demonstrates the problems during planting (May and June) and harvesting (September), due to excessive amounts of rainfall during those periods. The mean precipitation of the growing cycle over a 20-year period is 260 mm.

#### Relative humidity

Data in Figure 2 give the 20-year average relative humidity during the growing season. It ranges from 53 to 73%, which favors disease development.

#### Temperature

Figure 3 illustrates the temperatures during the growing season, based on a

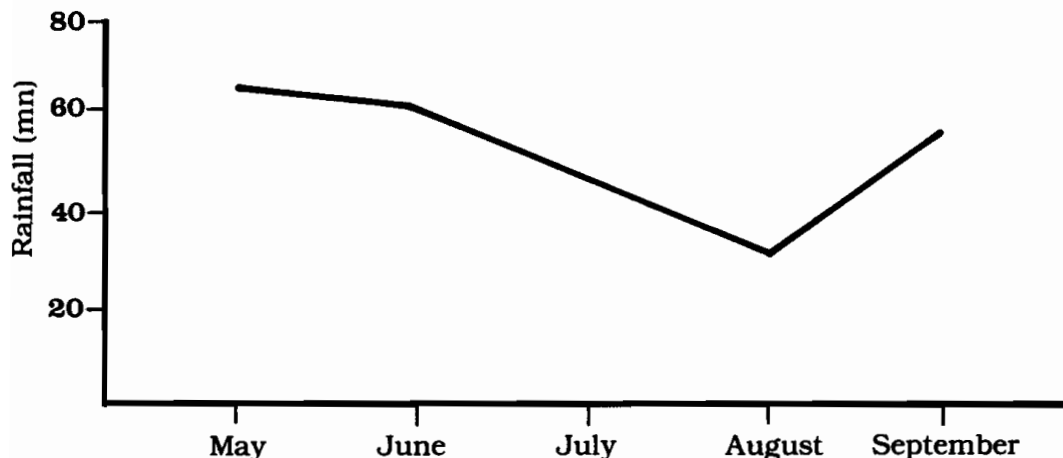


Figure 1. Rainfall during the wheat-growing season, northern Santa Cruz, Bolivia (20-year average)

20-year period. Also indicated are the high temperatures during September which, combined with the high precipitation of the area, provides favorable conditions for disease development. The average temperature for the season is 22°C. Table 1 presents monthly mean data for rainfall, relative humidity and temperature.

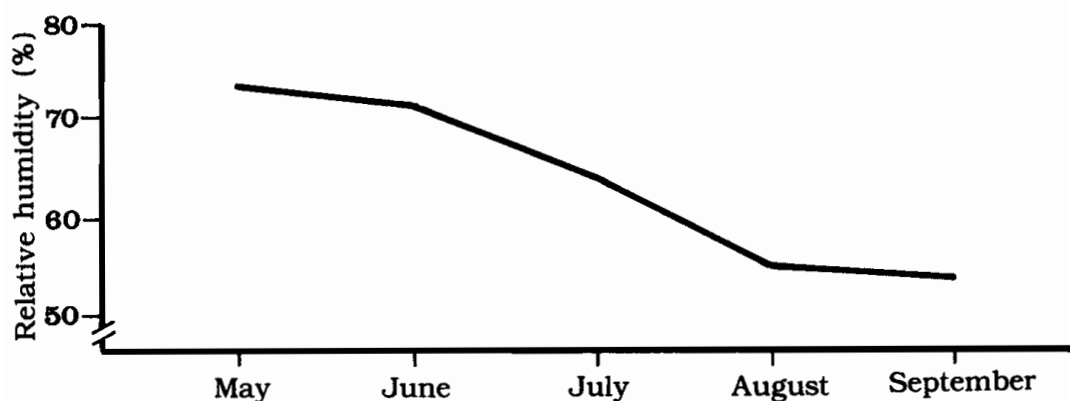
#### Wind

Wheat is cultivated during the winter, when winds create another problem for wheat cultivation. North winds are more frequent and are more humid,

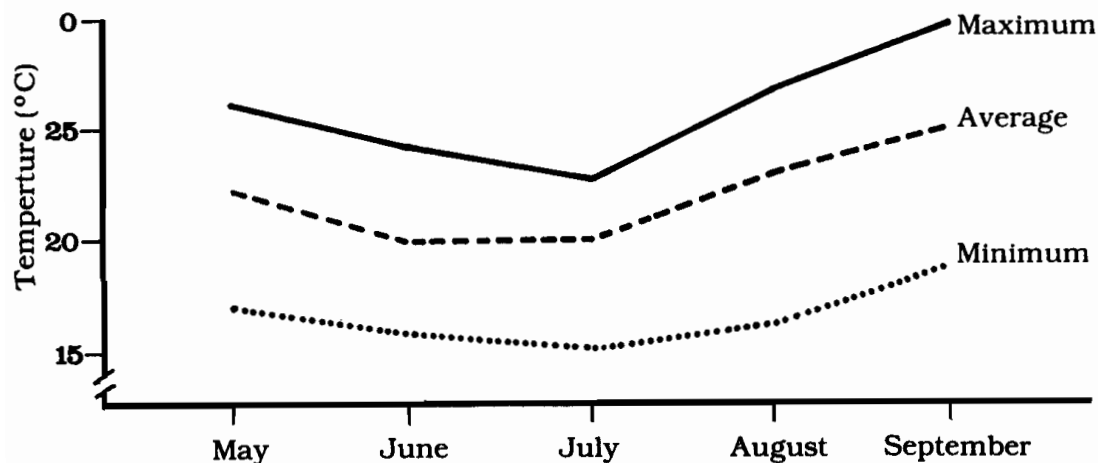
frequently causing lodging of the crop, especially after heavy rain. Also, they cause shattering of heads during maturity. South winds are strong, cold and wet, and can cause sterility of spikes due to frost.

#### Disease

The most prevalent diseases encountered are spot blotch caused by *Helminthosporium sativum*, leaf rust caused by *Puccinia recondita*, stem rust caused by *Puccinia graminis tritici* and blotch caused by *Septoria tritici*; root rots are also becoming important.



**Figure 2. Relative moisture during the wheat-growing season, northern Santa Cruz, Bolivia (20-year average)**



**Figure 3. Temperature range during the wheat-growing season, northern Santa Cruz, Bolivia (20-year average)**

### Commercial varieties

The most commonly grown varieties in the area are Quimori, covering 60% of the area, followed by Saguayo (25%) and Jaral 66 (15%). However, Quimori and Jaral 66 are susceptible to helminthosporium and will need to be replaced in the near future.

### Wheat Improvement Work

The Centro de Investigación Agrícola Tropical (CIAT) is encouraging wheat production in northern Santa Cruz; the central experiment station is located in Saavedra. CIAT's wheat program objectives for varietal improvement are:

- Good agronomic type
- High yield potential
- Resistance to heat and drought
- Earliness
- Resistance to diseases, e.g., helminthosporium
- Good leaf hygiene
- Good quality characteristics, such as high hectoliter weight

Yield trials are conducted as preliminary trials, advanced trials and regional trials.

Agronomy research is carried out in the areas of:

- Fertilizer use
- Seeding dates
- Transfer of technology to farmers

For plant protection, fungicides are being tested as possible control measures for the prevalent diseases.

Seed multiplication of the best varieties is being given priority.

The best advanced lines for adaptation, agronomic type and disease resistance are listed in Table 2. These lines are now in advanced and regional trials to further test their stability of performance in Santa Cruz. Hopefully, one or more of these lines will be outstanding and can become a replacement for presently grown varieties.

**Table 1. Mean rainfall, relative humidity and temperature for the wheat-growing season, northern Santa Cruz, Bolivia (20-year average)**

Month	Rainfall (mm)	Relative humidity (°/o)			Temperature (°C)	
		Min.	Max.	Avg.	Min.	Max.
May	66	73	17	26	22	
June	63	71	16	24	20	
July	46	64	15	23	20	
August	29	54	16	27	27	
September	56	53	19	30	25	

**Table 2. Best wheat lines for adaptation, agronomic type and disease resistance, Santa Cruz, Bolivia, 1984**

Cross and pedigree	Type of trial entry <sup>a/</sup>
KVZ-TRM x PTM-Anahuac CM43903-H-2Y-1M-4Y-0M	AV-I
KVZ-K4500-L-A-4 SWM176-3M-1Y-4Y-1Y-1M-0Y-2PTZ-0Y	AV-I
KVZ-K4500-L-A-4 SWM176-3M-1Y-4Y-1Y-1M-0Y-1PTZ-0Y	AV-I
Pato-Tobari 66	AV-I
Sapsucker "S" Pato(R) x Bluejay	AV-I

Table 2. (Con't)

Cross and pedigree	Type of trial entry <sup>a/</sup>
Nacozari F 76	AV-I
Veery No. 5 CM33027-F-15M-500Y-0M	Prel
Bobwhite'S" CM33203-K-9M-9Y-4M-4Y-1M-1Y-0M	Prel
Bobwhite'S" CM33203-H-4M-1Y-0M-161B-0Y	Prel
Tanager'S" CM30697-2M-8Y-3M-0Y	Prel
BR74.72-COC CM36889-31Y-10M-0Y	Prel
Kalyansona/Alondra'S" CM39612-JK4-LV-9M-4MM-0MM	Prel
Buteo CM31070-Y-1Y-2M-2Y-0M-0MM	Prel
Junco'S" CM33483-C-7M-1Y-0M	Prel
F3.71-Torim F 73 SWM5704-10Y-1M-3Y-3M-3Y-0B-2PTZ-0Y	IBWSN'84
Alondra'S" CM11683-A-1Y-1M-1Y-13M-1Y-1Y-500Y-0M	IBSWN'84
Veery'S" CM33027-F-12M-1Y-1M-1Y-1M-0Y-60B-0Y-1PTZ-0Y	IBSWN'84
Bobwhite'S"-Pavon F 76 CM61830-13Y-1M-3Y-2M-4Y-0M	IBSWN'84
Genaro F 81	IBSWN'84
Ures T 81	HSN'84
Seri 82	IBWSN'84, HSN'84
Buckbuck'S"-PVN'S" CM52359-12M-1Y-2Y-1M-0Y	HSN'84
Teeter'S"-Junco'S" CM59123-4M-1Y-1M-5Y-3M-0Y	HSN'84
NAC-Emu'S"/TOB(2)-7C x MN72131 CM60402-0-3Y-1M-1Y-1M-2Y-0M	HSN'84
Bobwhite'S" CM33203-G-5M-6Y-3M-1Y-1M-601PR-0P	3rd LACOS
Veery'S"-Seri 82 CM33027-F-15M-500Y-0M-87B-0Y	3rd LACOS
Neelkant'S" CM40454-33Y-4M-1Y-0M	3rd LACOS
PF70354-Alondra'S" CM47090-1M-110PR-1T-0T	3rd LACOS
Bluebird-Gallo x C371/T. AEST. x Kalyansona-Bluebird CM34555-B-1M-4Y-1M-1Y-1M-1Y-0M	3rd LACOS

<sup>a/</sup> AV-I = advanced yield trial; Prel = Preliminary yield trial; IBWSN'84 = 16th International Bread Wheat Screening Nursery, CIMMYT, Mexico; HSN'84 = Helminthosporium Screening Nursery, CIMMYT, Mexico; 3rd LACOS = Lineas Avanzadas del Cono Sur, CIMMYT, Southern Cone, South America

## Wheat in Costa Rica

**C.A. Salas, Estacion Experimental Fabio Baudrit Moreno,  
Universidad de Costa Rica, Alajuela, Costa Rica**

The economic crisis which at present is affecting Costa Rica has produced adverse effects in several areas of vital importance, one of which is the insufficient production of basic food products in relation to the level of national consumption. This has made necessary the importing of food supplies to assure the country of its basic food needs. The high cost of the prime materials for agricultural production, and the lack of adequate credit at the time when it is most needed to stimulate agricultural production, have been considered the principal reasons for this situation.

The wheat situation is still more critical, since Costa Rica depends absolutely on imports for this cereal; this amounts annually to 100,000 tons at a cost of US\$ 22,909,507 (\$1 billion). This corresponds to a per capita consumption of 31.7 kg, which provides 14.5 and 21.8% of the calories and proteins of the Costa Rican daily diet, respectively. It is for this reason that increased wheat production could eliminate an important part of the foreign exchange drain.

### Crop Feasibility

Several wheat production feasibility studies have been carried out through field experiments, and results have been considered positive. The areas considered appropriate for planting wheat in Costa Rica are located in the central valley, mainly Tierra Blanca, Sanatorio Duran, Oreamuno and Cot, as well as in Cartago province. These areas are between 1,600 and 2,800 meters elevation, and have a rainfall of 600 to 800 mm during the wheat-growing cycle. Geographically, the areas are situated around 9°56'N

latitude and 83°52'W longitude, with maximum and minimum average temperatures of 19.4 and 8.6°C, respectively. Planting occurs during the months of October and November, and harvest, in the month of March.

Yields of 10 t/ha have been obtained experimentally, and 7 t/ha commercially. However, more experimentation is necessary to offer real encouragement to the wheat farmer. In addition, adequate sources of credit, appropriate farm machinery and other indispensable conditions are needed to make wheat growing attractive to the farmer. Resolving these issues could significantly reduce imports of wheat, with the consequent reduction of foreign exchange expenditure and, at the same time, open new opportunities of employment, which are badly needed in Costa Rica to counteract unemployment and the present economic crisis.

### Recommended Areas for Experimentation

The central and northern areas of Alajuela province of Costa Rica are recommended for experimentation in wheat production. In central Alajuela, altitude fluctuates between 840 and 1,800 meters, with rainfall of 600 to 800 mm during the vegetative cycle. Planting time is September, and harvest, December. In the northern part of the province, planting time is in November, and harvest, in February and March.

Geographically, central Alajuela is situated around 10°01'N latitude and 84°16'W longitude and, in the north, the suitable areas of Fraijanes and Zarcero lie around 10°15'N and 84°14'W. The maximum and minimum average temperatures,

respectively, for central Alajuela are 28.2 and 17.5°C and, for the north, 21.2 and 19.9°C.

Production trials would also be possible in the lowlands (Guanacaste and Puntarenas provinces), provided wheat varieties appropriate for the tropics were available; these are zones with higher temperatures. Nevertheless, limitations exist to the possibility of establishing wheat production in Costa Rica, among them the lack of both government policy decisions and technical research.

### **Aspects of Government Policy Decision**

#### **Seed availability**

The National Seed Office, which supervises and authorizes seed production, relies upon private enterprise and the National Production Council for multiplying and processing seed. It would seem advisable, in the case of wheat, to guarantee the availability of certified seed of selected released varieties.

#### **Marketing**

The public entity which has the responsibility of purchasing local grain should guarantee a market for the wheat and a price equivalent to that of imported wheat. This would provide the necessary stimulus to farmers to grow the new crop.

#### **Bank credit**

The Banking Commission which advances money to farmers should establish a fund for wheat growers, as they have done for the other basic grains, and assure that the necessary resources are available to finance wheat production.

#### **Crop insurance**

The National Insurance Institute, through its crop insurance department, should guarantee protection to the wheat farmer against unexpected,

unfavorable climatic conditions and outbreaks of insect pests and plant diseases which may cause losses.

#### **Farm machinery**

The lack of appropriate farm machinery adapted to the topographic conditions of the central valley, such as specially designed planting, mowing and threshing machines and binders, has been one of the major factors in restricting the expansion of wheat production. In other countries, such as Italy, Japan and Taiwan, adequate machinery exists for these activities. In Guatemala, in localities which are similar to those of Costa Rica (Quezaltenango and Chichicastenango), almost half of the wheat needed for national consumption is being produced using such farm machinery. In the beginning of a national wheat production program, an official entity, such as the National Production Council, should provide specialized farm machinery service, as has been done with other crops on various occasions, thus helping to assure the farmers' success in growing wheat.

#### **Research Priorities**

Wheat research has been carried out in three areas in Costa Rica (Figure 1). Three experiment stations are utilized (Tables 1, 2 and 3).

#### **Soils**

From a fertility point of view, the soils in Fraijanes are the most problematical, with extreme acidity, trace amounts of phosphorus, high phosphorus-fixing capacity, high aluminum content and very low presence of calcium, magnesium and potassium (less than 5 meq/100 g soil). In order to obtain good crop responses to phosphorus fertilization, it is usually necessary to apply P<sub>2</sub>O<sub>5</sub> at 600 to 800 kg/ha, an amount which is not economical. Liming is also very important for these soils.

However, in field experiments with wheat, certain lines and cultivars have shown a better response to normal fertilization than others, probably due to better adaptability to low-fertility and low-pH soil conditions. It is important to select these cultivars, as well as other crops such as barley and triticale, for better adaptability to Fraijanes soils.

### Weed control

Weed incidence is high in the three areas where wheat research work has been conducted, Cartago and central and northern Alajuela. In central Alajuela, gramineous, cyperaceous and broadleaf weeds prevail and, in Cartago and northern Alajuela, the broadleaf weeds are dominant.

Allelopathy and other factors due to weed competition have been considered reasons for crop yield reduction, as a result of *Rottboellia exaltata* and *Cyperus rotundus* in central Alajuela.

Considering solely weed competition, the gramineous weeds *Eleusine indica*, *Digitaria* spp., *Cynodon dactylon*, *Ixophorus unisetus* and *Paspalum paniculatum* have been shown to be the most important. *Pennisetum clandestinum*, *Taraxacum officinale*, *Bidens pilosa*, *Amaranthus hybridus*, *Melampodium divaricatum* and *Spergula arvensis* are considered to be important weeds in Cartago and northern Alajuela.

At present, the alternatives for chemical control of weeds seem to be Diclofop-methyl and herbicides that inhibit the development of some hormone-induced hydrolytic enzymes (hormonals). Diclofop-methyl is used to control some gramineous species, and the hormonals, broadleaf and cyperaceous weeds. 2,4-D or MCPA is used for postemergence, and Perfluidone, for pre-emergence treatments. Linuron has also been used for broadleaf pre-emergence control.

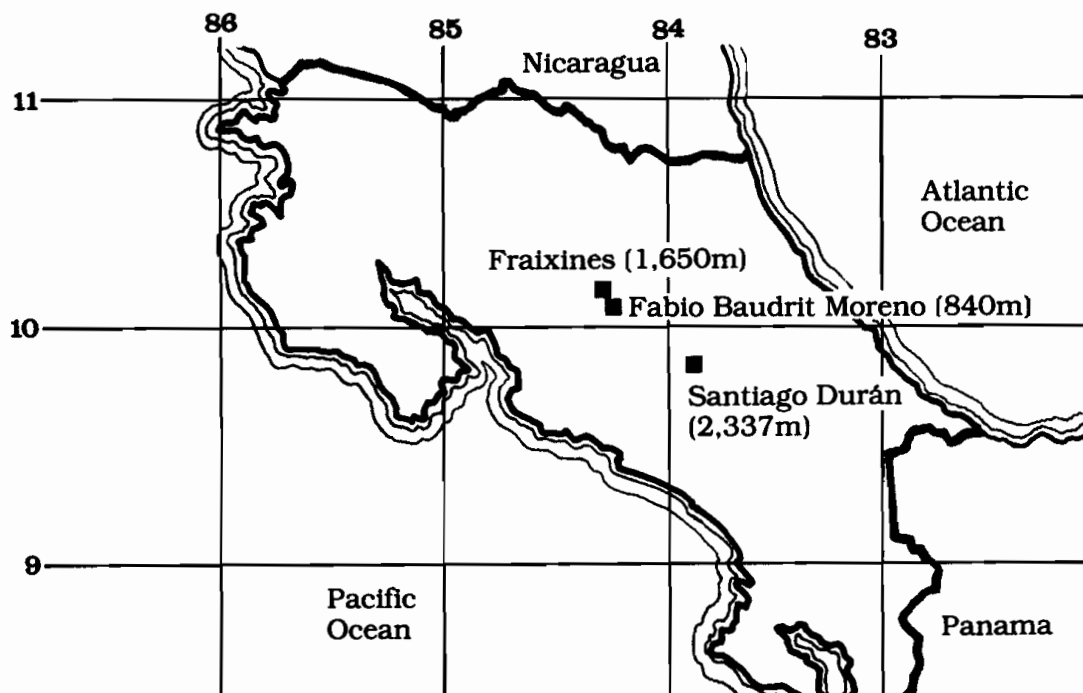


Figure 1. Wheat research centers in Costa Rica, 1984

**Table 1. Climatological data, Fraijanes Experiment Station, Alajuela, Costa Rica<sup>a/</sup>**

Month	Average maximum temperature (°C)	Average minimum temperature (°C)	Rainfall (mm)	Relative humidity (°/o)	Hours of sunshine
January	20.6	12.2	98.6	87.1	8.2
February	21.3	12.2	33.9	84.6	8.7
March	22.1	12.1	60.1	85.1	7.2
April	21.7	12.5	140.2	83.5	6.6
May	21.6	13.3	456.0	93.0	4.4
June	21.7	13.4	416.0	92.1	3.3
July	21.1	13.7	263.9	89.1	3.9
August	21.4	13.1	403.9	87.5	4.1
September	21.5	13.1	486.9	89.7	3.6
October	20.9	13.0	609.1	92.4	3.3
November	20.2	13.1	333.8	90.2	4.4
December	20.3	13.0	100.2	87.7	6.4

<sup>a/</sup> Latitude 10°15'N, elevation 1,650 m

Normal wheat planting time, October or November, normal wheat harvesting time, February or March

Average yield of five best advanced lines, 2,857 kg/ha

**Table 2. Climatological data, Fabio Baudrit Moreno Experiment Station, San Josecito, Alajuela, Costa Rica<sup>a/</sup>**

Month	Average maximum temperature (°C)	Average minimum temperature (°C)	Rainfall (mm)	Relative humidity (°/o)	Hours of sunshine
January	28.7	17.1	7.6	69.2	8.5
February	29.6	16.9	12.0	67.9	9.4
March	30.4	17.6	13.0	67.4	8.7
April	30.3	17.9	66.4	70.5	7.9
May	28.7	18.1	272.0	80.3	5.9
June	27.2	18.0	309.5	87.2	4.9
July	27.5	17.9	212.7	82.5	4.7
August	27.5	17.6	285.6	84.2	5.0
September	26.9	17.5	336.6	88.0	4.9
October	26.7	17.4	312.5	88.4	5.0
November	27.0	17.4	138.1	81.9	5.6
December	27.9	16.9	34.1	73.9	7.5

<sup>a/</sup> Latitude 10°1'N, elevation 840 m

Normal wheat planting time, September to November, normal wheat harvesting time, December to March

Average yield of five best advanced lines, 4,728 kg/ha

The use of hormonals cannot always be recommended, due to the large numbers of horticultural crops in the wheat-production areas. More investigation is needed to avoid spraying when and where a drift of fine spray or vapors may come in contact with nearby sensitive crops or ornamental plants.

There is an urgent need to plan for a major, continuing weed control program, instead of the isolated field trials which have been conducted so far.

#### Disease control

In central Alajuela, the diseases with most frequent incidence are zonate eyespot (*Helminthosporium giganteum*), *H. tritici repentis* and crown rot (*Fusarium* spp.). In trials carried out with CIMMYT materials during 1978, the triticales proved more tolerant to leaf blotch caused by *Helminthosporium* spp. under natural infection than did the wheats.

In both central and northern Alajuela, when grain maturity and high humidity coincide, head scab (*Fusarium* spp.) and saprophytic fungi make their appearance and negatively affect yield.

In the Cartago area (Sanatorio Duran), a high natural incidence of leaf rust appeared in a commercial planting of Siete Cerros. This permitted the determination of the reaction of several cultivars of wheat and one triticales which had been introduced from CIMMYT. The introduced cultivars were Cananea (Tcl), Bobwhite, Anza, Nacozari 76, Pavon 76 and Veery 1. With the exception of Nacozari 76, the cultivars showed tolerance, with infections of not more than 5% of *Puccinia recondita*. The virus disease known as alfalfa yellow dwarf has also appeared, but is found in low incidence.

It is absolutely necessary to continue working, with the valuable cooperation of CIMMYT, for new sources of germplasm with resistance to these and other diseases.

Table 3. Climatological data, Sanatorio Duran Experiment Station, Tierra Blanca, Cartago, Costa Rica<sup>a/</sup>

Month	Average maximum temperature (°C)	Average minimum temperature (°C)	Rainfall (mm)	Relative humidity (°/o)	Hours of sunshine
January	19.4	8.4	58.1	87.2	3.9
February	19.8	8.4	18.3	82.8	4.5
March	19.7	8.5	13.9	81.6	4.5
April	19.6	8.9	62.1	83.8	4.2
May	19.7	8.7	228.0	85.8	3.0
June	19.3	8.5	323.8	86.3	2.3
July	19.1	8.8	193.3	87.0	2.2
August	19.3	9.0	187.8	87.6	2.8
September	19.4	8.8	338.2	88.0	2.9
October	19.3	8.6	419.8	89.4	2.6
November	19.3	8.6	213.7	91.6	2.4
December	19.1	8.3	102.8	88.6	2.9

<sup>a/</sup> Latitude 9°56'N, elevation 2,337 m

Normal wheat planting time, October, normal wheat harvesting time, March

Average yield of five best advanced lines, 7,593 kg/ha

## Wheat Research in the Coastal Region of Ecuador

**J. Tola, Small Grains Program, Instituto Nacional de Investigaciones Agropecuarias, Quito, Ecuador**

The slopes and small plateaus of the highlands of Ecuador (2,500 to 3,200 meters altitude) are the traditional wheat-growing areas. In 1964, when 90,000 hectares of wheat were grown in Ecuador, the country was still importing 50% of its wheat needs. At that time, scientists at the National Institute of Agricultural Research (INIAP) decided to investigate the possibilities of growing wheat on the coast. Two major objectives were established:

- To increase the wheat-growing area in Ecuador, and
- To obtain an additional cropping season each year for breeding purposes.

In the beginning, three testing locations were selected at INIAP experimental centers. They were chosen to represent the most common environments of the Ecuadorian coastal region (Table 1).

From 1964 to 1969, more than 1,000 homozygous lines were tested during the two tropical seasons, the rainy season and the dry season. By 1969, it was clear that, with the germplasm

available, it was not possible to grow wheat under wet conditions. Poor agronomic type and high incidence of *Fusarium* spp. and *Erysiphe graminis*, as well as weed and insect damage, were the main problems. The best results in germplasm adaptation were observed at tropical, dry Portoviejo. Some lines were also fairly well adapted in the dry season at the intermediate zone of Pichilingue. However, at tropical and humid Santo Domingo, even in the driest months of the year, few plants formed grain and almost all were killed by *Fusarium* spp. Problems were similar at Pichilingue during the rainy season, but yield improved to a mean of 1.0 t/ha when the same lines were planted during the dry season. Some additional dry sites provided enough information to conclude that wheat plants had improved tillering and grain development and less disease incidence when they were planted during the drier months (Table 2).

Research efforts were concentrated at Portoviejo and several other locations with similar conditions. Segregating

**Table 1. A comparison of climatic conditions in three coastal locations, Ecuador**

Climatic condition	Location		
	Santo Domingo (tropical, humid)	Pichilingue (inter-mediate)	Portoviejo (tropical, dry)
Average temperature (°C)	22	24	25
Temperature range (°C)	15-33	19-34	17-35
Rainfall (mm)	2600	1600	250
Relative humidity (°/o)	91	82	75
Sunlight (°/o)	12	20	37

materials (F<sub>2</sub> to F<sub>3</sub> generations) were introduced, and the yield potential in some materials was acceptable (Table 3).

During this period, research was also conducted on planting date, plant density, fertilization, weed control and water requirements. Some of the results are presented in Tables 4 and 5.

Results showed that the dry season offered better opportunities for growing wheat. Appropriate seeding rate was found to be from 140 to 160 kg/ha, and the optimum economic fertilizer dosage, 80 and 40 kg/ha of nitrogen and phosphorus, respectively. Acceptable weed control was obtained with a mixture of Fluorodifen (1.5 kg a.i./ha) plus Linuron (0.5 kg a.i./ha).

Among the diseases, rusts were not a problem during the dry season, except that stem rust was observed in late tillers. For wet locations, *Fusarium* spp. and *Erysiphe* spp. were the most important diseases, causing spike and grain damage. In 1976, some spots of dead plants, in different vegetative stages, were observed; the causal agent was *Sclerotium rolfsii*. The disease spread very quickly from 1977 to 1979, killing 30, 60 and 85%, respectively, of the germplasm under evaluation.

## Conclusions

In 1979, the National Cereal Program decided to terminate research on wheat for the coastal areas after considering the serious limitations for the growth of wheat in that area. The most important reasons for this were:

- The low comparative economic return as compared to local crops;
- The lack of irrigation systems, which would be imperative for growing wheat in dry areas of the Ecuadorian coast;
- The relatively low yield potential (4 t/ha), compared to the potential for the highlands (6 t/ha);
- The cost of wheat production per hectare, which on the coast is twice that of the highlands, and
- The *Sclerotium rolfsii* problem, as well as the potential insect, disease and weed competition problems foreseen once farmers start planting wheat.

These problems would require major, costly research programs in breeding and agronomy.

**Table 2. Comparative wheat yields, wet and dry seasons, Portoviejo, Ecuador, 1964 to 1969**

Year	Yield (kg/ha)	
	Wet season (March-May)	Dry season (June-Sept)
1964	1100	--
1965	1200	--
1966	1950	2400
1967	1730	3800
1968	2700 <sup>a/</sup>	3200
1969	2300 <sup>a/</sup>	3400

<sup>a/</sup> Planting date: April and May

**Table 3. Average yield of best wheat lines, Portoviejo, Ecuador, 1974 to 1978**

Lines/varieties	Yield (kg/ha)				
	1974	1975	1976 <sup>a/</sup>	1977 <sup>a/</sup>	1978 <sup>b/</sup>
OCEPAR 73008	--	3980	1020	315	4410
NP-824	4200	3900	980	260	4100
Bluebird-Gallo x Carpintero "S" / PAV "S"	--	--	1000	320	4200
Alondra	--	3750	820	180	4120
Chenab 70	--	--	--	--	4120
NP-832	3940	3750	740	200	3800
Rumiñahie	--	3850	620	315	3900
Sonora 64	2640	3560	740	310	2900

<sup>a/</sup> *Sclerotium rolfsii* damage<sup>b/</sup> Different testing site in same region**Table 4. Average grain yield for Sonora 64 under different dosages of nitrogen and phosphorus, Portoviejo, Ecuador, 1973 to 1975**

Nitrogen (kg/ha)	Yield (kg/ha)	Phosphorus (kg/ha)	Yield (kg/ha)
0	2640	0	2640
20	2770	20	3070
40	2880	40 <sup>a/</sup>	3110
60	2950	60	2920
80 <sup>a/</sup>	3080	80	2970
100	3110	100	3020
120	3110	120	3105
160	2900	160	2790

<sup>a/</sup> Economic dosage**Table 5. A comparison of herbicide application and yield, Portoviejo Experiment Station, Ecuador, 1975 to 1977**

Herbicide	Dosage (kg a.i./ha)			Application time	Yield (kg/ha)		
	1975	1976	1977		1975	1976	1977 <sup>a/</sup>
Fluorodifen	3.0	4.0	3.0	Pre-emergence	2940	870	260
Fluorodifen + Linuron	1.5 + 0.5	1.5 + 0.5	2.0 + 0.4	Pre-emergence	2815	3844	265
Fluorodifen + Diuron	1.5 + 0.5	--	2.0 + 0.4	Pre-emergence	1900	--	180
2, 4-D (a)	0.75	0.50	--	Post-emergence (tillering)	1750	1700	--
Check <sup>b/</sup>	--	--	--		520	430	220

<sup>a/</sup> Severe *Sclerotium rolfsii* damage<sup>b/</sup> No herbicide application

## **Selection and Introduction of Wheat Types for Subtropical Conditions in Mexico**

**J.J. Martinez, Wheat Research Program, Centro de Investigaciones Agrícolas del Noroeste-INIA, Ciudad Obregon, Sonora, Mexico**

Wheat is the third most important component, after maize and beans, in the Mexican diet. Wheat is cultivated on about 850,000 hectares, with an average yield of 4.3 tons per hectare. In the fall-winter cycle of 1981-82, there was a record production of 4.3 million tons. This amount was sufficient to supply national demand; however, due to Mexico's rising population, it is estimated that annual national consumption will be over 6 million tons by the year 2000.

Over half of Mexico's wheat is produced in the state of Sonora in the northwestern part of the country. Sonora has an altitude of less than 100 meters above sea level; its climate is dry and the principal plant life is composed of cactus and thorny shrubs. The winter is mild, lending itself to the production of spring wheat. The highest yield is obtained on irrigated lands, with advanced methods of cultivation. The major limiting factors are plant diseases, principally leaf rust (*Puccinia recondita*), which limits the commercial life of a variety to three to five years. The use of improved varieties with high yield and resistance to this pathogen is necessary for maintaining wheat production at a high level in the region.

### **Wheat Production in Subtropical Mexico**

It is difficult to continue to increase yield in Mexico at the accelerated rate that was possible in the past; the genetic potential within the wheat species has already been largely realized. Therefore, to satisfy the future demand for wheat, it will be necessary to open up new lands for cultivation.

The subtropical areas in Mexico, located between 20° and 24° N latitudes, with an altitude of less than 500 meters and irrigation and soils adequate for wheat cultivation, cover an area of approximately 200,000 hectares. These areas are located principally in the San Lorenzo Valley in southern Sinaloa state and in the Huasteca area in the state of Tamaulipas on the coast of the Gulf of Mexico. Winters in these areas are less suitable for wheat production, because of high temperatures at the beginning of the planting season. Present varieties have poor tillering capacity and give poor yields; nevertheless, it has been possible to obtain yields of up to 4 t/ha.

During the 1983-84 season, a series of trials was conducted to test the effects of subtropical environments on wheat production. They were carried out in the Culiacan and San Lorenzo valleys in Sinaloa and in the Santiago Ixcuintla region of Nayarit. Results showed that wheat yields decreased considerably (from 7082 kg/ha to 722 kg/ha) when latitude and temperatures were less favorable for wheat production (Table 1). However, in the San Lorenzo Valley, which is considered as subtropical, the average yield of commercial varieties in the trial was 3148 kg/ha; that of Santiago Ixcuintla, where the temperature regime is marginal for wheat, was only 700 kg/ha. The diseases found to be common under these conditions was leaf rust and leaf spot caused by various forms of helminthosporium. Since wheat cultivation in these areas is new, yield can be substantially improved through better agronomic practices. Planting date and sowing density, fertilizer management and insect and weed control are some of the factors that need further research.

### Selection of Wheats for Subtropical Environments

For the past several years, a cooperative program for the genetic improvement of wheat has been conducted by INIA, Mexico, and CIMMYT at the CIANO experiment station in Ciudad Obregon, Sonora; the objective has been the development of germplasm tolerant to high temperature and drought. The strategy utilized has been that of the selection of early generations in the Yaqui Valley of Sonora. These materials are sown early in October when temperatures are high (23°C mean temperature). Irrigation is applied at germination and again, after 72 days, at flowering. Individual plant selection is practiced with regard to agronomic type and disease resistance. Advanced generations are evaluated in subtropical environments, in southern Sinaloa and central Tamaulipas. As a result of these trials, the experimental line Buckbuck“S”-PVN“S” has been developed. In subtropical San Lorenzo Valley, its yield has been 3630 kg/ha, 15% above the mean of present commercial varieties.

### Conclusions

As a result of research in Mexico, it is possible to obtain wheat yields of more than 4 t/ha under subtropical environments. It is necessary to further improve the yield potential of commercial varieties for these areas through breeding. Selection must be made for high yield and better tolerance to high temperature and diseases. The trials must be conducted under appropriate types of environmental conditions.

Wheat yields in the subtropics can also be improved substantially by improving agronomic practices, especially such factors as planting date and density, fertilization and insect and weed control.

Wheat cultivation in San Lorenzo, Sinaloa, and the Huasteca in Tamaulipas, covering an area of about 200,000 hectares in a subtropical climate, represents a production potential of approximately one million tons of wheat annually, 19% of Mexico's entire annual production.

**Table 1. Yields of selected commercial varieties in the traditional wheat-growing areas of the northwest and three subtropical environments of Mexico**

Variety	Yield (kg/ha)			
	Northwest	Subtropical environments		
	Yaqui Valley	Culiacan Valley	San Lorenzo Valley	Santiago Valley
Ures 81	7,300	6,700	3,100	700
Sonoita 81	7,200	4,500	1,900	400
Seri 82	7,000	6,100	3,900	900
Glennson 81	6,900	5,700	2,900	800
Genaro 81	6,900	6,000	3,700	600
Mean	7,100	5,800	3,100	700

## Wheat Production Status, Constraints and Research Priorities in Nigeria

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With the steady rise in income, consumption of wheat in Nigeria has recently increased considerably. Surveys show that the eating of bread has spread, even to rural areas. In 1982, consumption of wheat was estimated at an average of 60 grams per person per day (22 kg/year), with major towns averaging 210 g/person/day (77 kg/year). In terms of the drain on the nation's foreign exchange, it has been estimated that, in 1982, wheat and wheat flour imports into Nigeria totaled 1.425 million tons, valued at US\$ 290 million (Table 1).

The bulk of the wheat now grown in the country is on irrigated land. The area under wheat cultivation is about 15,000 hectares, yielding on average 2.5 to 3 t/ha. At present, the total production of wheat is about 40,000 tons, which is equivalent to about 2.6%

of the country's requirements; Nigeria's current annual wheat needs are in excess of 1.5 million tons.

From the consumption and production status, it is obvious that there is a big gap between supply and demand of wheat in Nigeria. In an effort to arrest the dwindling foreign reserve position, to which the importation of wheat contributes, Nigeria has embarked on a program of wheat cultivation in areas where growth conditions for the crop are suitable. As a result, the government has decided to put 50% of the irrigable land under wheat cultivation in the northern Guinea and Sudan savanna areas of the country (estimated at 345,000 hectares when fully developed).

### Constraints to Wheat Production

#### Land

Land is the most critical constraint on wheat production in Nigeria. Since the crop is grown under irrigation, only the limited land cleared and developed for irrigation by the various government-managed river basin projects is available for wheat cultivation. Unless the government accelerates the expansion of the irrigation schemes, land will remain a major constraint on wheat production, since local farmers are in no financial position to develop land for irrigation.

#### Temperature

Wheat is grown almost entirely during the harmattan period (November to February), when night temperatures are sufficiently low for adequate tillering. The main factor which prevents the extension of the crop southward in

Table 1. Wheat and wheat flour imports, Nigeria, 1973 to 1982

Year	Quantity (000 tons)	Cost (million US\$)
1973	304.0	42.5
1974	323.4	77.6
1975	407.5	82.5
1976	732.4	147.3
1977	719.7	144.6
1978	800.6	162.3
1979	928.0	187.2
1980	1000.0	205.4
1981	2352.0	277.1
1982	1452.0	290.0

Source: Nigeria Trade Summary (1973-82), Federal Office of Statistics, Lagos, Nigeria

Nigeria is high temperature. South of latitude 10°N, between November and February, maximum temperatures are consistently above 32.5°C and minimum temperatures are mostly above 15°C. These temperatures reduce the length of the growing season and yield potentials.

### **Inputs**

The inputs necessary for wheat production are also lacking or in short supply in most instances.

*Fertilizers*—Shortages of adequate supplies of fertilizer during the planting period has posed a problem to wheat farmers. Unfortunately, the planting time of the crop coincides with the period when all of the imported fertilizers have been exhausted on rainfed crops. Thus, lack of initial supplies of required nutrients reduces vigor and, subsequently, yield.

*Labor*—The planting season for wheat in Nigeria overlaps the period when late-harvested, rainfed crops (sorghum, cowpea and cotton) are harvested. Since most operations (except land preparation) are carried out manually, labor shortages tend to pose some problems, as labor is needed for harvesting the rainfed crops, delaying the planting of wheat. Late-planted wheat is known to yield up to 25% less than timely sown crops.

*Machinery*—Most of the major land preparation operations (except planting and fertilizer application) are carried out by machines from the government-organized tractor hiring units (THU). After harvesting the rainfed crops, farmers await their turn to get their land prepared for wheat. But, for several reasons, such as insufficient numbers of tractors, inadequate spare parts and lack of operators, the farmers' fields are more often than not prepared late. Also, during the harvesting of the crop, a lot of wheat is lost through damage by early rains owing to an inadequate number of threshers.

### **Water management**

During the wheat-growing season, there is practically no rainfall to support the crop. An average of about 6 mm of water per day is lost through evapotranspiration during the crop-growing season. This warrants the need for regular irrigation. At present, irrigation is scheduled on the basis of time interval (5 to 10 days), depending on soil type.

This approach has not been satisfactory, especially when border check and basin methods of irrigation are employed; it results in excessive water loss. Since water is a scarce resource, irrigation has to be scheduled to maximize wheat production per unit of water applied. An improvement in irrigation management is required if the country is to achieve its target of 700,000 tons of wheat per annum by 1990.

### **Fertilizer use**

Most of the work conducted on fertilizer use in relation to wheat crops in Nigeria has been confined to the three major nutrients, nitrogen, phosphorus and potassium, and their optimum rate, timing and method of application. The need for balanced fertilization for optimum wheat production on the savanna soils cannot be underestimated. No information is yet available on micronutrients. With the passage of time, a deficiency of these nutrients may arise, thereby limiting the production of the crop, especially under intensive cultivation.

### **Research Priorities**

The federal government of Nigeria is presently committed to increasing wheat production locally. It has, therefore, been encouraging coordinated research projects between the Institute for Agricultural Research, Samaru and the various River Basin

Authorities involved in wheat production. Generally, the areas of research given priority include water management and fertilizer use.

#### **Water management**

The successful production of wheat, especially in a semi-arid, tropical environment like northern Nigeria, is dependent on a judicious irrigation program, based on knowledge of the effect of soil moisture stress on the crop. When water constitutes the limiting resource, research efforts must be directed towards:

- Finding the best scheduling method, quantity and time of irrigation for the wheat crop;
- Investigating the effect of variable water stress on late-planted wheat, since the effect of stress can vary according to the maturity of the variety and time of seeding, and
- Discovering the effect of fertilization on water-use efficiency of wheat.

#### **Fertilizer use**

From a report submitted by a committee that reviewed research work on fertilizer use in irrigated agriculture, the following research areas are being given priority in relation to wheat fertilization:

- Interaction of phosphorus with other major nutrients and with irrigation frequency;
- Phosphorus availability/fixation in wheat under intensive, irrigated agriculture;

- Potassium requirements of wheat under different irrigation regimes, and
- Micronutrient requirements of wheat.

#### **Conclusions**

Nigeria's current annual wheat requirements are in excess of 1.5 million tons annually. Present local production is about 40,000 tons, which is equivalent to about 2.6% of the nation's needs. Increased production is thus a challenge for both the government and the farmer.

The government should accelerate the expansion of projected irrigation schemes, and ensure timely land preparation and provision of inputs to farmers. Research work in progress on efficient water management, fertilizer use and other suitable production technologies should be adequately funded, as these will help increase wheat production per unit area. It is estimated that, with efficient water management and good crop management practices coupled with farmer experience in wheat cultivation, crop yields could exceed 4 t/ha. In this case, the government wheat production target of 700,000 tons per annum could be realized by the year 1990.

## Wheat Production in Bangladesh: Its Constraints and Research Priorities

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Wheat production in Bangladesh has increased substantially since 1975, both in terms of production area and yield (Table 1). Wheat is now cultivated on about 570,000 hectares, with a production of one million tons. Before 1975, little wheat was grown and the varieties were low yielding (0.8 t/ha), disease susceptible, tall and late maturing. Total production was only about 0.1 million tons. When the performance of semidwarf, high-yielding varieties was found to be satisfactory, an ambitious wheat program was initiated in 1975-76 by importing seeds of high-yielding varieties (HYV) from India to replace

local varieties. Fifty-nine percent of the 150,000 hectares planted that year were planted with HYV. Production was approximately doubled, from 114,000 tons in 1974-75 to 215,000 tons in 1975-76. Within five years, the wheat area increased about five times and production, about nine-fold. At present, HYV occupy 98% of the area under wheat cultivation.

### Reasons for Success

The introduction of high-yielding varieties and the adoption of technologies for better management and seed preservation, generated through research in the mid-1970s, helped Bangladesh to become a wheat-growing country. Farmers were interested in growing HYV when they observed three to four times more yield as compared to local varieties; also, wheat could be grown more easily in residual soil moisture or under partially irrigated conditions. As compared to boro rice cultivation, three to four times more land could be irrigated with the same amount of irrigation water. The cost of cultivation was less, along with reduced problems of weed competition, disease and insect pests.

Wheat is sown in the winter months, from mid-November to mid-December, and is harvested in mid-March. During this period, most of the lands had previously been idle, after the harvest of transplanted and broadcast amon rice. Farmers are using this opportunity to grow wheat as an additional crop on this type of land. There is no problem for growing the subsequent crop, jute or aus rice, after the harvest of wheat.

**Table 1. Wheat production in Bangladesh, 1967-68 to 1982-83**

Year	Area (ha)	Average yield (t/ha)	Production (tons)
1967-68	77,800	.744	57,900
1968-69	117,300	.786	92,200
1969-70	119,900	.862	103,305
1970-71	126,000	.872	109,000
1971-72	127,300	.899	113,195
1972-73	120,200	.745	89,500
1973-74	123,500	.884	109,200
1974-75	126,100	.911	114,870
1975-76	150,100	1.430	214,700
1976-77	160,000	1.596	255,400
1977-78	188,900	1.813	342,500
1978-79	264,700	1.971	486,200
1979-80	433,200	1.869	809,700
1980-81	591,200	1.819	1,075,200
1981-82	534,412	1.776	949,000
1982-83	567,000	1.870	1,061,000

Source: Bureau of Statistics, Government of Bangladesh, Dhaka, Bangladesh

Although rice is the staple food in Bangladesh, the country has long been importing wheat to make up its food deficits. Wheat flour is consumed primarily as chapatis (handmade flat bread), bread in loaves and pastries. The dietary habit of the people has changed considerably, and wheat has now become a desirable food supplement to rice.

The extension service took an active role in providing wide publicity on how to cultivate high-yielding varieties through field demonstrations on varieties, fertilizer rates and sowing time, and through organizing block farms in irrigated areas. Research findings and recommendations were also communicated to growers through booklets, leaflets, field days, radio broadcasts and other audiovisual means.

Seeds were made available through continued imports, and local seed production was also strengthened by the Bangladesh Agricultural Development Corporation (BADC) on their farms and on contract growers' fields. Farmers were advised to preserve their own seed in sealed kerosene containers, biscuit tins, diesel or petrol drums, thick polyethylene bags or earthen pitchers. About 80% of the total requirement for seed is met through farmers' stocks and sales among themselves.

The Department of Food procured grain from growers at support price (a little over the market price fixed by the government at the time of harvesting) so that, during the peak sale period, the price did not fall too much. Some credits and loans were also provided through commercial banks for the purchase of inputs, such as fertilizer and irrigation equipment, to boost production.

### **Production Constraints**

According to the Bangladesh Soil Survey report, about 3.1 million hectares of land are physically suitable for wheat cultivation. Currently, the net area available for wheat is about 1.5 million hectares, after leaving land for other winter crops. It has been observed that, since 1980-81, there has been no further expansion of wheat cultivation, and a number of practical reasons exist for this fact. The potential area for the expansion of wheat is the land available after the harvest of transplanted aman rice. Aman rice is harvested in December, when soil moisture is the main limiting factor for the germination of seeds. Irrigation facilities exist for about 30% of the land and, if aman rice production is affected by flood or drought, many farmers prefer to grow boro rice in the irrigated areas.

Sufficient seed of short-duration varieties cannot be provided. As Bangladesh farmers prefer white grain, there is always a heavy demand for white-grained varieties, especially Sonalika because of its good performance under late-seeding conditions.

Threshing is a big problem. Farmers do not yet have effective, low-cost, small-scale threshing equipment. All wheat is threshed either by trampling with bullocks or by beating with sticks. The onset of early monsoon rains frequently destroys many harvested crops. Some competition from other winter crops, such as mustard and lentils, exists now, because of the high market price of these crops. Also, the wheat procurement price has not kept pace with the increased price of fertilizer and seed. Due to these problems, farmers are not encouraged to bring more areas under wheat cultivation.

## Research Priorities

### Varietal development

Research on high-yielding varieties of wheat was initiated a few years before the independence of Bangladesh, but systematic research was initiated only in 1971, with the scheme entitled the Accelerated Wheat Research Program. This program was based on the development of germplasm and of personnel; CIMMYT provided help in both areas. Initially, promising varieties selected from international nurseries were recommended for commercial cultivation and, simultaneously, agronomic requirements of the varieties and seed storage practices were made available to the growers.

Varieties now under cultivation include Sonalika (60 to 70%), followed by INIA 66 (10 to 15%); others grown are Tanori 71, Jupateco 73 and Pavon 76. The farmers' preference for Sonalika is due to its short maturity period (100 to 105 days), attractive large white grain and wide adaptation under both irrigated and dryland conditions; it is especially suitable for late seeding. However, Sonalika is now susceptible to leaf rust and leaf blotch diseases. Balaka, a white-grained variety, recommended in 1979 for late seeding under dryland and partially irrigated conditions, is now in cultivation (1983-84 season). Four new varieties, Ananda, Kanchan, Akbar and Barkat, were released in 1983 and are in a seed-multiplication program. They are resistant to leaf rust and moderately resistant to other foliar diseases and have a 10 to 20% yield advantage over Sonalika. It is hoped that these varieties will soon replace Sonalika.

The breeding materials from national and international programs are being evaluated. The superior genotypes selected from international sources are entered into the national program. At

present, about 400 single and top crosses are made annually. Individual plant selections are also made under Bangladesh conditions from the segregating F<sub>2</sub> spring x winter and spring x spring crosses, including the F<sub>2</sub> helminthosporium nursery material received from CIMMYT.

Since the majority of the wheat area is rainfed, tolerance to drought and resistance to leaf rust and other foliar diseases, especially leaf blotch caused by *H. sativum*, is of primary importance. Emphasis is being placed on the following areas:

- Evolve short-duration varieties, similar to Sonalika in maturity, with post-anthesis tolerance to heat and suitable for late plantings after the harvest of transplanted amon rice;
- Develop varieties with high yield potential for optimum seeding dates (mid to late November), suitable for dryland and irrigated situations;
- Evolve juvenile heat-tolerant varieties suitable for late October or early November planting, especially for improved tillering ability under high temperatures;
- Develop varieties suitable for semisaline soils, which are found in vast areas and are lying idle in the southeastern and southwestern parts of the country;
- Develop varieties tolerant to the low pH of some areas, and
- Develop durum wheat varieties which can improve the quality of foods, such as suji, semolina and noodles, which are now being prepared from bread wheats.

**Agronomic practices**

Much attention is needed in agronomic research. Cultivation techniques for a rice-wheat cropping pattern must be studied in regard to the effects of tillage, soil moisture conservation and water management. For transplanting rice, soil is puddled with a wooden country plow that creates a strong plow pan in some soils; this is a barrier to penetration by wheat roots. It causes the crop to be more susceptible to moisture stress or, if irrigated, creates waterlogging and a lack of normal plant development. Conservation of soil moisture by appropriate tillage methods is also necessary for rainfed areas.

Research should be strengthened for refining fertilizer recommendations, especially for potassium, and studies on micronutrients, such as sulfur, zinc,

copper and manganese, should be undertaken. Mixed cropping or intercropping with other winter crops is a practice followed, and this must be considered in all its ramifications.

**Post-harvest technology**

Research on farm-level seed and grain storage needs further attention. Low-cost threshing devices must be developed to resolve the present threshing problem.

**Conclusions**

In 1981, the Canadian International Development Agency (CIDA) provided grants to strengthen the existing wheat research programs carried out by Bangladesh in cooperation with CIMMYT. It is hoped that, as a result of this cooperative research program, Bangladesh will be able to close its recurring food gap (1.5 to 2 million tons) by increased wheat production.

## Wheat Improvement Programs for the Hotter Parts of India

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Wheat is the most important cool-season food grain crop of India. During 1983-84, wheat was cultivated on more than 22 million hectares, producing about 45 million tons of grain. This represents a tremendous increase over the 6.46 million tons of wheat grain produced in 1950-51. During this period, the productivity per hectare has increased from 663 kg/ha to more than 1,800 kg/ha. The increased productivity is attributable partly to better irrigation facilities and the increased use of fertilizer; the major factor, however, is the popularization of high-yielding dwarf wheats which have enabled efficient utilization of the created resources. The figures for area, production and productivity over the period since Indian Independence are given in Table 1.

The major wheat-growing states are Punjab, Haryana, Uttar Pradesh, Madhya Pradesh, Rajasthan, Bihar, Gujarat, Maharashtra and West Bengal.

Area production and yield per hectare in various wheat-growing states are shown in Table 2.

Among the important wheat-growing states, wheat in Karnataka, Maharashtra and Madhya Pradesh is grown in a typical hot, tropical climate. In considerable areas of Gujarat, Bihar, West Bengal and Assam, wheat is also cultivated in a fairly hot climate. The maximum and minimum temperatures during the wheat crop season at four locations representing typical wheat-growing areas of the country are presented in Figure 1; average temperatures are presented in Figure 2. It is clear from these figures that wheat is grown primarily in the coolest environments in the hills, followed by the northwestern parts of the country; in the east and south it is cultivated under much higher temperatures. Another aspect which is clear from these figures is that temperatures are highest at times of planting and

**Table 1. Wheat area, production and yield, India, 1946-47 to 1982-83**

Year	Area (000 ha)	Production (000 tons)	Yield (kg/ha)
1946-47	10,120	6,232	616
1951-52	9,471	6,182	653
1956-57	13,424	9,403	695
1961-62	13,750	12,072	890
1966-67	12,832	11,393	887
1971-72	19,139	26,410	1380
1976-77	20,922	29,010	1387
1981-82	22,308	37,833	1696
1982-83	23,000 <sup>a/</sup>	42,500 <sup>a/</sup>	1847 <sup>a/</sup>

<sup>a/</sup> Estimated

Source: Area and Production of Principal Crops in India

maturity in most parts of India. In fact, wheat growth duration in various parts of the country is determined by temperature limits.

Agronomists and physiologists have found that, for the planting of wheat, average temperatures should be around 20 to 22°C. They have also found that grain development is adversely effected if the average temperature exceeds 25°C. These temperature limits represent the limits of crop growth duration. The spring wheats, which are commonly grown in India, seem to be capable of adjusting their growth duration to these temperature variations. It is interesting to note that appropriate temperatures for sowing are reached at more or less the same time throughout India, and the recommended dates for planting are also similar for all parts except the hills, where they are earlier. Days to flowering of five widely adapted wheat genotypes in some of the representative parts of the country are

given in Table 3, showing how the number of days is inversely related to temperature.

It is obvious from this table that crop duration is reduced to less than half in the extremely hot temperatures as compared to the cooler climate of the hills. Other unfavorable effects of high temperature include:

- Reduced crop stand;
- Rapid entry into the reproductive phase, leading to very early flowering;
- Reduced tillering due to inadequate vegetative growth;
- Reduction in grain size (physiologists have estimated that there is a 10 to 15% reduction for every 5 to 6 degree rise in temperature above 24°C);
- Dessication of the leaves;
- Changes in disease and pest prevalence patterns, and
- Low yield.

**Table 2. Wheat area, production and yield in important wheat-growing states, India, 1981-82**

State	Area (lakh ha) <sup>a/</sup>	Production (lakh tons)	Yield (kg/ha)
Assam	1.02	1.16	1130
Bihar	17.44	25.69	1473
Gujarat	7.04	14.07	2000
Haryana	15.62	36.82	2357
Himachal Pradesh	3.54	4.30	1216
Jammu and Kashmir	1.98	2.04	1032
Karnataka	3.42	2.30	674
Madhya Pradesh	32.93	32.74	994
Maharashtra	11.28	9.88	876
Punjab	29.17	85.53	2932
Rajasthan	17.73	29.42	1660
Uttar Pradesh	78.49	128.83	1641
West Bengal	2.13	3.02	1417
Total India	223.08	378.33	1696

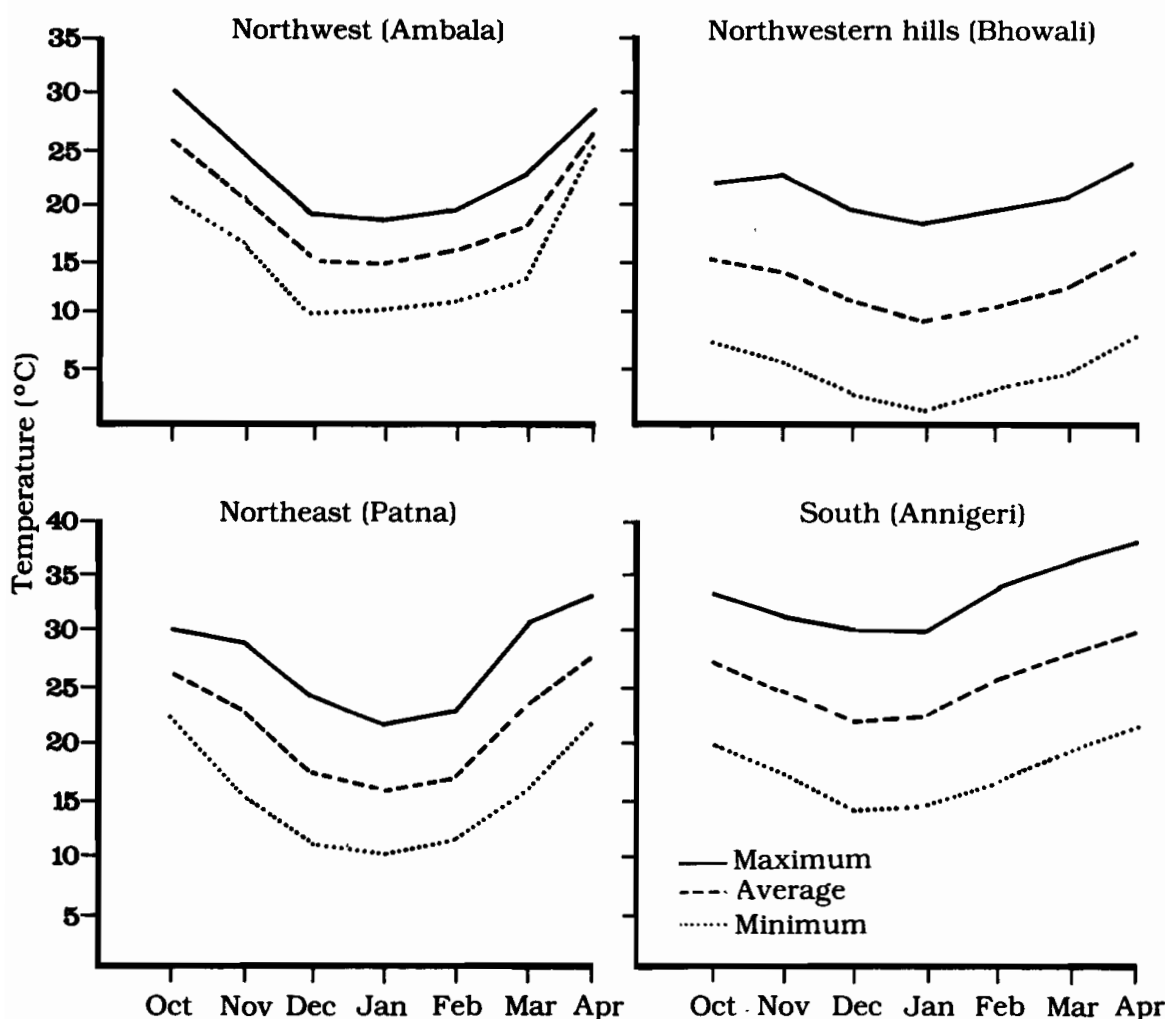
<sup>a/</sup> 1 lakh = 100,000

In India, a series of wheat varieties have been developed that have yield potential, under tropical conditions, which are comparable to those in other parts of the country. Some of the important recommended varieties for areas where wheat is grown under relatively hotter climates are:

- Northeast—Sonalika, UP262, K7410, HP1102, HP1209, UP115, HUW55, HUW206, HUW213
- Central regions—Kalyansona, J24, WH147, Lok-1, HD2236, HP2278, Swati, Sujata, Raj 1555(d), A206(d),

- Peninsular regions—NI5439, HD2189, Kalyansona, DWR39, HD2278, Melvika(d), N59(d), MACS1967

These varieties show normal plant development when grown under recommended cultural practices. One of the few major deviations from normally recommended cultural practices is for the peninsular zone, where wheat is grown under the hottest temperatures in the country; there it is recommended that the seed rate be increased from the normal 100 kg/ha to 125 kg/ha.



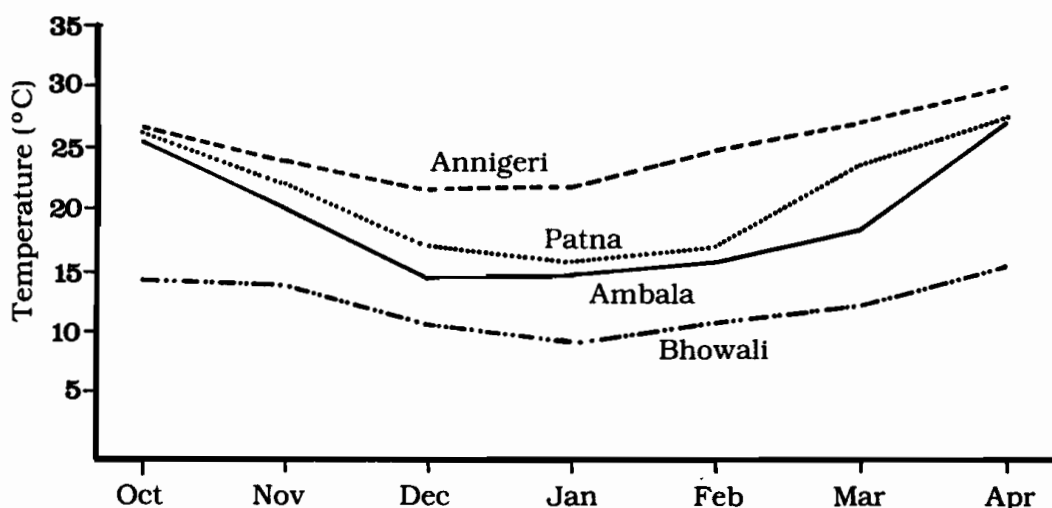
**Figure 1. Temperature variations during the wheat crop season in various regions of India**

In the central and peninsular parts of the country, wheat is cultivated under rainfed conditions. In most of India, although the monsoon rains end by about the middle of September, wheat cannot be sown until the end of October or the beginning of November, when temperatures make seeding possible. During the intervening period, there is severe loss in soil moisture. A number of cultural practices are recommended to conserve moisture but, in many fields, moisture levels in the upper layers become so depleted that achieving good plant stands becomes almost impossible.

None of the improved varieties is capable of being sown earlier than normal, as such sowing leads to severe high temperature symptoms. In recent years, attempts have been made to identify genotypes which show a minimum of adverse effects from high temperatures when wheat is seeded early. Some of these are Hindi 62, Raj 1771, Raj 1777, HI1011, HI1012 and VL616. These varieties possess some sort of temperature insensitivity and do not show reduced tillering or decreased vegetative phase, and they give good

plant establishment and growth. These materials are being used as sources for developing superior strains for early sowing. In fact, VL616 has recently been recommended for early sowing in the hills; however, high temperatures are not a serious constraint there. The main purpose of its release is to escape frost damage to floral parts, which is acute if ears emerge during the very cold temperatures of December to February. Most of the improved varieties show early ear emergence when planted prior to the end of October, even in the hills. In the development of VL616, one of the genes governing vernalization response has been exploited to regulate entry into the reproductive phase when severe cold has passed.

High temperatures during grain filling pose another constraint to wheat production, although crop duration in most parts of the country is so adjusted that it matures before extremely unfavorable temperatures are reached. However, a sudden rise in temperature prior to normal maturity is a widely prevalent phenomenon in almost all parts of the country. Such erratic rises



**Figure 2. Average temperatures during the wheat crop season in various regions of India**

in temperature are capable of causing considerable reduction in grain yield. Some differences among genotypes have been recorded, but this aspect

needs further research, especially from the point of view of heat-tolerant genotypes and the incorporation of this characteristic into improved varieties.

**Table 3. Days to flower for five wheat cultivars in four locations in India**

Variety	Days to flower			
	Almora, Uttar Pradesh (cool)	Hissar, Haryana (cool)	Pusa, Bihar (fairly hot)	Dharwar, Mysore (hot, tropical)
Sonalika	114	93	71	46
HD2285	121	101	78	47
HD2329	119	102	80	49
WH147	121	102	80	48
Raj 1555	121	101	78	47

## Wheat Research and Production in Pakistan

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Wheat is the staple food of the inhabitants of Pakistan; its straw constitutes an integral part of the daily ration for livestock. Spring-type bread wheat (*T. aestivum* L.) is the most common species grown in the ten wheat-production zones of the country, while some durumms are also cultivated in a very limited area, mainly in the rainfed area. The cultivation of wheat is spread throughout four provinces. The majority of both wheat-growing area and production is found in the province of Punjab (72% of each), with smaller amounts in Sind (14 and 17%, respectively), Northwestern Frontier Province (11 and 8%) and Baluchistan (4 and 3%).

### Bread Wheat Improvement

Work for the improvement of wheat was initiated in the country as early as 1883, and a number of varieties (T9, T11, 8A, 9D, C518, C591, C250, C217, C228, C271 and C273) were released from time to time until the mid-1950s. The wheat program was, however, revolutionized by the release of the first semidwarf, fertilizer-responsive, disease-resistant wheat variety Mexipak 65 in 1965. This variety almost doubled the yield of the old tall local wheats. Since that date, 30 bread wheat varieties have been released for different wheat-growing areas of Pakistan.

Although remarkable improvement has been made in wheat production, yield per unit area is still lower than that of many developing and developed countries of the world. This paper deals with improvements made in input resources, future wheat requirements, the various constraints causing the yield gap, breeding efforts for stabilizing and enhancing production and future research strategies.

### Improvement in Input Resources and Varieties

During the 1970-71 season, the wheat-growing area in Pakistan increased from 6 to 7.1 million hectares, seed distribution rose from 8.32 to 50.14 thousand tons and water availability per hectare of land from 24.69 million acre feet (MAF) to 39.07 MAF, compared to the previous season. Between 1971-72 and 1980-81, fertilizer use per hectare of arable land increased from 31.6 to 74.21 kg/ha, and credit distribution from US\$ 0.43 to 25.47 million.

The combination of the release of improved varieties with this increase in inputs has led to an increase in wheat production of 192%, from 3.81 million tons in 1960-61 to 11.15 million tons in 1982-83. Yield has increased 107%, from 822 to 1,707 kg/ha.

### Population and Wheat Requirements

For 1985, the projected population for Pakistan is 92.97 million, and wheat production, 12.67 million tons; 12.81 million tons of wheat would be required for that population. Self-sufficiency in wheat was attained in 1981-82, before the expected time, due to bumper crops. However, this marginal self-sufficiency may be disturbed by natural hazards at any time; therefore, concerted efforts are needed to maintain the tempo of increased production to meet the future challenge.

### Yield Gap

A substantial yield gap has been observed between yield at the experiment stations and on farmers' fields in each province. This gap is

primarily due to a lack of finances on the part of the majority of farmers for implementing modern technology for wheat production. Thus, there is great scope for improving wheat production and yield in the country.

### Constraints to Production

Like many developing countries, wheat production is confronted with both biophysical constraints (disease, fertilizer, water, seed, varieties, cultural practices and salinity/sodicity) and socioeconomic constraints (credit, knowledge, experience, tradition and institutions).

### Disease

Although several diseases attack wheat, the most important are stripe and leaf rusts, loose and flag smuts, Karnal bunt, powdery mildew, helminthosporium leaf spots and foot and root rots. Other diseases, such as those caused by *Septoria* spp., downy mildew, black point and black chaff, are of minor importance. The major thrust in the breeding program at present is to develop wheat varieties which are resistant or tolerant to the principal diseases. Measures to minimize their adverse effects on production are also being investigated. The reactions of commercial wheat varieties to important diseases are shown in Table 1.

**Table 1. Reactions of commercial wheat varieties to six diseases, Pakistan**

Variety	Disease reaction <sup>a/</sup>					
	Yellow rust	Leaf rust	Loose smut	Flag smut	Powdery mildew	Complete bunt
Blue Silver	S	S	S	S	S	S
Barani 83 <sup>b/</sup>	MR-MS	MR-MS	S	R	S	—
Indus 79	MS	MS	S	S	S	—
Bahawalpur 79	MS-S	MS-S	S	S	S	—
LU26	S	MS-S	S	MR	R	—
Lyallpur 73	S	S	S	S	S	S
PARI73	MS-S	S	S	S	S	S
Sandal	MR-S	S	S	MR	S	S
Sonalika	MS-S	S	S	S	S	—
Punjab 81	MS-S	MR	S	S	S	—
Pakistan 81	MR	MR	S	S	R	—
Faisalabad 83 <sup>b/</sup>	R	R	S	MR	S	—
Arz	MR-MS	MR	S	S	S	—
Zamindar 80	MR-MS	MS	S	S	S	—
Zargoan 75	MR	S	S	S	S	—
Khyber 79	MR-MS	S	—	—	—	—
Jauhar 78	S	S	—	—	—	—
Sarhad 83 <sup>b/</sup>	R	R	—	—	—	—
Kohinoor 83 <sup>b/</sup>	R	R	S	S	S	—

<sup>a/</sup> S = susceptible, MS = moderately susceptible, MR = moderately resistant, R = resistant

<sup>b/</sup> Candidate for release

The stripe rust races 66EO, 6E16, 66E16 and 38E16 have been found to be the most important while, for leaf rust, races 57 and 77 have been most aggressive and frequent. S.A. Rizvi has reported that LR19, LR24, LR25, LR28 and LR29 genes have shown resistance against a number of virulent isolates of leaf rust. For controlling leaf rust attack, fungicides such as Indar, Daconil and Balytan have proven effective.

Wheat varieties Chat "S", Bulbul, Chris, Super X, WL1145, WL1146, WL1257 and WL1562 have shown resistance against smut inoculum. The fungicides Baytan, Topsin-M, Vitavax-200 and Benlate have given good control of loose smut, as has the solar energy method which involves soaking wheat seed in water for four hours and drying it in the sun. Diseases such as flag smut, powdery mildew, helminthosporium leaf spots and foot and root rots, which earlier were not of much significance, are now becoming important.

#### **Insect pests**

Fortunately, wheat is not attacked by any serious pests; however, infestation with armyworm, cutworm, stem borer, cornstalk borer and green aphids has occurred in localized areas.

#### **Drought**

About 21% of total wheat area in the country is rainfed. The screening of plant materials and the testing of new varieties for drought tolerance are carried out in rainfed areas or under simulated moisture stress. Some of the varieties (Blue Silver, Lyp 73 and Pak 81), which were developed for irrigated areas, have also proved very successful under rainfed conditions; therefore, the testing of new varieties under both irrigated and rainfed conditions is encouraged. The new variety Barani 83 is now awaiting release.

#### **Salinity/sodicity**

At present, 2.4 million ha of land in Pakistan have been rendered saline-sodic and, with the continuous use of low-quality water, this menace is increasing every year. Wheat yield has been found to be reduced by 19% under moderately saline-sodic soils.

#### **Lack of nutrients**

Yield constraint experiments in irrigated and rainfed areas have shown that the proper application of fertilizer is of utmost importance. Yield reductions ranging from 51 to 73% have been observed without proper fertilizer use. This clearly demonstrates that wheat yields can be substantially increased if fertilizer use is properly regulated in the country.

#### **Planting date**

More than 50% of the wheat in Pakistan is planted late, i.e., during the month of December. Planting date experiments have shown that yield is progressively reduced with delays in planting. Yield was found to be reduced by 28.8 and 57.8%, respectively, when sowing was delayed from November to December and from November to January.

#### **Weeds**

*Chenopodium* spp., *Phalaris minor* and *Convolvulus* spp. have been found to be the major weeds. Wheat yields were found to be increased by 167.7, 140.7 and 136.3%, respectively, over the weedy control when weeds were controlled by the herbicides Dicuran MA, Tribunil and Graminon.

#### **Durum Wheat Improvement**

Systematic durum wheat improvement work was begun in the mid-1970s, and two promising durum lines, V79717 and V79736, have shown superiority in yield and disease tolerance as compared to the bread wheat checks; they are in the final stages of release.

### **Triticale Improvement**

Regular breeding work for the improvement of triticales has been initiated, and efforts are under way to develop new primary and secondary triticales and to improve spike fertility, grain hardness, color, plumpness and milling, baking and nutritional quality. Although three triticales lines, T-1-83, V1399 and V80523, have shown good yield performance, their commercial exploitation seems doubtful before flour yield (extraction), grain hardness, bread-making quality and grain color are improved.

### **Summer Wheat Nursery in Kaghan**

The second wheat crop (off-season) is grown during the summer at high elevations at Kaghan (2134 m) to advance a generation, increase seed of

elite lines and screen promising lines for disease resistance. The station is proving very useful for accelerating the breeding program.

### **Future Research Strategies**

Future strategies for the improvement of wheats and triticales will involve more emphasis on breeding varieties which possess wider adaptation and can withstand various types of stresses (disease, high temperature, cold and frost, moisture shortage, salinity-sodicity and waterlogging). Efforts will also be made to develop wheat varieties with low input requirements. Improvement of grain characteristics and milling and baking quality of triticales will also receive greater attention.

## Production Constraints and Research Priorities in the Southern Winter Wheat Region of China

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Wheat has been cultivated in China for more than 4,000 years, and it is grown in almost all parts of the country.

According to natural environmental conditions, cropping systems and varietal distribution, the wheat-growing areas are broadly classified into three major production regions, including the northern winter wheat region, the southern winter wheat region and the spring wheat region (5,6). These are subdivided into ten different ecological regions to better define the varietal type needed for successful wheat production (Figure 1).

### Wheat Production in the Southern Winter Wheat Region

The southern winter wheat region of China is situated to the south of the Huai River and Qinling Mountains, and covers three ecological regions, the mid-lower Yangtze Valley winter wheat region, the southwest winter wheat region and the South China winter wheat region (regions 3, 4 and 5, Figure 1).

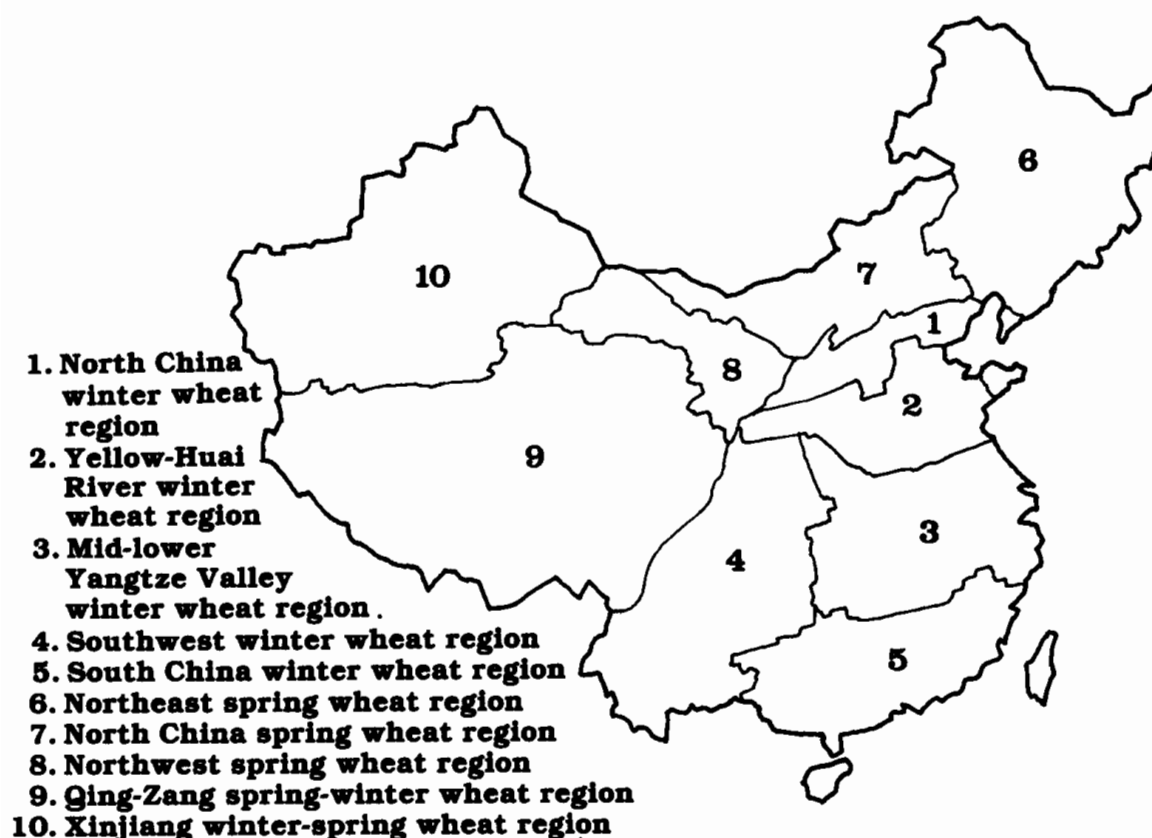


Figure 1. Wheat-growing areas in China, 1983

Source: Chinese Wheat Cultivars and their Pedigrees, S.B. Jin, ed. 1983. Agriculture Press, Peking, China.

The climate in this region is warm, with sufficient rainfall. Wheat is more widely grown in the subtropical zone than in the tropics. In the Yangtze River Valley, the annual average temperature is 15 to 19°C. The average temperature in January varies from 2 to 10°C, with the minimum temperature about -10°C. Annual rainfall is between 800 and 1,500 mm, and the frost-free period lasts 220 to 280 days, depending on the area. In South China, the annual average temperature varies from 16 to 24°C, and the average temperature in January, from 6 to 19°C. Annual rainfall, depending on the area, ranges from 1,000 to 2,400 mm. The frost-free period lasts 240 to 300 days; less frost occurs in the southern part of the region.

The soil pattern in the southern winter wheat region is complex, including rice soils, yellow soils, red soils, purple soils, yellow-drab soils, drab soils and brown soils. The cropping index is high, with three types of double-cropping systems, wheat with rice, wheat or barley with upland cotton and wheat with food grains other than wheat or rice. Among these, the double cropping system of wheat-rice is the most prevalent, covering more than two-thirds of the total wheat area; a triple cropping system of wheat-rice-rice is also practiced.

Under these climatic conditions, soft red wheat (*Triticum aestivum* L.) is widely cultivated. Wheat varieties are fall sown, but are mainly of spring habit with little or no vernalization requirement and photoperiod sensitivity. Some varieties are semiwinter types, with medium to early maturity and a long dormant period which prevents sprouting in the head before harvest.

Wheat ranks next to rice in importance in cereal production in the southern winter wheat region. In recent years,

about 9 million hectares of wheat have been grown; of this, about 5 million hectares are in the mid-lower Yangtze Valley, 3.2 million hectares in the southwest winter wheat region and 0.8 million hectares in the South China winter wheat region. Average wheat yields have increased greatly in the past 30 years, rising from 0.7 t/ha in 1949 to 2.7 t/ha in 1982. These average yields have exceeded that of the country as a whole. In the last several years, the wheat area in the region represented 33.2% of the total wheat area of China, and total production represented 37% of the entire country.

During the last few years, the nation's highest average wheat yield has been in this region. For example, the average yield in Jiangsu province reached 3,720 kg/ha in 1983 (Table 1). The Jiangsu Academy of Agricultural Sciences and other institutions attained yield levels of more than 7.5 t/ha between 1979 and 1982; this shows the prospects for wheat production in the region.

### Variety Improvement

The wheat breeding program in the southern winter wheat region started many years ago. In the early 1920s, the

**Table 1. The development of wheat production in Jiangsu province, China, 1949 to 1983**

Year	Cultivated area (000 ha)	Production (000 tons)	Yield (kg/ha)
1949	3229	2165	670
1959	2227	2472	1110
1969	2460	3325	1351
1979	2375	8261	3478
1980	2324	7789	3351
1981	2367	7383	3119
1982	2424	8639	3563
1983	2704	10061	3720

famous early-maturing variety Jiangdong Men was selected from the indigenous variety, Sanyuehuang. In the 1930s, the former National Agricultural Research Bureau (NARB) and some other institutions launched a cross-breeding wheat program. A number of crossing combinations were first made in 1934 in Nanjing, from which emerged the first varieties, such as Liying 3, Liying 4 and Liying 6. Yield levels were still very low in the 1940s. Indigenous varieties were mainly grown, making up more than 90% of the total wheat-growing area.

The indigenous varieties in the region are usually characterized by good adaptation to the local environmental conditions, and some have good tolerance to excessive soil moisture and wheat scab. However, they generally have poor yield potential and no resistance to rusts. Nevertheless, these varieties are valuable resources for wheat breeding and genetic studies today.

The wheat breeding programs in the region use indigenous varieties with good adaptability to local ecological conditions. At the same time, much attention is paid to the introduction of foreign varieties and the direct or indirect utilization of their characters in

order to attain the best varieties for the region. According to incomplete statistics, 357 new improved varieties have been selected and released in the region during the last 30 years. These varieties have replaced the old, indigenous varieties and have contributed a great deal to wheat production in the region. Generally, these new varieties have good adaptability, medium to early maturity, disease resistance and better yield. Wheat rusts in the region have been effectively controlled for 20 years through genetic resistance. Some famous improved varieties that have been released are Huadong 6 and 7, Aiganzao, Wumai 1, Ningmai 3 and 6 and Yangmai 1, 2, 3 and 4 (Jiangsu province); Zhemai 1 and 2, (Zhejiang province); Emai 6 and Jingzhou 1 (Hubei province); Wannian 2 (Jiangxi province); 5.1 Mai, Chuan Mai 8, Fan 6 and 7 and Mianyang 11 (Sichuan province); Yun 778 and Yun Mai 32 (Yunnan province), and Jinmai 2148, Fumai 7 and Longqi 35 (Fujian province).

Introduced foreign varieties with good rust resistance gene(s) and high yield potentials have been used extensively as parents in variety improvement in this region. The improved varieties have been developed by various breeding methods (Table 2).

**Table 2. Improved varieties of wheat developed in the mid-lower Yangtze Valley, China, 1950s to 1970s**

Breeding method	1950-1959		1960-1969		1970-1979		1950-1979	
	No.	% of total	No.	% of total	No.	% of total	No.	%
Introduction	8	27.6	6	15.8	9	9.1	23	13.9
Pedigree selection	6	20.7	7	18.4	17	17.2	30	18.1
Intervarietal crossing	7	24.1	16	42.1	57	57.6	80	48.2
Wide crosses	8	27.6	6	15.8	3	3.0	17	10.2
Radiation breeding	0	0	3	7.9	13	13.1	16	9.6
Total	29	17.5	38	22.9	99	59.6	166	100.0

Recently, the pedigrees of 125 improved varieties from the mid-lower Yangtze Valley were analyzed. Twenty-eight of them were derived from indigenous varieties, and 92 from Italian varieties; about three-fourths of the improved varieties were derived from Italian varieties. There were also a few varieties derived from varieties from other countries; eight were from the USA, seven from Chile, three from the USSR, three from Australia and two from Mexico.

### **Major Wheat Production Constraints**

Wheat production in the southern winter wheat region has developed rapidly in the last ten years, but the factor of yield instability still exists. For instance, during the past 34 years, production increased 18 years in the southern part of Jiangsu province and decreased 16 years. This was caused by various production constraints in the region.

First, there is excessive and poorly distributed rainfall during the wheat-growing season, particularly in the spring. It generally considerably exceeds wheat's physiological requirements, and seriously influences growth and development. For instance, in the winter wheat region of the mid-lower Yangtze Valley, average precipitation from the seedling stage to maturity usually amounts to 430 to 755 mm, of which 224 to 626 mm is in the spring (March to May), making up 48.5 to 82.9% of the total rainfall during the wheat-growing period. According to meteorological data for the southern part of Jiangsu province from 1951 to 1980, average rainfall during the period of elongation to maturity was 270 to 320 mm; there was one rainy day in every 2 to 2½ days. In the years of over-abundant rain, there may be up to 400 mm during this period. Excessive moisture is the most important reason for the instability of wheat production, and it also enhances scab infection.

Statistics from the Suzhou Prefectural Agricultural Research Institute for the last 28 years shows that serious scab epidemics occurred in five of those years; the rate of infection reached 50 to 100% and caused yield losses of 20 to 40%. There were ten years with medium epidemics, with a rate of scab infection of 20 to 40% and yield losses of 10 to 20%; light or zero scab damage occurred in 13 years. The average frequency of scab epidemics was 53.3%, with one year of serious or moderate scab epidemics out of every two years. For this reason, varieties with high tolerance to excessive soil moisture and good resistance to wheat scab are urgently required for the region.

The second limiting factor in the region is high temperature during the late growing period of wheat. The average number of days when air temperature goes above 30°C is usually 2.2 to 9.1 days during the ripening period. Sometimes, before harvest, there may be high temperatures with low humidity, high evaporation and hot, dry southwest winds. This combination of factors dries the grain so quickly that premature senescence or even green death during the milk stage can occur; this, of course is a major reason for low grain weight. Thus, it is necessary to develop a wheat variety with quick grain filling, early maturity and a long period of seed dormancy in order to resist germination in the head caused by the excessive precipitation and high temperatures in the late growing stage.

High and stable yields of wheat are also limited by poor drainage facilities, low soil fertility, rough tillage, weeds and damage by diseases and insect pests. There is also a large amount of red-yellow soils in Jiangxi, Hunan, Yunnan and Guizhou provinces. This type of soil is not suited to the growth of wheat, and yield per unit area in these provinces is very low.

Practice has showed that the following measures would be effective in resolving the above problems:

- Establish systems for rapid drainage, so that the ground-water level is lowered and soil moisture content decreased. With the consequent increase in soil aeration, injuries from excessive soil moisture would be avoided or alleviated:
- Improve tillage practices in order to make the soil more suitable for the growth of wheat;
- Utilize proper rotation systems of rice, wheat, rape seeds and green manure crops so that soil fertility is increased, and
- Eliminate damage from disease and insect pests. Scab, rusts (stem, leaf and stripe), powdery mildew, sheath blight, armyworm and aphids are major problems in the region. Bavistin spray at the flowering stage is an effective deterrant. Powdery mildew and rusts can be controlled with Bayleton; Validamycin is recommended for sheath blight.

### **Research Priorities in the Southern Winter Wheat Region**

Wheat production in this region has been greatly increased in the last 30 years. Without doubt, this has been closely related to varietal improvement, research on the rice-wheat rotation and the improvement of farm capital investment. Research must now resolve the problems of instability while further increasing production and average yield. The wheat research programs will focus on variety improvement, with special attention on disease resistance, early maturity and increased yield potential.

### **Disease resistance**

Diseases are one of the main production constraints to increasing wheat yields in the region. Wheat scab, rusts, powdery mildew and sheath blight are all present, but head scab causes the greatest damage. Breeding for scab-resistant varieties has been carried on in Jiangsu province since 1975.

*Screening for scab-resistant germplasm*—Although no germplasm has been found with complete immunity to scab, the response of varieties to scab are different. Some have fairly good resistance to scab, while others are badly damaged. For instance, Wangshuibai is an old indigenous variety with good scab resistance. Scab-resistant germplasm is being used in the crossing program. A few advanced lines have been developed with high resistance to scab and other diseases, combined with better yield potential and early maturity.

*Identification of scab-resistant strains*—Artificial inoculation in the laboratory or in the field by soil-surface infection is being conducted in Nanjing. Multilocation tests are also being conducted on 30 sites in the mid-lower Yangtze Valley and Fujian province to identify materials with enhanced scab resistance.

### **Early maturity**

Early-maturing varieties with high yield potential could meet the needs of a double or triple cropping system and escape destructive diseases and premature senescence caused by high temperatures and excessive moisture injury.

### **Increased yield potential**

In the better production areas, semidwarf varieties that have large spikes and that are responsive to inputs and resistant to lodging are required and must be developed.

Variety improvement must also be combined with agronomic research. Agronomists in southern China have been working on the population structure of high yielding wheat, including yield components and cultivation techniques. These technologies have led to better yields of wheat after rice in the last ten years, and have played an active role in increased wheat production. Agronomic research must be further stressed in order to increase the production, quality and economic benefit of wheat in the region.

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## Wheat Production Constraints and Research Priorities in Indonesia

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While rice production in Indonesia is nearing self-sufficiency, wheat imports are rising dramatically. Wheat consumption has increased significantly each year during the last decade; this is clearly reflected in increasing wheat imports. In 1970, wheat flour imports were 557,000 tons, and total wheat grain imports have continued increasing until, by 1981, they reached 1.5 million tons (Figure 1).

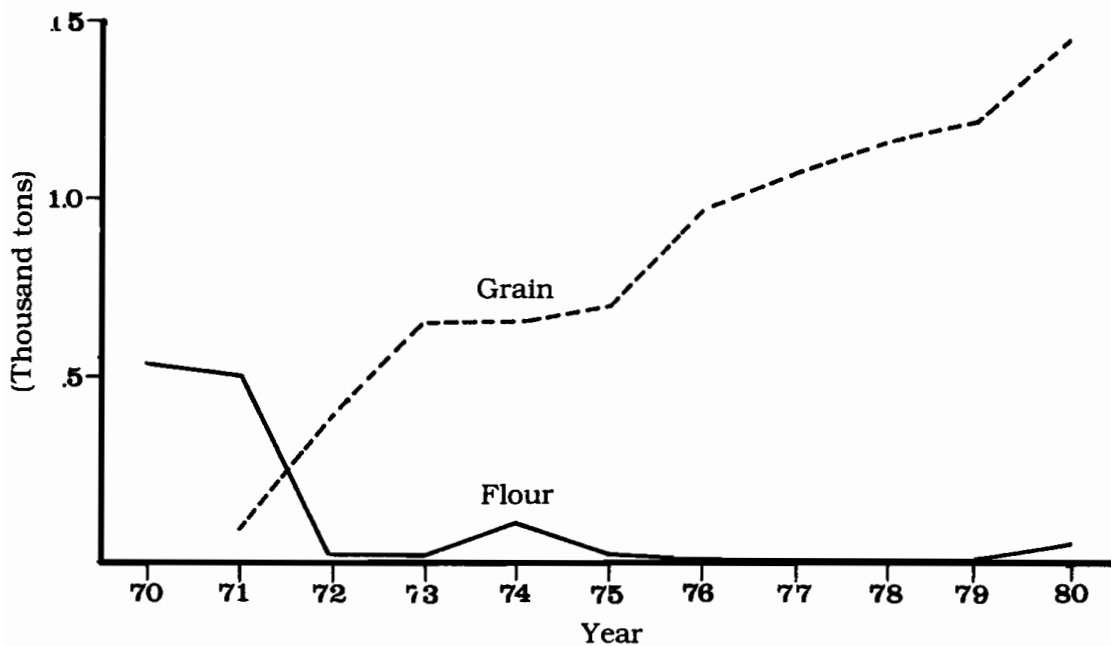
Wheat has been grown in Indonesia for a couple of centuries, especially in the relatively isolated highlands, such as Pangalengan in West Java, the Dieng Plateau and Salatiga in Central Java and Brumo-Tosari in East Java. The area has always been nominal, compared to that occupied by other food crops. Limited adaptation to high elevation and competition from highly profitable crops, such as vegetables and

industrial crops, have kept the wheat-growing area negligible.

It now appears that, by the end of Indonesia's fourth Five Year Plan in 1989, domestic wheat production will be making a contribution towards self-sufficiency in food carbohydrates within the country. Therefore, since early 1981, the Indonesian government has given more emphasis to increased wheat production.

Wheat research was begun in the early 1980s, after wheat materials were received from India and Pakistan and, subsequently, others were received from Spain, the Philippines and, especially, from CIMMYT.

Research will concentrate on the development of wheat lines that are adapted to the various growing conditions in Indonesia, identification of



**Figure 1. Indonesia imports of wheat and flour, 1970 to 1980**

those areas that are suitable for growing wheat, wheat husbandry and time of planting, disease control and post-harvest technology, including the processing of wheat.

### Production Constraints

Earlier reports indicated that wheat could be grown with reasonable yield at high elevations in the tropics. Results from recent experiments in Indonesia show that some varieties can be grown successfully in relatively low-elevation tropical environments. In 1982 and 1983, in Kuningan, West Java (550 meters above sea level), the average yields of the five best varieties were 2.09 and 1.97 t/ha, respectively. Some of these results are presented in Tables 1 and 2.

Data were also obtained from a trial in Mojosari, East Java (50 meters above sea level), where the average yield of the five best varieties was 1.59 t/ha. These results indicate that wheat can be grown in the tropics, even at low elevations. In fact, most of the varieties tested were "physiologically" adapted to the tropics (they produced viable seed). Low yield was the result of agronomic measures which need further research, as well as of the need for breeding better-adapted lines.

**Table 1. Mean grain yields of several varieties grown in the dry season, Kuningan, Indonesia, 1982**

Variety	Origin	Grain yield (t/ha)
HI784 (Swati)	India	2.33
R164 <sup>a/</sup>	CIMMYT	2.14
UPLW <sub>1</sub>	Philippines	2.13
Sandal	Pakistan	2.12
IWP72	India	2.11
NI5439	India	2.04
Lyalpur 73	Pakistan	1.81

<sup>a/</sup> CM2699-12M-1Y-5M-2Y-4M-0Y

Constraints against a continually successful wheat crop are still great. Scab incidence is a continuous threat, especially when there is unusually heavy rain during the flowering stage. Until now, there has been no single variety identified as having true tolerance to this disease. Effective measures against root rot caused by *Sclerotium rolfsii* must still be investigated. Fungicides available for seed treatment have not been found to be effective.

In the tropics, it is a well-known fact that it is easier to maintain soil fertility in the lowlands (paddy fields) than in the uplands, since the latter is prone to heavier erosion. The deteriorating soil fertility of the uplands has complicated varietal evaluation to the extent that the varieties have been blamed as not being adapted to the hot, humid tropical environments. In a soil fertility trial, the use of 20 tons of manure per hectare was found to be optimal for yield. Since this practice would be difficult on a large scale, alternative measures to improve the growing environment must be considered, such as proper crop rotations and the use of green manure crops. Only in such improved environments would the evaluation of wheat potential in the tropics be meaningful.

Determining proper tillage operations for upland crops grown in lowland paddy fields (normally after the second rice crop) is also difficult. Various management practices need to be tested and evaluated for raising a successful wheat crop.

### Research Priorities

The general objective of the Indonesian wheat research program is to identify and develop high-yielding varieties adapted to growing conditions in Indonesia. Also necessary is the identification of technology that would guarantee yields of at least 1.5 t/ha. Research will be conducted under

various growing conditions, with wheat as a secondary crop after rice and on irrigated as well as rainfed uplands. Initially, research will depend heavily on introductions from traditional wheat-growing countries and, especially, from CIMMYT. Screening will have as its priority, yield capability and adaptation, tolerance to important pests and diseases and good quality characteristics.

Special objectives toward which attention will be directed are:

- The identification and development of superior wheat genotypes through extensive introduction and, later, hybridization or other techniques for combining high productivity with good quality, nutritional value and adequate environmental stress tolerance;
- The determination of land preparation practices for guaranteeing reasonable plant density for high yield;
- The evaluation of agronomic characters and disease tolerance of selected materials in different locations;
- The determination of nutritional value and quality characteristics of selected varieties at the cereals laboratory, Sukamandi Food Crops Research Institute (SURIF);
- The determination of consumer acceptability, according to the intended use of the wheat;
- The evaluation of crop production practices for enhancing yield, and
- The determination of proper planting dates of wheat within multiple cropping systems.

**Table 2. Yield and yield components of wheat varieties grown at Kuningan, Indonesia, 1983<sup>a/</sup>**

Variety	Yield (t/ha)	1000-grain weight	No. grains per spike	No. spikes per m <sup>2</sup>
HI784	2.05 a	39.8 c	22 ab	347 abc
V1287	2.04 a	37.5 de	21 abcd	333 abc
Lyallpur 73	2.04 ab	39.3 cd	19 abcd	340 abc
UPLW1	1.92 abc	34.0 ghi	18 abcd	378 a
LOK1	1.80 abcd	36.8 ef	18 abcd	337 abc
HD2009	1.73 abcd	34.9 defgh	24 a	326 abc
Sonalika	1.72 abcd	43.0 ab	16 d	343 abc
LU26	1.72 abcd	33.7 ghij	20 abcd	326 abc
Sandal	1.69 abcd	35.8 efg	21 abcd	283 abc
Lakhish	1.65 abcd	39.6 cd	20 abcd	328 abc
SA75	1.64 abcd	31.5 jk	21 abcd	346 abc
R164	1.60 bcd	36.3 ef	18 abcd	335 abc
UP115	1.59 cd	33.8 ghi	17 bcd	320 abc
Sureño	1.59 cde	32.6 ijk	22 ab	303 abc
HW135	1.55 cde	41.0 bc	17 bcd	274 bc
B-3	1.54 cde	32.5 ijk	22 ab	355 abc
IWP72	1.53 cde	44.9 a	16 cd	295 abc
UP262	1.50 cde	41.4 bc	16 cd	337 abc
Chenab 79	1.40 d	31.2 k	21 abcd	368 ab
K342	1.36 de	33.3 hijk	20 abcd	263 c
Blue Silver	1.15 e	34.8 fg	16 cd	261 c

<sup>a/</sup> Means followed by the same letter or letters are not significantly different at the 5% level

## **Wheat Growing in the Philippines**

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Wheat research and production are not new ventures in Philippine agriculture. Historical records show that wheat was first grown successfully in 1664, and flourished during the Spanish regime. However, later it totally disappeared from the Philippine scene.

Several attempts were made to revive wheat production, but these failed, mainly due to the lack of suitable varieties. While progress has been slow, long years of experimentation and experience have indicated that wheat can be grown in selected areas of the country. Varieties Trigo 1 (UPLW1) and Trigo 2 (UPLW2) have been developed and are adapted to selected agroclimatic conditions. Specific areas of production and cultural management requirements also have been identified and wheat production technology has been packaged; nevertheless, much still remains to be accomplished.

### **Pilot Wheat Production Program**

The present joint program of the National Science and Technology Authority, the Philippine Council for Agriculture and Resources Research and Development (PCARRD) and the National Food Authority (NFA) will include wheat in their packages of technology (POT) that will be demonstrated for the rice-based production system. This system is relevant to many areas of northern and central Luzon, where irrigation water is too limited to allow a second rice crop. During the coolest part of the year, December to February, wheat could successfully complete its cycle of growth and development.

The National Wheat Production Program, which was started in 1982, is coordinated by PCARRD and has

participation from five government and private agencies; it covers three regions (Regions 1,2 and 3) of the country. During the first year, it was conducted in eight locations, with a total area of 24.85 hectares. For the 1983-84 cropping year, a total of 46.89 hectares, involving 94 farmer-cooperators, were included.

With the experience gained from the previous cropping season, better yields were obtained during the 1983-84 season. For example, in Ilocos Norte and Ilocos Sur, average wheat yields were 1,146 and 1,018 kg/ha, respectively. Generally, farmer-cooperators who adhered to the recommended practices obtained better yields. The average cost of producing 1 kg of wheat grain was estimated at P3.86 (US\$ 0.20). In terms of harvest quality, about 85% of the harvests were classified as seed grade; that seed was purchased by NFA at P5.20/kg (US\$ 0.26). Some sites, however, had poor yields and even failures, due to various production and management constraints.

### **Production Constraints**

Continuous assessment of the applicability of the POT at the different pilot sites identified several needs before improved wheat production can be realized, such as fertilization, pest and weed control, seed quality, credit and crop insurance.

The delayed harvesting of the rice crop preceding wheat planting, which was brought about by a long drought in most prospective pilot sites, caused the withdrawal of some farmer-cooperators from the project.

Lack of needed pesticides in the local market resulted in heavy infestation of foot rot and *Helminthosporium* leaf spot, as well as damage from stem borers in some pilot areas. It is also evident that some farmer-cooperators need further training in carrying out certain components of POT.

### **Research Priorities**

PCARRD is committed to the effective and efficient management of agricultural research and resources. Since its establishment in 1972, PCARRD has carried out its mandate to unite all research undertakings, manpower, facilities, funds and other program resources into a potent force for national development. Thus, it sets the long-range research directions for the total research system, rationalizes the strategies and orchestrates the mechanisms for attaining them.

Continuous breeding for high-yielding varieties, adapted to the climate of the Philippines, is a vital part of wheat research. Yield potentials must be increased through selection for agronomic characteristics such as tolerance to environmental stresses and resistance to *helminthosporium* leaf spot, foot rots, corn earworm and pink stem borer. New introductions of wheat from CIMMYT and the International Center for Agricultural Research in Dry Areas (ICARDA) will be screened for adaptability. This must be accompanied by varietal testing of promising selections on a regional level.

Seed production of the most promising selections and varieties will be vigorously pursued to make the seed available for applied research trials and for interested farmers and seed producers. Varietal characters needed if wheat is to fit into rice-based cropping systems have to be precisely determined, as well as further

information on production constraints such as weeds, diseases and insects. The economics of wheat production in combination with corn, mungbean and soybean must also be considered.

The need for more on-farm research is essential. Recommendations for fertilizer use and weed and disease control that are developed in the research stations must be verified on farmers' fields.

Socioeconomic studies will be incorporated into the research to assess the profitability and acceptability of the production program. Information from the pilot areas with respect to the methods and management procedures of individual farmers in relation to yields obtained and problems encountered will provide a data base for decisions, policy making and further research directions.

### **Future Plans**

Concerned people are optimistic that most of the requirements for commercial wheat growing can be met through:

- Intensive seed production/multiplication, especially of the new promising lines;
- Expansion of the program, using seeds produced from previous crops, and
- Continuous refinements of the POT to suit local conditions.

Detailed biophysical and socioeconomic characterization and analysis of the various pilot sites will be carried out to rationalize the successes or failures obtained from this pilot testing. The training of technicians and farmer-cooperators in wheat culture and management will also be a continuing program. Interagency and multi-disciplinary cooperation will be further strengthened.

## Thailand Winter Cereals Program

**P. Chandhanamutta, Rice Research Institute, Kasetsart University, Bangkok, Thailand**

Thailand is a tropical country, lying between 5 and 21°N latitudes; it has a total area of about 513,000 square kilometers. Wheat production is possible in the cooler area of northern Thailand, which lies above 18°N. This region is a mass of mountains, with several rivers, and level areas along the larger rivers and streams. Total area of lowlands, uplands and highlands are 0.9, 3.1 and 6.5 million hectares, respectively. The lowlands are about 300 meters above sea level, rising to an average elevation in the mountains in the north of 1,600 meters. Mean minimum and maximum temperatures from November to February (the wheat-growing season) in the lowland area are 13 and 28°C, respectively; mean rainfall during the same period is 10 mm. Under these conditions, wheat has a crop cycle of 100 to 120 days.

### Wheat Consumption

The current population of Thailand is about 50 million. Rice is the staple cereal food. Per capita consumption of rice in 1981 was 144 kg; that of wheat was only 4.7 kg. Long-term prospects for growth in wheat consumption are tentatively placed at around 12% annually. Wheat grain and flour imports in 1981 amounted to some 230,000 tons; about 85% of the imports was in wheat grain which went to four flour mills in Bangkok. The mills are currently running below full capacity.

### Pricing

Thailand imports most of its wheat from the United States. The CIF Bangkok wheat price is US\$ 200 per ton or US\$ 0.20 per kg. The Thai government charges a tariff and other taxes on wheat imports, estimated to be about 40% of the CIF value. This puts the cost to the millers at approximately

US\$ 0.28 per kg. Local wheat farmers expect to get US\$ 0.35 per kg as a farm gate price. Therefore, only through government protection and subsidy can local wheat be competitive with imported wheat. However, commercial white flour costs about US\$ 0.60 per kg or more. It is conceivable that a market for a local flour would be an incentive to farmers to grow wheat.

### Wheat Use

Wheat farmers in Thailand produce about 160 tons of grain annually, and this small amount is sufficient to make some local food products. Enzymes from wheat sprouts are mixed with cooked glutinous (waxy) rice to make liquid glucose, which is used in special candies. Cracked roasted wheat is fermented with soybean to prepare soy sauce and miso. Steamed cracked wheat is used as a medium to culture oyster mushroom spawn. The four modern flour mills produce a variety of high-quality flours and semolina, which are used to make bread, cakes, pastries, biscuits and noodles, as well as some Thai and Chinese foods.

### Wheat Marketing

With the limited local wheat production, a direct trade between farmers and food processors is generally practiced. If the volume of trade is expanded, the private merchants that currently market rice and other field crops would take wheat as a new commodity. However, this middleman in the rice marketing system is reaping a very high profit. Therefore, wheat marketing might bypass this middleman. It is suggested here that wheat production should be incorporated into various rural

development projects. Wheat campaigns at the village level would encourage farmers to grow and learn how to prepare wheat for food. A small mill and bakery could first be established. Then, with production experience and a larger number of farmers involved, the point might be reached when there would be enough locally produced wheat to supply the modern mills in Bangkok.

### Potential Wheat Area

Wheat can be grown in three situations, on 1) the rainfed highlands, 2) the uplands, either rainfed or with irrigation, and 3) the lowlands after rice, either rainfed or with irrigation.

A thorough survey of potential wheat area has not yet been made. One recent study estimated that about 117,000 hectares of lowland rice soil in Chiang Rai province are suitable for wheat farming. The soils are loamy, somewhat acid, moderately light in texture and more than 150 centimeters deep. A preliminary crop water use study suggests an available soil-water capacity of 250 mm in an area where the 75 mm of rainfall normally required for reliable rainfed crop production can be expected in the month of October.

### Research and Development

Wheat research commenced in the early 1960s as a project of the Ministry of Interior. From that program, the two currently available varieties, INIA 66 and Sonora 64, were selected. During the 1970s, other organizations became involved and, in 1979, the first National Wheat Workshop was held to exchange data and to coordinate research. The workshop is now an annual event.

There are three separate entities conducting breeding programs in Thailand:

- The Department of Agriculture, based at Samoeng, with the objective of breeding and selecting wheats for the cooler medium and higher altitudes;
- Chiang Mai University, selecting for the areas with about 300 meters altitude, and
- Kasetsart University, selecting for the hot, dry northeast region of Thailand.

These three programs submit entries to the Thailand Observation Nursery and the Thailand Yield Nursery, which are grown at many sites throughout the country. The lines under evaluation are largely selections from various CIMMYT and ICARDA nurseries, although a number have been derived from locally made crosses.

Progress is being made in the selection of wheats which outperform current varieties (Table 1). Agronomic trials have been carried out by the three organizations over the past four years, and agronomic recommendations have been tentatively formulated.

**Table 1. Mean yields of the five best-performing lines in the Thailand Yield Nursery, 1984**

Name/pedigree	Mean yield (kg/ha)
UP262	2266
Quimori	2257
Pi-Frond x Pi-Mazoe/Mexipak, PK2858-7a-3a-3a-0a	2251
Buckbuck "S", CM31678-R-4Y- 2M-15Y-2M-1Y-0M	2124
Bluebird-CNO67 x INIA-Soty, CM1502-8M-3Y-3M-2Y-0M	2102
INIA66	1979
Sonora 64	1838

Many farmers are now exploring the possibility of growing wheat, mainly as a result of its promotion as a cereal for home consumption ("local use") by the Department of Agriculture Extension Service. Agronomic recommendations will be verified on small-scale plantings. Other areas receiving attention in the overall program are plant protection, provisions for seed production and storage facilities, economic and marketing issues and the training of technicians and farmers in wheat production techniques.

### **Summary**

Thailand's increasing consumption of wheat (12% annually) will bring about a huge trade deficit in the future. Wheat is currently being grown in a small area in the northern provinces, but most farmers are unaccustomed to wheat production and utilization. A renewed wheat program with CIMMYT support is being launched for farmers, and advances are being made in selection for high-yielding varieties. Due to the lack of a marketing system, the crop is initially being introduced for home consumption through small local markets.

## Dryland Wheat Production in the Subtropics of Queensland, Australia

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The subtropical, dryland wheat-growing regions of Queensland, Australia, are characterized by a summer-dominant but extremely variable rainfall (Figure 1). This leads to the need to store large quantities of water in the soil prior to planting (120 mm available water being common) as a buffer against the low winter rainfall. Figure 1 also presents the mean daily temperature which has an average range of 16°C. A frost risk extends from June to August, but is quite variable at specific sites, depending upon the local topography.

As a result of extensive field investigations, the preferred planting time in regions of low frost risk has

changed from June (with flowering after the danger of frost has passed, and an average grain yield of 1.4 t/ha), to March and April (with flowering occurring from June to early August). The early planting allows for growth and, hence, increasing transpiration potential to be timed to coincide with declining evaporative demand, rather than having these factors in phase, as occurs with June plantings. This results in a considerable saving in total water use from planting to anthesis. For a given planting date, it is possible to match potential water use in the pre and post-anthesis phases, since most of the water likely to be available to the

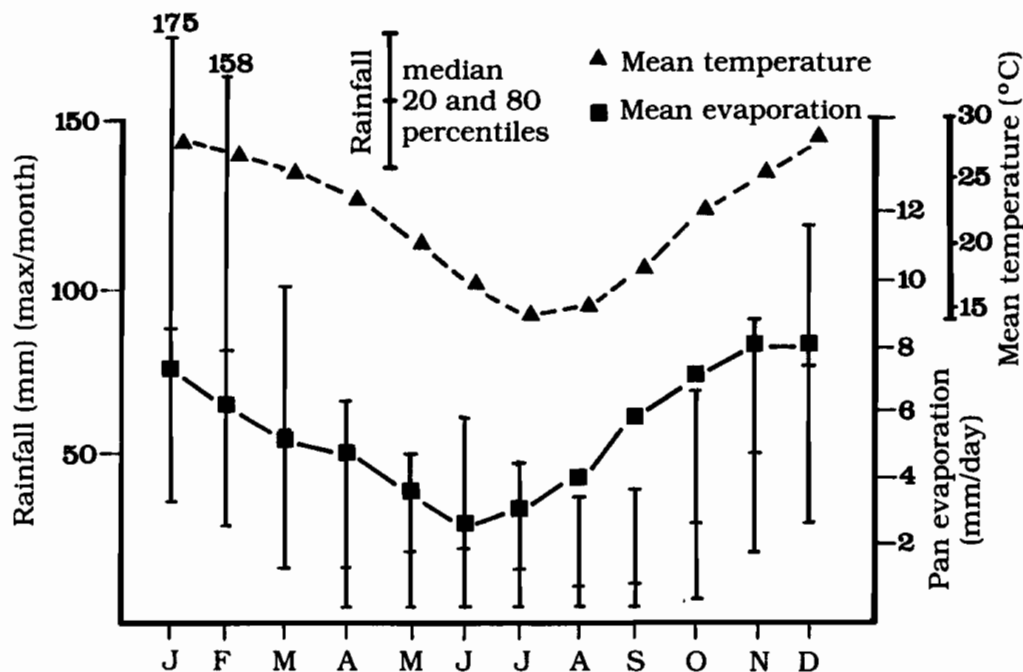


Figure 1. Long-term climatic conditions, Emerald, Australia

Latitude 23°30'36''S, longitude 148°09'43''E, altitude 212 m

Rainfall, mean over 91 years

Evaporation, mean over 12 years

10% probability of 0°C screen temperature: first, June 5, last, August 18

crop is present, and known, at planting. This may mean restricting growth duration and biomass production to levels where grain yield is below potential in years of high growing-season rainfall; the improved reliability of grain yield, however, more than compensates for this loss and gives an expected long-term average yield of approximately 2 t/ha.

Planting under high temperatures and photoperiods of around 12.5 hours per day allows a full expression of genotype variation in phenology, which is often masked in winter planting by the effects of low temperature on vegetative development. Under conditions conducive to very high growth rates, small differences between genotypes, agronomic practices and disease incidence can have disproportionate effects on grain yield expectancy, especially when using short-season genotypes which produce relatively low biomass by anthesis. Under these conditions, the total radiation interception by the crop, especially up to apical spikelet production, is extremely important. However, genotypes differ in radiation interception, and such differences are due to variations in phenology and the area of the first few leaves produced. This is reflected in genotypic variation in tiller and biomass production per unit of time, which appears to be more marked and durable than under more temperate conditions. The agronomic manipulation of radiation receipt by varying plant population and arrangement does not often interact with genotype. A planting rate of 50 kg/ha is sufficient to maximize grain yield, except when the crop grows only on seminal roots; then a higher planting rate can be advantageous.

Establishment of the crop under high temperature conditions is critical, not only for its effect on initial leaf cover, but also in relation to the position of the crown node. There is a large genotype and temperature interaction on

coleoptile length; at constant 35°C there is little genotype variation in coleoptile length (4 cm), whereas at 20°C it varies from 6 to 14 cm (Figure 2). The semidwarf genotypes have the shortest coleoptiles. Attempts to break the linkage between short coleoptile and Norin 10 genes have as yet been unsuccessful. Soil type and condition, rather than genotype, appear to be the major factors in determining whether the leaf emerging underground will reach the surface and establish a plant.

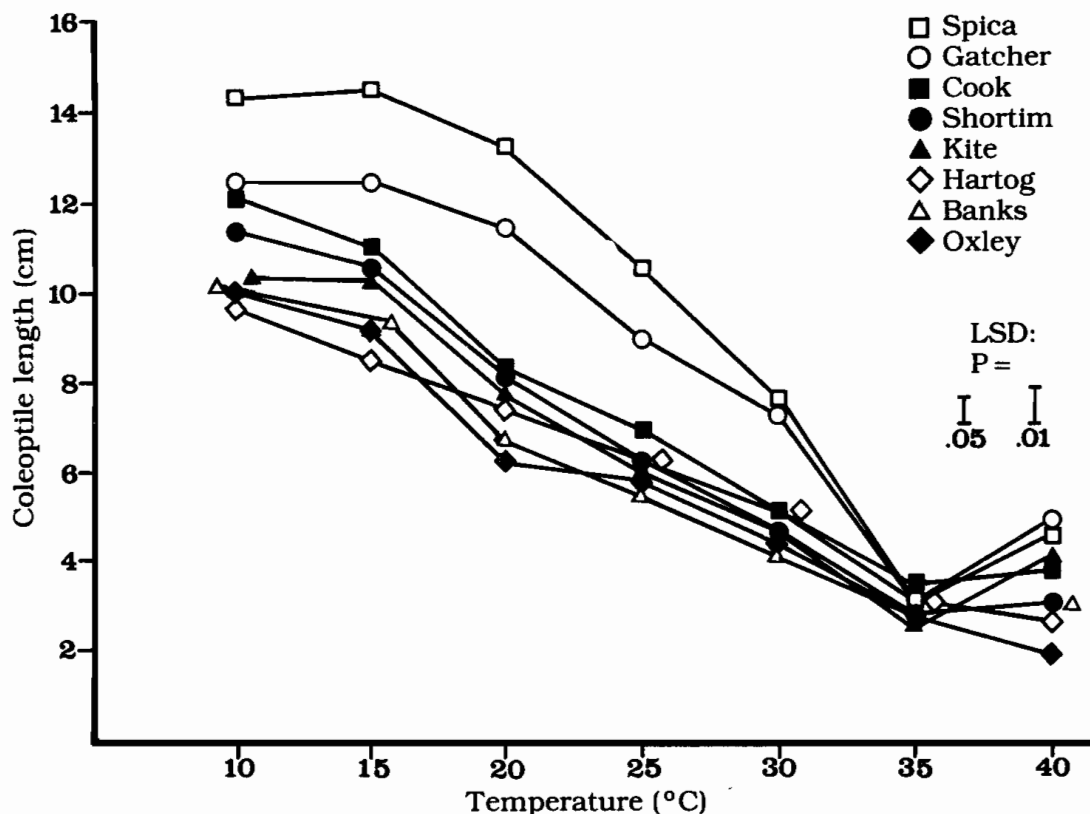
On many soils, it has been found necessary to use presswheels over the planted row to reduce the depth of March plantings in order to gain effective establishment. Subsequent rainfall tends to wash soil into the depressions over the seed, thus increasing the depth of the crown node in the soil. The deeper the crown node, the better is nodal root production following subsequent rain. Rainfall soon after planting appears to be necessary to obtain maximum tiller production, although whether this is due to nodal root production or nutrient availability and uptake is unknown. Tiller production under high temperatures does, however, appear to be extremely responsive to nutrient availability.

Commercial production under conditions of high temperature during vegetative growth is currently restricted to areas of low frost risk, since grain development continues into midwinter. Since no wheat breeding or selection is conducted specifically for this system, the cultivars are chosen from the pool of generally adapted Queensland cultivars on the basis of their tested phenological adaptability to the environment. Diseases have not yet become a problem, due to the low humidity and good resistance present in commercial genotypes; however, leaf and stem rusts are potentially serious. Current research is assessing the viability of still earlier planting to allow

completion of grain growth before any significant frosts occur, even in areas of moderate frost risk. Moving vegetative growth and anthesis into higher temperature and humidity conditions has resulted in the appearance of head scab (*Gibberella zeae*), which has been severe on certain genotypes, and spot blotch (*Bipolaris sorokiniana*), which has occurred on barley. Base rot (*Sclerotium rolfsii*) is present in all cereals and, together with other root diseases, has the potential to become serious. When anthesis has taken place under conditions of high temperature and prolonged high humidity, some damage to anthers has reduced grain set. Whether this is a direct effect of environmental factors or is associated

with microbial growth on the anthers has yet to be determined, as has any genotype variance in this factor.

In conclusion, it is believed that, in the absence of serious diseases, satisfactory wheat yields can be achieved under dryland, subtropical conditions in Queensland. Agronomic practices are critical, however, in gaining satisfactory performance. Substantial genotype variations for characters which appear to be of importance in these environments do exist, and the determination, not only of their importance but also of the selection environment needed to exploit these variations, is critical to the development of a viable wheat industry in these regions.



**Figure 2. Effect of temperature on the coleoptile length of eight cultivars**  
By permission: B. Radford, unpublished

## Contributed Papers

### I. Breeding

#### Breeding Wheat for More Tropical Environments at CIMMYT

R.L. Villareal, S. Rajaram and W. Nelson, Wheat Program, CIMMYT, Mexico

##### Abstract

*Tropical wheat is defined as early genotypes with the ability to give acceptable yields under tropical conditions, and with resistance to helminthosporium and leaf rust and tolerance to high temperatures. Tropical areas include those between 23°N and 23°S latitudes with elevations of less than 1500 meters above sea level. The goal of CIMMYT's Tropical Wheat Improvement Program is to breed wheats for the nontraditional, tropical wheat-growing areas, including parts of Thailand, Philippines, Sri Lanka, the Chaco region of Paraguay, the lowlands of Bolivia and the Cerrados of Brazil. Two years of research have been completed in the identification of suitable lines for tropical conditions. Adapted germplasm has been extensively used in crosses, resulting in a large number of segregating populations. Materials coming from the breeding program, as well as germplasm from countries around the world, have been distributed to target countries through CIMMYT's international nursery network. In cooperation with CIMMYT pathologists, mass screening techniques have been developed for helminthosporium resistance.*

CIMMYT's bread wheat program aims to produce, in close collaboration with national wheat research programs, widely adapted, high-yielding varieties characterized by semidwarf plant stature, photoperiod insensitivity, acceptable industrial quality, and resistance to such environmental stresses as drought, heat, cold, aluminum toxicity, salinity, and prevalent diseases such as stem rust, leaf rust, stripe rust, septoria leaf blotch, septoria glume blotch, helminthosporium, scab and barley yellow dwarf. The program's main objective is the production of advanced lines suitable for various agroclimatic areas of the world where wheat is currently the major food crop or where its consumption is rapidly rising.

Disease complexes, soil types and climatic conditions vary considerably from one target area to another. Thus,

CIMMYT's breeding approach is to develop a base of widely adapted, high-yielding, disease-resistant wheat lines that possess the specific attributes necessary to achieve higher yield under specific target-area conditions. The breeding methodologies used for each environment are similar, with slight modifications. To simplify this presentation, only the development of wheats for warmer and nontraditional wheat-growing areas in the tropical belt will be discussed.

##### Tropical Wheat Research at CIMMYT

CIMMYT's interest in exploratory work to further extend wheat into the lowland tropics was initiated in 1978. The Mexican location of Poza Rica (21°N, 60 meters altitude) was used for early screening work.

At the recommendation of the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research (CGIAR), and with special project funding from the United Nations Development Programme (UNDP), CIMMYT expanded its exploratory research on tropical wheat in 1981. Preliminary investigations have included:

- The continuation of the evaluation of wheat germplasm and related species possessing desirable characteristics for tropical areas;
- The development of screening techniques, and
- The identification and establishment of working relationships, where necessary, with locations for the testing of advanced materials.

After the successful completion of the preparatory phase of the Tropical Wheat Improvement Program, CIMMYT, with special five-year project funding from UNDP, has recently undertaken a small experimental research and training effort for the development of wheats with specific traits necessary for certain warmer environments. The overall objective of the research program is to develop high-yielding, disease-resistant, semidwarf wheats that perform well and at profitable levels during the cooler season in the tropics and subtropics.

### **The Tropical Wheat Environment**

Variable hydrological, climatic and edaphic factors make a specific definition of a tropical wheat-growing system difficult. However, a working definition would include all existing and potential wheat-growing areas between 23°N and 23°S latitudes, and with elevations less than 1500 meters above sea level. As its first step in the

program, CIMMYT's aim is to breed wheats adapted to the warmer and nontraditional wheat-growing areas of the world, such as parts of Thailand, the Philippines, Sri Lanka, the Chaco of Paraguay, the lowlands of Bolivia and the Cerrados of Brazil. Extension to other areas can occur later.

### **Production Constraints and Breeding Objectives**

In developing wheat varieties for tropical environments, a number of production constraints must be taken into consideration. The breeding objectives pursued are dictated by the water regimes and relevant physiochemical and biological stresses of the target areas.

Production conditions and constraints are far too varied between locations to specify precisely the combinations of traits that would be desirable for an adapted wheat variety. However, some of the more important characters that should be emphasized are a stable high yield, good agronomic characters, desirable grain quality and resistance to environmental stress, diseases, insects and sprouting.

#### **Stable high yield**

This is the most important consideration in developing wheat varieties for tropical areas. Varieties that provide a stable yield give the farmer a degree of certainty that he will have something to harvest, regardless of the environmental stress.

#### **Good agronomic characteristics**

Several agronomic characteristics are important for the successful production of wheat under tropical conditions.

*Early vegetative vigor*—This characteristic is of primary importance in helping to overcome weed competition, in compensating for missing plants and in helping to ensure that the crop achieves its critical leaf

area at flowering. Vegetative vigor is related to various combinations of rapid seedling emergence and development, early and heavy tillering and early and rapid increase in seedling height. Considerable variation in early vigor exists among CIMMYT wheat germplasm.

*Early maturity*—This is another trait that is clearly advantageous for wheat in intensive rotation patterns with other crops. In a rice-wheat cropping system, rice is normally harvested in October or November, after which wheat is sown. By the time land preparation is completed, the sowing date for wheat is already delayed beyond the optimum for medium to late-maturing varieties. Earliness also minimizes risk by shortening the crop's exposure to adverse high temperature conditions.

*Semidwarf stature and lodging resistance*—These are definite agronomic requirements, especially under moderate to high fertility conditions. Considerable yield loss occurs when the crop lodges, and harvesting becomes very difficult. The advantages of short, sturdy culms have been dramatically demonstrated in the high-yielding varieties of wheat.

### **Resistance to environmental stresses**

Wheat varieties for the tropics will need resistance to various environmental stresses.

*Heat tolerance at the juvenile and later growth stages*—This is a characteristic that must be incorporated. Unadapted types tend to have reduced tillering, poor plant vigor and very early flowering dates. Fertility and seed weight also decline when wheats flower or ripen during periods of high temperatures. Therefore, to perform well under tropical environments, a variety must have some degree of tolerance to warm temperatures and humid conditions.

*Drought resistance*—This is another characteristic to be emphasized. Wheat in most target areas will be grown under rainfed conditions, and the crop must be grown primarily on residual soil moisture. In addition, winter rainfall cannot be depended upon; drought stress can occur at any point of the growing cycle. Hence, tolerance to drought becomes critically important.

*Tolerance to adverse soils*—This is desirable, since wide fluctuations of mineral concentrations are associated with chemical changes that occur in tropical soils, due to alternate wetting and drying. Consequently, toxicities and deficiencies occur in many crops. Soils under tropical environments frequently have low pH and high aluminum content, resulting in aluminum toxicity in growing plants. Salinity problems may be another constraint to high wheat yields in the humid tropics. In general, soil salinity is caused by the presence or intrusion of sea water, or by surface evaporation of soil water that is initially high in salt content.

### **Disease resistance**

This is a very important breeding objective. It is essential that wheat varieties for the tropical areas be resistant to the major prevalent diseases. One serious disease constraint in most areas is leaf rust, caused by *Puccinia recondita*. This disease constitutes a major threat to yield, especially when wheat is grown over an extensive area. CIMMYT currently possesses germplasm with excellent resistance to leaf rust, and this can be transferred to germplasm that appears promising for the tropics.

Under production conditions of warm temperatures and high humidity, leaf blotch, caused by several *Helminthosporium* spp., may also be a serious problem. CIMMYT's preliminary

work on helminthosporium, supported by a special project research grant from UNDP, has resulted in the identification of advanced lines with varying degrees of resistance.

Resistance to head scab, caused by *Fusarium* spp., is especially needed in the more humid tropical environments, where conditions are ideal for the development of the disease. CIMMYT has recently intensified its efforts to develop high-yielding lines with scab resistance. By the end of 1983, lines had been identified that possessed some resistance.

Other disease problems confronting wheat in tropical climates are the soil-borne diseases, such as foot rot and seedling blight, caused by *Sclerotium rolfsii*. Damping-off of seedlings often occurs when temperatures are high and the soil saturated with moisture; it is still not known whether it will be possible to identify resistance to this particular disease. Possibly more promising would be the development of a chemical seed-treatment technique for disease control. Another soil-borne problem is fusarium, which causes seedling blight, root rot and the spike infection, scab.

Bacterial stripe, caused by *Xanthomonas translucens*, is another threat to wheat cultivars under tropical environments. A severe infection of this bacteria kills most, if not all, of the foliage of the wheat crop, causing a drastic reduction in yield. Bacterial stripe is widely distributed, but it only becomes important where susceptible varieties are grown and the growing season is predominantly wet.

#### **Insect resistance**

For tropical wheat varieties, this characteristic is also important, since insects such as the rice stem borer, corn earworm, corn semilooper, armyworm and aphids can be serious pests.

#### **Desirable grain quality**

Grain color and appearance and acceptable milling and baking qualities are important qualities. The wheat produced in the tropical areas will be destined primarily for local millers; hence grain type and quality will play an important role in farmer decision to adopt a particular variety.

#### **Sprouting resistance**

This is an obvious requirement for wheat varieties for tropical areas, as it hinders grain from sprouting in the spikes before harvest, which would lower the quality characteristics of the variety. Because of humid production conditions in the tropics, especially when rain is frequent during grain ripening, sprouting can be a serious problem.

#### **Breeding and Screening Methodology**

CIMMYT's principal breeding approach is the development of a base of widely adapted, high-yielding and disease-resistant wheat germplasm that possesses attributes necessary to achieve higher productivity under varying conditions. New lines must be developed quickly if they are to be of value to the less-developed countries.

Toward this objective, CIMMYT grows two generations in Mexico each year, resulting in 8,000 to 10,000 simple and top crosses which combine different traits needed to develop lines suitable for those areas of the world included under their operational mandate (Table 1). The germplasm used in the crosses is obtained from all over the world and is chosen because of useful genes. Before crosses are made, candidates for parents are studied carefully for their agronomic, pathologic and quality characteristics. Decisions are based on experience and rapid assessment of available data, rather than on a genetical analysis of each parent. The number of lines produced differs from year to year, but 40 to 50%

of the plants selected from each generation are subsequently discarded, due to unacceptable seed characteristics.

As a result of many years' experience in wheat breeding, CIMMYT places emphasis on the pedigree and modified bulk breeding systems and the use of simple and top crosses. This method permits rapid combination of

germplasm and increases genetic diversity; this is especially important because of CIMMYT's mandate to breed for diverse climates and regions with different problems.

To accomplish the breeding objectives of CIMMYT's Tropical Wheat Improvement Program, and to facilitate

**Table 1. World target environments included under CIMMYT's operational mandate**

<b>Areas</b>	<b>Countries and regions</b>	<b>Important diseases</b>
Irrigated Areas	Ganges plains of India, Indus Valley of Pakistan, Bangladesh, Tarai of Nepal, Egypt, Mexico, Zimbabwe, Lybia, Sudan	Stem rust, leaf rust, stripe rust
Dryland areas, 500 mm rainfall	Mediterranean North Africa, Middle East, China, Southern Cone countries	Stem rust, leaf rust, stripe rust, <i>Septoria tritici</i>
Drylands areas, 500 mm rainfall	Central India, parts of the Middle East, North Africa, Southern Cone countries	Bunts, loose smut
Aluminum toxic areas	Brazil, Central African highlands	Stem rust, leaf rust, <i>Septoria tritici</i> , <i>Septoria nodorum</i> , <i>Fusarium</i> spp., <i>Helminthosporium</i> spp., <i>Xanthomonas translucens</i>
Highlands areas, above 1500 m	High plateaus of Mexico and Guatemala, Andean countries, East Africa	Stripe rust, BYDV, <i>Septoria tritici</i> , <i>Septoria nodorum</i> , <i>Fusarium</i> spp., <i>Helminthosporium</i> spp., <i>Xanthomonas translucens</i>
Tropical areas, 23°N-23°S latitudes, excluding highlands	Central America, Caribbean, South and Southeast Asia, West Africa	Leaf rust, stem rust, <i>Fusarium</i> spp., <i>Helminthosporium</i> spp., <i>Xanthomonas translucens</i>
Areas affected by salinity	Certain dryland areas of the Middle East and North Africa, Pakistan	Leaf rust, stem rust

the distribution and adoption of suitable germplasm, a number of activities are underway or in the planning stages.

### Shuttle breeding

The main activity is shuttle breeding between two contrasting climates in Mexico, one for a winter crop at Ciudad Obregon (27°20'N latitude, 40 meters altitude) and the other for a summer crop at Toluca (19°N latitude, 2640 meters). Both are characterized by endemic rust attacks, and enable breeders to select for day-length insensitive, widely adapted types with high levels of rust resistance. Selections can also be made at Toluca for resistance to septoria and fusarium diseases. This two-cycle approach also cuts in half the time needed to develop a new variety.

In addition to these testing sites, CIMMYT regularly employs the screening environments of El Batan (19°N, 2240 meters) for low rainfall conditions, Tlaltizapan (18°N, 940 meters) for heat tolerance, and Poza

Rica (21°N, 60 meters) for helminthosporium diseases. Similarly, tropical Tampico (22°N, 40 meters) is also used in cooperation with the Instituto Nacional de Investigaciones Agrícolas (INIA), as a supporting location for screening work under tropical conditions. The relationship of these experimental locations is illustrated in Figure 1.

CIMMYT employs additional tropical locations in other countries to gather genetic information for use in the crossing program and for general screening activities. Maximum utilization of advanced materials coming from the bread wheat program is also considered a major part of the overall strategy of the Tropical Wheat Improvement Program.

In the future, shuttle breeding between the locations of Poza Rica, for helminthosporium disease and leaf rust screening during the winter, and Tlaltizapan, for heat tolerance and plant-type screening during the summer, will be used as an alternative breeding strategy.



**Figure 1. Location and elevations of experiment stations in Mexico at which CIMMYT conducts research for tropical wheat**

### **Screening for tropical adaptation**

The world wheat germplasm collection is also being screened for materials with desirable characteristics which will be continuously introgressed into the breeding program for the tropics.

In carrying out all of the above-mentioned objectives, CIMMYT utilizes a multidisciplinary, coordinated approach, involving the participation of scientists trained in various disciplines.

### **Program Results**

#### **Early maturity**

CIMMYT's breeding objective for the last few years has been to select and develop wheats with earlier maturity. In trying to obtain such lines, the earliest-maturing segregates are selected from F<sub>2</sub> segregating populations. For comparison, the variety Sonalika from India is used as the early check variety. When a low percentage of plants in a segregating population reach physiological maturity, they are selected and harvested. Then, as F<sub>3</sub>s, they are handled in a separate nursery, together with other segregating and advanced early materials. This system of handling the materials is more for practical reasons, since damage from birds and other pests is particularly severe on early plants left in the field.

Using this selection method, advanced lines that are as early as Sonalika have been obtained. Two hundred sixty early lines were tested for yield in Ciudad Obregon in the 1983-84 cycle. Table 2 presents 14 lines that were as early as Sonalika or earlier, but which have better yield potential. These materials are now in the First International Early Screening Nursery, together with other early germplasm in the program.

#### **Helminthosporium resistance**

Efforts to improve resistance to *Helminthosporium* spp. began in the early 1980s. Helminthosporium screening work is done at Poza Rica, in the tropical area of Mexico, and also at

the Tlaltizapan station. It is hoped that germplasm with both helminthosporium resistance and heat tolerance will result from selections at these locations. Helminthosporium resistance is evaluated on the basis of the following characteristics:

- Slow development of the disease;
- Acceptable agronomic characteristics;
- "Good finish," the ability to have clean, fertile and bright heads at maturity, and
- Good seed quality.

Table 3 presents the best varieties and advanced lines which were found resistant to helminthosporium in Poza Rica in 1983-84. These lines are now in the new Crossing Block and Third Helminthosporium Screening Nursery. All of these lines showed better resistance than BH1146, a resistant check variety from Brazil.

#### **Heat tolerance**

In the breeding program, testing has been initiated to identify varieties and advanced lines having tolerance to high temperature. Heat tolerance is evaluated in Ciudad Obregon by planting advanced lines in mid-January, so that early growth stages occur during a period of rapidly rising temperatures. The final performance of the lines is evaluated in late April. The following characteristics are used as selection criteria for heat tolerance:

- Longer leaf duration, the "stay-green" characteristic
- High tillering capacity
- Acceptable spike fertility
- Relatively high grain weight
- High hectoliter test weight
- Relatively high yield

More than 200 advanced lines were identified as having some heat tolerance in 1983. These same lines were reevaluated in Ciudad Obregon in

**Table 2. Advanced lines of bread wheat, as early or earlier in maturity than Sonalika but with better yield potential, Ciudad Obregon, Mexico, 1983-84**

Cross and pedigree	Yield		Days to maturity
	Kg/ha	% of Sonalika <sup>a/</sup>	
Chukar'S'/HD2172 CM68199-10Y1M-1Y-1M-0Y	6498	124	115
Veery'S'/Huacamayo'S'/Woodpecker'S'/NAC CM68810-B-1Y-1M-2Y-1M-0Y	6374	122	113
VeeryS'/Huacamayo'S'/Woodpecker'S'/NAC CM68810-B-1Y-1M-2Y-2M-0Y	6296	120	113
Bluebird/CNO67/5/FN/TH*3//1144.29/ *2TH/3/*4CTFN/4/SR/6/PVN'S" CM46712-1Y-1M-1Y-1Y-0M	5487	117	112
TOB/CNO67//TOB/8156/3/Calidad//Bluebird/ CNO67/4/BB/INIA/5/Alondra'S" CM59177-1M-1Y-1M-4Y-1M-0Y	5770	115	115
Bluebird/CNO67/5/FN/TH*3//1144.29/ *2TH/3/*4CTFN/4/SR/5/PVN'S" CM46712-1Y-1M-1Y-2Y-0M	5287	113	112
HI669/4/Tordo'S'/HD832*2//TOB/3/Tordo'S'/ 2*HD832 CM62550-1Y-1M-2Y-1M-3Y-1M-0Y	5692	110	114
Manantial//CNO67/PJ/3/NAC/4/Emu'S"-Dougga CM60960-B-1Y-4M-1Y-4M-1Y-1M-1Y-1M-0Y	5379	107	113
Alondra'S'/Altar'S" CM68045-3Y-1M-1Y-0M	5634	107	113
Yaco'S" CM41195-A-13M-2Y-3M-1Y-1M-0Y	4958	106	113
HD669.1B/Chiroca'S" CM62536-5Y-1M-1Y-3M-1Y-1M-0Y	4677	104	113
IAS54/Alondra'S" CM56805-3Y-1Y-4M-1Y-1M-1Y-0M	5932	103	115
COC/Bluejay'S'//NAC/Buckbuck'S" CM63992-5M-1Y-1M-7Y-1M-3Y-0M	5307	103	115
Redpoll/Ani'S'//PVN/Veery'S" CM68735-I-4Y-1M-3Y-3M-0Y	5363	102	114
Sonalika (early check)	---	---	115

<sup>a/</sup> Percent of Sonalika for the respective yield trial

**Table 3. Best advanced lines of bread wheat resistant to *Helminthosporium sativum*, Poza Rica, Mexico, 1983-84**

Cross and pedigree	Disease score <sup>a/</sup>			Diseased grain (%)
	Heading	Flowering	Milk stage	
JUP/4/7C/Pato(B)/3/LR64/INIA//INIA/ Bluebird/5/ANA CM37760-C-21Y-2M-1Y-3M-9Y-0M	1	3	4	10
RD2206/Hork"S" CM39808-58M-2Y-4M-1Y-1M-1Y-0B	2	3	4	20
Lira"S" CM43903-H-4Y-1M-1Y-3M-2Y-0B	2	3	4	15
Lira"S" CM43903-H-4Y-1M-1Y-3M-3Y-0B	2	4	5	16
CI14227/TRM//Madeira"S" CM47943-V-5M-3Y-1M-1Y-0Y	2	4	4	14
Alondra"S"/IAS58 CM53481-6Y-1Y-4M-1Y-1M-1Y-0M	3	4	5	16
Bluejay"S"/TOB/Chanate CM55912-10Y-3Y-1M-3Y-2JO-0JE	2	3	5	12
Veery"S"/Sunbird"S" CM61981-4Y-1M-6Y-3M-0Y	2	3	4	12
HI669/4/Tordo"S"/2*HD832//TOB/3/ Tordo"S"/2HD832 CM62550-1Y-1M-2Y-1M-1Y-0M	3	4	4	10
Kea"S"/4/Kalyansona/Bluebird//CJ"S"/3/Alondra"S" CM64617-9M-1Y-1M-1Y-0M	2	3	4	18
AU/UP301//Gallo/SX/3/Pewee"S"/4/Maipo"S"/ Maya"S"/Pewee"S" CM67245-C-1M-2Y-1M-3Y-0M	3	3	5	12
Antbird"S"/Yaco"S" CM67618-2Y-3M-3Y-2M-0Y	2	4	6	12
BH1146 (resistant check)	2	4	5	20
CIANO79 (susceptible check)	5	6	9	58

<sup>a/</sup> Scoring scale 0 to 9 (0 = highly resistant, 9 = highly susceptible)

1984, and a high percentage were confirmed as being heat tolerant. Since the program is in the initial stage of heat-tolerance screening, no crosses have yet been made for this purpose. However, there are plans to initiate breeding for heat tolerance within the next two years.

### **Drought resistance**

Drought resistance is defined here as "the ability of one genotype to be more productive with a given amount of soil moisture than other genotypes." From the beginning, CIMMYT's objective in this area has been to produce germplasm which combines responsiveness under both drought conditions and high-yielding environments. To achieve this goal, a breeding program has been implemented in which spring x winter materials are subjected alternately to reduced moisture levels and optimum irrigated conditions. The shuttle takes place between Ciudad Obregon in the winter season, and the highland locations of El Batan and Huamantla in the summer.

The performance of 12 advanced lines in Ciudad Obregon (two irrigations) and El Batan (rainfed conditions) are given in Table 4. It appears from this table that these lines will perform well under both environmental conditions. These materials are in the new Drought Screening Nursery for international yield testing, which will provide additional data on their stability.

### **Conclusions**

The CIMMYT Tropical Wheat Improvement Program has completed two years of research to identify suitable lines for tropical conditions. The crossing program has continuously utilized adapted germplasm as parental lines in crosses, resulting in a large number of segregating populations. Materials selected from the breeding program, as well as germplasm from countries around the world, have been distributed to target areas through CIMMYT's international nursery network. The materials are classified for traits and entered into the following nurseries:

- Helminthosporium Screening Nursery
- Drought Screening Nursery
- Heat Tolerance Screening Nursery
- Early Screening Nursery
- Scab Resistant Lines

These nurseries serve as a means to verify resistance and as mechanisms for germplasm introduction into national programs.

In cooperation with CIMMYT pathologists, techniques for mass screening for such major tropical diseases as helminthosporium have been developed. These techniques are now being further refined.

In the years to come, CIMMYT will endeavor to recombine genes for high yield, early maturity under high temperature conditions and resistance to leaf rust and helminthosporium. In spite of the fact that only about 4% of its total wheat budget is directly related to tropical wheats, CIMMYT will continue to integrate and test all of its advanced lines for the improvement of germplasm for the tropical wheat areas.

**Table 4. Highest yielding advanced lines of bread wheat, grown under two irrigation regimes, Ciudad Obregon, 1982-83, and under rainfed conditions, El Batan, 1983**

Name and pedigree	Ciudad Obregon		El Batan	
	Yield (kg/ha)	% of Ures 81	Yield (kg/ha)	% of Genaro 81
Veery "S" CM33027-F-15M-4Y-4M-3Y-2M-1Y-0M	5976	118	5480	119
Tyrant "S" CM40610-25Y-3M-3Y-1M-2Y-0B	5672	118	5113	111
Veery "S" CM33027-F-12M-1Y-12M-1Y-2M-0Y	5835	115	4707	102
Veery "S" CM33027-F-15M-500Y-0M-75B-0Y	5806	115	5360	116
Flycatcher "S" CM43598-II-8Y-1M-5Y-2M-2Y-0B	5335	111	5447	118
Maya/Moncho "S"//KVZ/TRM CM44083-N-2Y-2M-1Y-1M-1Y-1M-0Y	5333	110	6133	133
Veery "S" CM33027-F-15M-500Y-0M-98B-0Y	5430	107	5533	120
PAT10/Alondra "S"//PAT72300/3/PVN "S" CM49922-1M-2Y-1Y-1M-3Y 0M	5739	104	4280	94
Tanager "S" CM30697-2M-8Y-7M-1Y-1B-0Y	5220	103	5147	112
Veery "S" CM33027-F-15M-500Y-0M-66B-0Y	5198	103	5567	121
Bluebird/ON//CNO67 "S"//NO/3/PVN "S" CM46718-28M-1Y-1M-3Y-0M	5446	101	4973	108
AZ//CHR/DD.05P/3/F12.71/Bolillo "S" CM48326-A-3M-1Y-1M-2Y-1Y-0M	5437	101	5013	109

## Wheat Germplasm Development for Heat and Drought Tolerance for Nigeria

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### Abstract

*Heat and drought constitute two of the major wheat production constraints in the dry tropics. In Nigeria, these environmental stresses restrict wheat production to some irrigated areas in the north between 10 and 13°N latitudes, where temperatures during the cool "harmattan" period (November to February) range between 5 and 30°C. In order to overcome the limitations caused by high temperatures and lack of moisture, there is a need to develop wheat germplasm with heat and drought tolerance; an intensive screening program for these stresses is suggested. The potentials of some exotic germplasm are emphasized, and some characteristics that might enhance tolerance to heat and drought stresses are discussed.*

Heat and drought are common wheat-production problems in Nigeria, as well as in most regions within the dry tropics. Little attention has been paid to vulnerabilities associated with these environmental stresses over the years (1); however, some work has been done on the effects of temperature on wheat under controlled conditions (9,18,11,3,20). Such studies were limited to a few genotypes for differential temperature tolerance. In another study, Sisodia, *et al.* (21) identified ten genotypes of *Triticum* spp. that have relatively high temperature tolerance.

As in the case of heat stress, there is still no sound information on a specific drought-resistance mechanism, although information needed to explain the basic physiological principles for drought tolerance has continued to increase. Fischer *et al.* (8) defined drought tolerance in agriculture as the ability of a crop to give an economic yield under low moisture conditions and to give a maximum yield under optimum conditions. Attempts have been made to classify various mechanisms by which drought might be tolerated. May and Milthorpe (12) called them drought escape and

drought endurance, while Levitt (10) referred to them as drought avoidance and drought tolerance. These definitions and terms are also utilized in this paper. Fischer and Maurer (7) screened for drought tolerance in a large number of tall and dwarf wheats. In that study, they attempted to separate effects due to drought escape and those due to the operation of resistance mechanisms. They concluded that tall wheats were more tolerant to drought.

### Environmental Limitations of the Nigerian Wheat Region

In general, high temperature has restricted wheat production in Nigeria to certain parts of the northern states, which lie between 10 and 13°N latitudes, mainly in the Sudan savanna. Here the cold "harmattan" period (November to February) provides the required temperatures, ranging from 5 to 30°C. Wheat is sown in mid-November, and harvested at the end of February or in early March. Thus, only cultivars with 70 to 120 day maturities are usable. High temperature is detrimental to the establishment of an early-sown wheat crop, and to grain filling in a late-sown crop. If the crop is

very late, high temperatures at the end of February or in early March, while the crop is in anthesis, can cause sterility of the florets, resulting in very low yields.

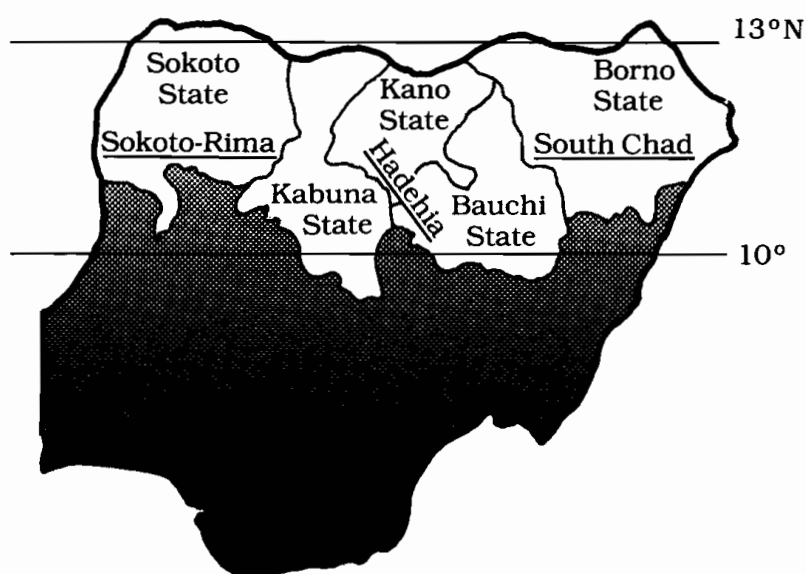
The massive irrigation schemes in Nigeria's wheat-growing regions, the Chad, the Hadehia-Jama'are and the Sokoto-Rima river basins in Borno, Kano-Bauchi and Sokoto states, respectively (Figure 1), are the main vehicles to the possible attainment of Nigeria's green revolution (16). However, these rivers are fed by scanty rainfall, 300 to 500 mm in Borno state, 600 to 900 mm in Kano/Bauchi and 400 to 600 mm in Sokoto. It is spread over a short period, mainly from July to September; thus, water is expensive and may be limiting, especially in years of low rainfall.

The effect of drought is usually very severe on wheat, as it not only cuts off water needed for normal metabolism, but also decreases the supply of nutrients from the soil. Under such stress situations, farmers face a considerable amount of risk. There is, therefore, a need to develop wheat

germplasm with a reasonable amount of heat and drought tolerance, in order to stabilize yield under present conditions and to effect a more successful extension of wheat production into southern Nigeria.

### Germplasm Improvement in Nigeria

In the last two decades, over 15,000 wheat varieties and lines have been introduced and screened in Nigeria by the Institute for Agricultural Research, Ahmadu Bello University, Zaria. The objective has been to identify cultivars which are high yielding under Nigerian conditions and possess acceptable bread-making qualities (14). Wheat introductions have come mostly from CIMMYT, the International Center for Agriculture Research in the Dry Areas (ICARDA) in Syria, the Food and Agricultural Organization (FAO) and other parts of the world (14,15). Although INIA 66, Indus 66 and Mexipak are grown in some areas of the South Chad Scheme, only five varieties have been recommended by the



**Figure 1. Wheat-growing regions in Nigeria**

Institute for Agricultural Research. These include two tall non-Mexican wheats, Tousson and Florence Aurore 8193, and three Mexican semidwarfs, Sonora 63, (Lee x N10B)GB55)GB56 and Siete Cerros (14,15,16). Although Siete Cerros is the most popular variety and is cultivated all over the wheat-growing region (especially in the Kano River Project), the other varieties are beginning to gain acceptance.

### Performance of Nigerian Selections

Table 1 shows the performance of twenty lines and varieties in replicated trials grown at four locations in Nigeria. The Nigerian Regional Wheat Variety Yield Trial 1982-83 was grown in Kadawa, Samaru, Bakura and

Ganawuri, with the variety Siete Cerros as the check. The lines/varieties which performed well were Pavon 76, 7C-On x INIA-B.Man, Kalyansona x V534, Junus x Y50E-Kal<sup>3</sup>/Pal, (Tf-CNO67/Bluebird-CNO)Za, HD832-55 x CNO-JAR, Moncho "S", C271 x Sonora 64, Jupateco, and Super X, with mean yields ranging from 3450 kg/ha to 4350 kg/ha. It is important to note that yields had been higher in previous years, particularly in Kadawa where bird damage has come to constitute yet another production problem in early-sown wheat.

Another experiment was conducted in Bakura in the 1982-83 growing season to investigate the most critical growth stages for moisture stress in five lines/varieties of bread wheat and,

**Table 1. Yields of entries in the Nigerian Regional Wheat Variety Trial over four locations, 1982-83**

Variety/cross	Grain yield (kg/ha)					Yield as % of check
	Kadawa	Samaru	Bakura	Ganawuri	Mean	
Pavon 76	4305	3725	5000	4350	4345	147
7C-ON x INIA-B.MAN	2963	3313	6663	3150	4022	136
KAL x V534	3325	4438	5375	2280	3854	130
(TF x CIANO 67/Bluebird-CIANO)ZA	2888	3750	5688	2775	3775	128
Junus x Y50E-KAL <sup>3</sup> /PAL	3713	3813	5263	2325	3775	128
HD832-55 x CIANO-JAR	2563	4063	5350	2850	3706	125
Moncho "S"	3238	3250	4000	3975	3615	122
C271 x Sonora 64	3000	3475	5213	2550	3559	120
Jupateco	2833	3475	3975	3675	3489	118
Super X	2950	3250	5425	2175	3450	117
NP876-164 Roch/CIANO "S"						
Bluebird	2175	3625	4175	3675	3412	115
Barouk	2500	3125	5838	2175	3409	115
BYC "S" x 3Kalyansona x Kalyansona-Bluebird	2813	3688	3888	3000	3347	113
Y50E-Kalyansona	2713	4063	3538	2700	3253	110
Nacozari 76	3120	3625	3600	2700	3261	110
(GB80-5892 x MP-33)	2363	3188	5413	1650	3154	107
PJ62-GB55 x NAI60	3370	2875	4363	1725	3083	104
Pi62-Frond/Pi62-Mazoe x Mexipak 65	3363	2913	3863	1875	3003	102
Fury-Siete Cerros	1600	3063	4088	3000	2937	99
Siete Cerros (check)	2900	3338	3563	2025	2956	100
Mean	2935	3503	4714	2732	—	—
S.E.	491	431	412	469	—	—

Source: Orakwe and Olugbemi (16)

hence, select for drought tolerance. The experiment consisted of 45 treatment combinations, five varieties and nine irrigation treatments (Table 2).

Due to wide variations between replicates of different treatments, there was no significant difference between the varieties. Interaction between irrigation treatments and varieties was also not significant. Of all the varieties, only HD832-55 x CNO-JAR was seriously affected when irrigation was withheld twice consecutively at the jointing stage (T7). Missing two irrigations at the flowering stage (T8) affected all of the varieties considerably. Varying yield reductions were observed in all other treatments, but it appeared that the two most critical stages for moisture stress are T7 and T8, jointing and anthesis.

### Characteristics Affecting Selection for Heat and Drought Tolerance

#### Earliness

An understanding of a stress-tolerance mechanism is necessary in order to correctly suggest useful characteristics by which a plant can tolerate stress. Under Nigerian conditions, it appears that the main mechanism leading to good performance in wheat is escape or avoidance. The variety should grow and mature within the cold period, i.e., with maturities of 70 to 120 days. Thus,

only early or medium-early lines/varieties will perform well. This is also true for drought tolerance, since earliness enhances water economy.

#### Yield

In addition to earliness, superiority in yield under optimal conditions is necessary for both heat and drought tolerance. According to Blum (4) varieties with superior yield at optimal levels will also yield relatively well under sub-optimal levels.

#### Adaptability

Wide adaptability is a necessary factor, since it is believed that, when stress tolerance is present in a variety, it may be expressed as an unidentified component of stability in performance over various environments (4,11,17).

#### Developmental synchrony

Plants should tiller uniformly, hold most of their leaves intact and mature uniformly.

#### Test weight

The grains of plants should have good test weight, which results from good and uniform grain filling.

#### Spike fertility

Increased fertility of the spikes assures that most florets will be fertile under stress conditions, as well as at optimal levels.

**Table 2. Effects of variety and moisture stress on grain yield of bread wheat, Bakura, Nigeria, 1982-83**

Variety	Grain yield (kg/ha) according to irrigation treatment <sup>a/</sup>								
	T1	T2	T3	T4	T5	T6	T7	T8	T9
HD832-55 x CIANO-JAR	2747	1907	1720	1813	2087	1687	833	1587	2220
Super X	2627	1893	1960	1667	1887	1987	1433	1147	1820
(TF x CIANO67/Bluebird-CIANO)ZA	1840	2033	1860	1887	2527	1960	1733	1187	1867
NP876-164 x Roch/CIANO"S"-Bluebird	2380	1960	1960	2020	1860	1600	1793	1453	1720
Pi62-Frond/Pi62-Mazoe x Mexipak 65	2293	2427	1867	1487	2427	1860	1667	1333	2120

<sup>a/</sup> T1 = control, 19 irrigations; T2 = one irrigation withheld at tillering; T3 = one withheld at jointing; T4 = one withheld at flowering; T5 = one withheld at grain filling; T6 = two irrigations withheld at tillering; T7 = two withheld at jointing; T8 = two withheld at flowering; T9 = two withheld at grain filling

**Leaf area**

There should be a small leaf area in terms of number and/or size. Although it is not easy to generalize, this characteristic seems to be essential in order to reduce evapotranspiration and, hence, enhance drought tolerance (19).

**Tillering**

Since the number of tillers depends on the number of leaves (as tillers are initiated in leaf axils), it follows that the drought-tolerant variety should have reduced tillers (19).

**Water utilization**

The drought-tolerant line should have the ability to efficiently utilize available water. Such a variety should maintain its photosynthesis and growth at low water availability. The developmental plasticity of the variety should be such that it gives an economic yield under water stress, as well as best yield under good moisture situations. This increased efficiency in water use could result from a restriction on the relative ability of the plant to extract water from the soil during early crop growth, leaving more water to support the plant in the grain-filling stage. This characteristic might be developed through selection of plants with erect leaves and reduced tillering (6).

**Density tolerance**

Dow (5) showed that maize hybrids resistant to density stress were also more drought tolerant. Thus, density trials may also help in selection for drought tolerance, as plants resistant to density stress should have a relatively greater ability to withdraw water from the soil.

**Root systems**

A good root system is necessary for tolerance to both drought and moisture stress, because it enhances early plant establishment, as well as efficiency in the water-uptake capacity of the plant.

**Conclusions**

In Nigeria, high temperature and drought constitute problems for wheat production. Fortunately, these problems are not as erratic as are some problems under rainfed conditions in other tropical countries. High temperatures mainly affect the plant during establishment and tillering and during the grain-filling stage. High temperatures are the main limitation to wheat production in southern Nigeria.

Drought, on the other hand, is periodic. Drought-tolerant lines/varieties will invariably enhance water economy. Thus, both heat and drought tolerance are desirable characteristics to be incorporated into Nigerian selections, in order to stabilize yield and increase production.

Performance of adapted wheat germplasm indicates that yields ranging from 3 to 4 t/ha are possible under optimum conditions. Therefore, heat and drought-tolerant lines yielding 1.5 to 2.5 t/ha under stress conditions and up to 4 t/ha under optimum conditions should be selected. It is difficult to generalize as to genetic traits which enhance heat and drought tolerance, but some of the characteristics described above have been shown to be relatively effective in field crops, and in wheats in particular.

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## Breeding Wheats for Heat and Drought Tolerance in Central India

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### Abstract

Conditions for wheat cultivation in central India impose severe drought and temperature stress. High temperatures at sowing time (32 to 35°C) and at maturity (30 to 35°C) cause defective germination and grain dehydration, respectively; frost at ear-emergence stage frequently causes 50 to 100% loss in yield. In breeding for drought tolerance in India, local cultivars have been utilized; disease resistance, which is also very important, is introduced at the same time. The cultivars C306, Sujata, Hy65, NI5439, N59, A9-30-1 and Meghdoot have been developed, and genetic improvement has been made for characters, such as number of ears per plant, grain weight per spike and 1000-grain weight. From about 300 cultivars tested for temperature tolerance, seven possess good tolerance and compare favorably with Hindi 62; these also incorporate resistance to rusts and leaf blight. Some of the cultivars, such as HI1011, HI1012, Raj 1771 and Raj 1777, have proved to be promising for heat tolerance. A few lines, recently received from CIMMYT, also appear to be promising. Encouraging results have been obtained from spring x winter crosses and will be further exploited.

In Central India, stresses of drought and temperature affect wheat cultivation, under both rainfed and irrigated conditions (Figure 1). Soil

moisture at seeding depth is directly related to germination, and temperature also plays a major role. The relationship is shown in Table 1.

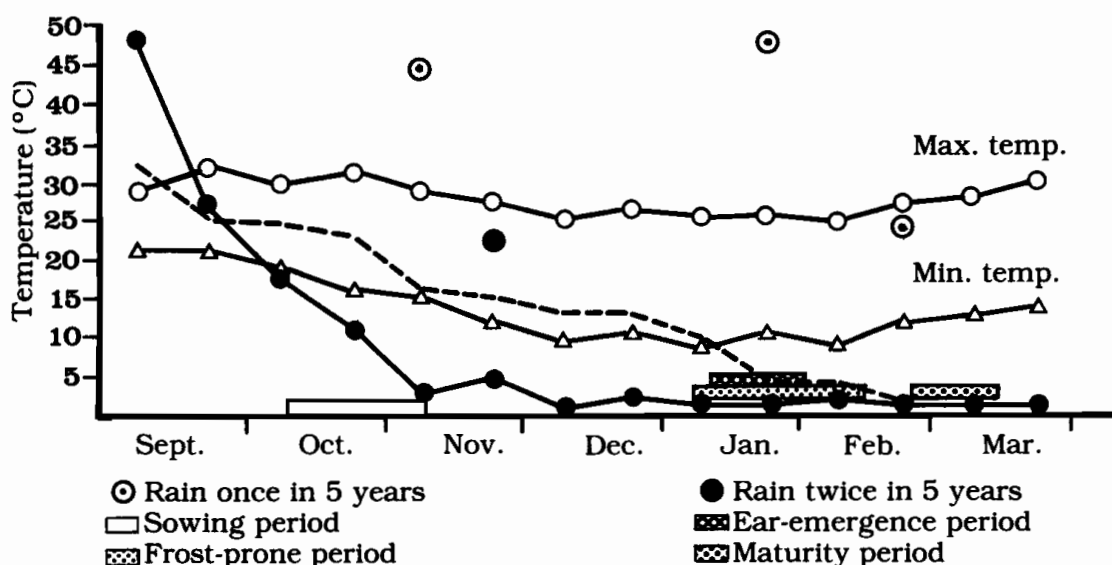


Figure 1. Weather conditions for the wheat-crop season, Indore, India, 1979 to 1984

While germination increased with increasing soil moisture in the seeding zone, germination was higher in the colder months of December and January than it was with higher moisture levels in mid-October.

In the Bhal tract of Gujarat, temperatures between October and December vary between 35 and 39°C maximum and 22 and 25°C minimum. At 30.2°C mean average temperatures in 1979, germination was 56%. In subsequent years, a decrease in mean temperature gave a linear increase in germination. By 1983, when the mean temperature was 26.5°C, germination percentage was 84%.

Soil cracking is a regular phenomenon after January, and causes extensive root damage in the upper 60 cm. Frost conditions cause spikelet sterility when ear emergence coincides with a sudden drop in temperature. Total crop losses have occurred with Kalyansona, WH147 and Raj 911 under irrigated conditions. Continuous high temperatures in the low elevation regions of Maharashtra and Madhya Pradesh have resulted in the flowering of Kalyansona within 45 days, which reduced yield by 60 to 70%.

Breeding for drought and temperature tolerance has been going on for the past five decades in central India. Selections from the local durums A206, EK69 and Kathia 25, and the bread wheat, Ujjain 22, have proved to be very widely adapted. Hybridization between durums and *T. dicoccums* produced drought-resistant wheats, such as Jay and Vijay as early as 1936. Later, the durum cultivar, Gaza, and Gabo and several Kenya wheats were used in a crossing program with local varieties and strains resistant to rusts and blight: NP401, NP404, A9-30-1, Meghdoot, Bijaga Yellow and N59 (durums) and Hy65, NP832, Narmada 4 and Mukta (bread wheats) were used in the program. Three varieties, C306, Sujeta, an improvement over C306, and NI5439 (RFPM/80 x NP710<sup>3</sup>), proved to be outstanding for drought and temperature tolerance throughout the central and northern parts of the country. C306 has a winter wheat, Regent, in its pedigree. An analysis of the genetic improvements compared with the respective local parents is presented in Table 2.

The ability of the local cultivars to establish better plant populations under low moisture conditions seems to be due to natural selection over centuries, as is their ear production and yield per

**Table 1. Effect of temperature and soil moisture on germination of wheat, India**

Sowing date	Average mean temperature (°C) <sup>a/</sup> over 3 weeks	Soil moisture (°/o at 7-8 cm depth)	Germination (°/o)
Oct. 15	25.0	16.9	22.7
Oct. 29	24.6	18.2	49.8
Nov. 20	22.1	19.9	61.8
Dec. 3	21.4	18.1	40.1
Dec. 31	17.3	16.4	40.2
Jan. 12	16.4	15.0	28.7

$$\text{a/ Mean temperature} = \frac{(\text{maximum} + \text{minimum})}{2}$$

unit area. However, looking at some of the yield components, there has been improvement in the number of ears per plant in A9-30-1 and Hy65 and in grain number per ear and grain weight per ear in A9-30-1, Hy65 and C306; test weight has been improved in Meghdoot, Hy65 and C306.

### Screening and Evaluation for Temperature Tolerance

During the past six years, more than 300 varieties from different breeding stations have been screened at a number of centers over different latitudes (12 to 31°N) and longitudes (74 to 84°E). Sowing was done from September 20th until December and data such as germination, productive ears, grain yield and 1000-grain weight were collected. Maximum temperatures ranging from 30 to 35°C, and minimum temperatures of 10 to 21°C were encountered. It was observed that the varieties showed very poor germination before October 20th, and then improved until November 15th;

after that date germination again decreased. The number of days to ear emergence was profoundly influenced by latitude and prevailing temperatures. Heading took 50 to 75 days at Dharwar (12°N), 60 to 90 days at Niphad (20°N), 65 to 100 days at Indore (22°N) and 100 to 125 days at Gurdaspur (31°N). With early sowing, emergence was delayed. Phenological studies revealed that varieties which flowered very early had better yield in peninsular India, and those flowering mid-late were best adapted in the central region. Late types, with 105 to 115 days to ear emergence, were superior in the north. The prostrate characteristic combined with thin narrow leaves during tillering and narrow, semi-erect leaves on the stems were desirable. This reduced direct soil moisture evaporation and evapotranspiration losses from the plants. An adverse effect of late sowing on kernel development has been observed. In early October sowings,

**Table 2. Genetic improvement shown by improved cultivars compared to local cultivars under stress conditions, India, 1974 to 1977 <sup>a/</sup>**

Cultivar	No. of seedlings/m <sup>2</sup>	No. of ears/m <sup>2</sup>	Yield (g/m <sup>2</sup> )	No. of ears/plant	No. of grains/ear	Grain weight/ear (g)	1000-grain weight (g)
<b>Durum wheats</b>							
Kathia (local)	195	287	227	1.5	20.1	0.79	49.3
Malvi (local)	197	272	242	1.4	19.2	0.89	49.1
Meghdoot	152	208	184	1.4	17.5	0.88	54.1
				(100)	(91)	(99)	(110)
Arnej (local)	245	266	279	1.1	20.6	1.05	45.6
A9-30-1	180	261	320	1.5	32.7	1.23	41.8
				(136)	(159)	(117)	(92)
<b>Bread wheats</b>							
Pssi (local)	215	304	233	1.4	15.9	0.77	41.2
HY65	141	246	217	1.7	20.4	0.86	42.7
				(121)	(128)	(112)	(104)
C306	154	209	228	1.4	18.1	1.09	45.0
				(100)	(118)	(142)	(109)

<sup>a/</sup> Numbers in brackets = percent of local

average 1000-grain weight was 42 grams; in late October sowings, it was 40 grams and, in early November sowings, 34 grams.

After considering phenological characters such as flowering and maturity, effective tillers, grain production per ear, yield ability and disease resistance, varieties such as HI1011, HI1012, Raj 1771, Raj 1777, Ju H72-4 and VL421 have been identified as heat tolerant. HI1011 and HI1012 compared favorably with Hindi 62, which was identified in 1973 and is currently the best cultivar. All new varieties are resistant to the rusts and leaf blight, while Hindi 62 suffers heavily. Although Hindi 62 produces more ear-bearing tillers, grain production per ear and kernel weight are low. The Indore selections 1011, developed from the cross E4870(C303 M5292)666-5 x Perico, and 1012, from the spring x winter cross N10B-P14-101-65-39/Kal-Bb, show promise. In general, productivity is lower in more tropical areas like Niphad, Dharwar and Hyderabad, intermediate in the central region and high in the northern belt. Generally, there is no moisture stress in the north.

### **Utilization of Winter x Spring Crosses**

The prolific root system of winter wheats is being utilized in breeding. Crosses with the University of Nebraska's high protein lines have yielded some promising material. Two lines from the cross NP839 x V1027 compare favorably with Sujata. Studies on F<sub>1</sub>s and parents have shown that Mukta, Raj 1777 and NI5439 exhibit a 22 to 79% increase in grain production and a 20 to 58% increase in productive

tillers. Among winter wheats, Favorit, Maldova, Roussalka and Sava have given better combinations. Sujata and C306 frequently produce necrotic hybrids and, therefore, cannot be exploited in direct crosses. Recently, some promising lines have been identified from the CIMMYT 1982-83 Drought Screening Nursery. Four promising lines are from spring x winter crosses Klim x D6301-Nai60/Kalyansona-Bluebird(entry 19), TJB845-Misc. Hari 599 x MHM/Sapsucker"S" (entry 25) and PMF-LFN x Chiroca"S"(entry 28) and (Pi"S"-MAZOE x CNO67/LFN) Chiroca"S"(entry 27). The spring wheat crosses, Veery"S"(entries 48 and 50), Kalyanson-Bluebird x Moncho"S"(entry 66), Neelkant"S"(entry 67), K4500.2-Bluejay"S"(entry 70), JUP-Emu"S" x Grajo"S" = Flycatcher"S"(entry 77) and Buckbuck"S"-Bluejay"S"(entries 98 and 99) have given better stands and higher yields than the check varieties Ures and Sujata under complete dryland (conserved moisture) conditions.

### **Future Strategy**

Apart from the ability to establish well under stress conditions, the ability to remain in the vegetative phase for a longer duration, even though temperatures are high, is the most desired character for wheat for central India. These traits have been observed in some of the local and improved cultivars, and must be combined with better disease resistance, since new virulences have appeared. In-depth studies on crown depth, root vigor and higher grain production are envisioned. Plans are being made to improve the bread wheats Pissi, a soft white type, Hy65, Hindi 62 and NI5439, and the durumms A206, Kathia 25, A9-30-1 and Meghdoot. The exploitation of winter wheats seems promising, and selections from crosses with local improved types is in progress.

## Identifying Wheats Adapted to More Tropical Areas of the Southern Cone of South America

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### Abstract

*The low productivity and high cost of production for wheat in the more tropical areas of the Southern Cone region are the result of a combination of unpredictable climatic conditions and severe disease pressures. The combination of heat, drought, frost and high rainfall, as well as abrupt changes in the temperature-humidity relationship, determine the type of wheat plant which can adapt to these areas. Specific germplasm which can resist physiological disorders caused by high evapotranspiration rates needs to be combined with broad-based resistance to a complex of diseases. In addition, the wheat varieties will be required to adapt to poor soils with high saturation levels of some minerals and low available phosphorus.*

The rapid expansion of wheat cultivation into more tropical areas of the Southern Cone region has come in response to two important factors, a steady increase in demand, resulting in a serious drain on the national economies due to imports, and the farmers' need for a cover crop to follow maize, soybean and cotton. These factors together have been responsible for the seeding of approximately 1.5 million hectares of wheat in tropical areas of Argentina, Brazil and Paraguay. There is, however, a tremendous potential for further increase in all three countries, especially Brazil.

To date, the farmers' experience with wheat has been a series of successes and failures. Low-level productivity and the high cost of production have been two discouraging elements. In addition, unpredictable climatic conditions and severe disease epidemics are major limiting factors for the type of wheat germplasm which might adapt to the area.

The number of plant characters that need to be combined for more tropical areas are so numerous and so varied from those of traditional wheat-growing regions that they cause serious concern among plant breeders, regarding such factors as availability of sufficient

genetic variability, screening methods and breeding priorities. Similarly, agronomic or crop management factors need critical analysis to reduce the cost of production, while stabilizing productivity at a higher level.

In order to identify wheat varieties which will adapt to these warmer areas, it is important to understand the interplay among various climatic conditions that limit wheat production and their influence on plant characters and diseases.

### Climatic Stresses

Unstable climatic conditions are a characteristic of the tropical regions of the world, and their unpredictability from year to year or within the same year can be considered a major problem for stable wheat production. An important aspect of climatic stresses is that of abrupt changes in the relationship between temperature and relative humidity over short periods of time. For the purpose of discussion, the northern Parana region in Brazil is representative of a majority of the tropical areas under wheat in the Southern Cone. Even at the risk of taking averages of completely different years, Figure 1 shows the major climatic stresses at Londrina, Parana,

from 1958 to 1980. These, in turn, determine the type of wheat plant which can adapt to these areas.

**Heat**

Higher temperatures (average + 21°C) throughout the crop cycle are probably more important during the early and late stages of the crop. The effect of heat in reducing the number of tillers produced or the killing of secondary

tillers is a principle reason for poor stands, which are hard to overcome through higher seeding densities. Similarly, a sudden rise in temperature after flowering results in quick drying of the plants, causing grain shriveling and low test weight.

**Drought**

The rainfall pattern of the region is so erratic that it is difficult to predict a



**Figure 1. Climatic chart of Londrina, Brazil, 1958 to 1980**  
 Climatic classification: Cfa (hot, humid, subtropic), as per W. Koeppen

Source: Seventh DISME, MA, SP: Courtesy A.R. Correa

standard date for sowing. In spite of the useful guidelines provided in Figure 1, a drought can occur at any stage of the crop and for an undetermined length of time. Although the date of seeding can be adjusted to good moisture availability, the poor water-retention capacity of the soil can provoke early drought, thereby causing reduced plant density and non-uniform stand. The constant mid-season drought around the heading stage is crucial in the reduction of potential yield. Germplasm of high yield potential and tolerance to drought at this stage of the crop cycle would help stabilize yields to some extent.

#### **Frost**

One of the most feared limiting factors for wheat production in the region is frost injury, especially at the heading stage. Some adjustment in the date of seeding can serve as an escape mechanism, but this leads to other problems at the beginning and the end of the crop cycle. In fact, farmers customarily spread wheat seeding over a long period of time to escape frost; the various seedings suffer from drought, frost, late rains and severe disease epidemics. To solve this problem, the earlier-mentioned heat and drought tolerance must be combined with late heading, through the addition of a single gene for vernalization, in order to escape the major frost frequency period.

#### **High rainfall**

It is paradoxical to discuss the problem of high rainfall and drought at the same time, yet it seems a rule in the more tropical areas. In normal years, high rainfall is generally a problem for late varieties or late-seeded crops, causing difficulties in the harvest process, such as deterioration in grain quality and, in some cases, preharvest sprouting. In abnormally wet years, the intensity of various diseases is so severe that even chemical control is not sufficient to maintain average productivity.

Considering these climatic factors, a model wheat variety should have high tillering ability, tolerance to early heat, tolerance to drought in the mid-season, late heading to escape frost and a short ripening period to mature before the onset of rains. To these can be added semidwarf plant stature to resist strong winds and small fertile spikes to ripen quickly. Such a wheat variety will then need ample resistance to the various diseases and insect pests prevalent in the region.

### **Biological Stresses**

#### **Diseases**

By far the most common factor limiting wheat production in more tropical areas of the Southern Cone region is disease. In a recent analysis done for CIMMYT's Economics Program, the average losses in yield due to wheat diseases in the Parana, Matto Grosso do Sul and Sao Paulo regions of Brazil were 11% per year. What is more important is that these losses occurred in spite of the fact that over 90% of the farmers used chemical control. Where there was no chemical protection, these losses ranged between 20 and 60% (Table 1) and, in some cases, as high as 100%.

A combination of high temperature and high humidity favors a large complex of diseases in this region; the importance of spot blotch (*Helminthosporium sativum*) is highlighted in the data presented in Table 2. During the 1981 to 1983 period, spot blotch alone constituted between 50 and 90% of the yield loss caused by the total disease complex in the western Parana region. This picture was quite different during the mid-1970s, when leaf rust was the major disease.

Other important diseases in the complex are stem rust, scab, bacterial blight, glume blotch and powdery mildew. However, in the past few years,

it has been observed that common root rot and take-all are causing undetermined losses each year in the wheat-soybean rotation system.

There is sufficient genetic variability available for resistance to most of these diseases. However, a large proportion of the variability, especially for the foliar blights and spike diseases, needs to be

**Table 1. Effect of chemical control on the reduction of losses due to the disease complex, Parana, Brazil, 1976 to 1983<sup>a/</sup>**

Year	Yield (kg/ha)		Loss in yield (%)
	Check (no chemical control)	Recommended chemical control (3 applications) <sup>b/</sup>	
1976	1347	2170	38
1977	1880	2410	22
1980	834	2054	59
1982	768	1220	37
1983	1390	2618	47
Average	1244	2094	41

<sup>a/</sup> Average of 14 experiments conducted by Y.R. Mehta, IAPAR, Brazil

<sup>b/</sup> 1st and 2nd application for control of leaf rust, spot blotch and scab

**Table 2. Reduction in wheat yield due to the disease complex of western Parana, Brazil, 1981 to 1983**

Variety	Level of control <sup>a/</sup>	Yield (kg/ha)	Loss (%)	Disease
1981 Cocoraque	T1	2016	0	
	T2	1883	6.59	Spot blotch
	T3	1769	12.25	Disease complex
1982 Anahuac	T1	2226	0	
	T2	1423	36.07	Spot blotch
	T3	1302	41.51	Disease complex
1983 Anahuac	T1	2935	0	
	T2	2361	19.56	Spot blotch
	T3	2291	21.67	Disease complex

<sup>a/</sup> T1 = total control of all diseases, T2 = total control of all diseases except spot blotch, T3 = no control

Source: M.A. Oliviera, OCEPAR, 1984

transferred into high-yielding and adapted wheat varieties. This will require novel breeding approaches, combined with efficient screening systems, in order to produce adapted varieties. Until this is done, chemical control will have to safeguard wheat production.

### **Insect pests**

There are very few traditional wheat-growing areas in the world which have problems with insect pests. In the more tropical environments, however, aphids and stemborers are important. The lesser cornstalk borer (*Elasmopalpus lignosellus* Zeller) can wipe out complete fields of wheat, if the weather remains warm and dry after seeding. In addition, cereal aphids such as *Metopolophium dirhodum*, *Sitobion avenae*, *Schizaphis graminum* and *Rhopalosiphum padi* are widespread on the crop. At the present time, very little information about genetic variability for resistance to these insect pests is available in wheat, and chemical control has been an effective alternative. But as the area under wheat in tropical environments increases, it will become necessary to screen wheat germplasm for insect resistance and breed it into the new varieties.

### **Soil and Soil Management Stresses**

Vast areas in this tropical region have highly leached, acidic soils with high aluminum saturation and low available phosphorus, and their subsequent correction to deep levels is of utmost priority. Other areas, with soil salinity, micronutrient deficiency and manganese or iron toxicity, also cause serious concern. In the presently practiced system of two crops per year, many management factors, such as soil compaction and erosion, have also become very important. Most of these factors will probably be discussed in detail at this workshop by the production agronomists.

From the standpoint of wheat breeding, plant characters such as deep rooting systems, resistance to aluminum and/or other mineral toxicities and efficient phosphorus extraction need to be identified. Some progress has already been made in the development of high-yielding and well-adapted wheats for acid soils with aluminum toxicity. This is the result of the successful mixing of Brazilian and Mexican wheat gene pools. The next phase in this program will be to screen for adaptation to low phosphorous soils, as well as for other desirable characters such as better resistance to the tropical disease complex.

In those tropical regions where irrigation facilities are in existence or can be developed, water management problems, irrigation systems and their interaction with the spread of diseases are important. Irrigated wheat provides a more stable production system, with higher levels of productivity, than the rainfed wheat discussed earlier.

### **Conclusions**

In conclusion, the problems in identifying wheats for more tropical areas are so numerous and diverse, compared with those for the traditional areas, that they require the development of a completely different plant type for proper adaptation. New germplasm, which can withstand the physiological stresses caused by the high evapotranspiration rate in the tropics, will have a greater role to play in increasing present levels of productivity. Some of these characters, not easily located in wheat or available in alien species, will need to be transferred through wide-crosses. The problem of developing wheats for more tropical areas is very complex, and opens up vast fields of research that are still unexplored. Finally, research conducted on phosphorus liberation by mycorrhiza or nitrogen fixation in tropical grasses may be applied to increase wheat production.

## Wheat Breeding in Rio Grande do Sul, Brazil

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### Abstract

*Rio Grande do Sul is the southernmost state in Brazil, bordering on Uruguay and Argentina. Its soils are acid, deficient in phosphorus and have high levels of exchangeable aluminum and manganese. The aluminum and manganese levels of the oxisols in the most important wheat-growing region of the state are sufficient to cause great reduction in plant growth or even death in cultivars which are susceptible to crestamento (toxicity caused by aluminum and/or manganese, etc). Wheat breeding has been carried out for tolerance to crestamento. All wheat cultivars recommended to farmers in Rio Grande do Sul are tolerant to crestamento, the most tolerant being BR6, CNT1 and IAC-5 (Maringa). The breeding program underway in the state maintains such tolerance through plant selection under these soil conditions. These soils are also characterized by unavailable applied phosphorus. By working with cultivars tolerant to crestamento, it was possible to identify the Brazilian cultivars Toropi and PG1 as having a greater development capacity in soils with low phosphorus availability. Attempts are now being made to transfer this increased phosphorus-use efficiency to other cultivars with better yielding capacity.*

Rio Grande do Sul is the southmost state of Brazil, bordering on Uruguay and Argentina. It is located between 27 and 33°S latitude and 50 and 57°W longitudes, and covers an area of 282,184 square kilometers.

Spring wheat is grown in the state, sown at the end of fall and beginning of winter (May to July); it is harvested from October to December. Rains are well distributed throughout the year, occurring in sufficient amounts to meet crop requirements, although in some years there may be an excess. Better yields are usually obtained in the region in years with less rainfall, especially during heading and ripening of wheat.

The wheat-producing areas in the state are located in altitudes ranging between 50 and 1200 meters. The largest number of hectares sown to wheat in Rio Grande do Sul occurred in 1979 with 2,184,899 hectares; statewide average yields have varied between 309 kg/ha (1972) and 1,224 kg/ha (1981).

The soils in Rio Grande do Sul are acid, deficient in phosphorus, show high levels of exchangeable aluminum and manganese, and have varying values of other elements in the different types of soil in the main wheat-producing region. Some soil characteristics, at seven locations in the state, are shown in Table 1. In that sampling, the content of exchangeable aluminum ranged between 0.6 and 3.0 meq/100 g of soil, while exchangeable manganese varied between 32.4 and 546.8 ppm.

To better explain the wheat breeding problems in the state, certain ecological information is given for Passo Fundo, the site of the National Wheat Research Center of EMBRAPA (Table 2). This area is representative of the major wheat-producing areas of Rio Grande do Sul, as well as of Santa Catarina and south central Parana. It is located at 28° 15'S latitude, 52° 24'W longitude and at an altitude of 684 meters. Frost occurs every year, being more frequent in June, July and August; sometimes it occurs in September, and can result in severe injury to the crop.

**Table 1. Chemical properties of soils from seven locations in the main wheat-growing region of Rio Grande do Sul, Brazil (sampling depth 0-12 cm)**

Location	Soil mapping unit	pH	Exchangeable aluminum (me/100 g)	Exchangeable manganese (ppm)	Exchangeable Ca + Mg (me/100 g)	Available phosphorus (ppm)
Passo Fundo	Passo Fundo	4.6	3.0	78.3	4.3	14.1
Julio de Castilhos	Passo Fundo	4.9	1.6	93.2	3.4	9.7
Cruz Alta	P. Fundo-Sto. Angelo (Intergrade)	5.0	0.7	117.4	9.5	9.1
Coxilha	P. Fundo-Estacao (Intergrade)	4.6	1.5	303.8	9.9	2.5
Lagoa Vermelha	Erexim	4.7	2.7	32.4	2.5	1.5
Vacaria	Vacaria	4.5	1.9	546.8	3.0	1.8
Chiapeta	Santo Angelo	4.8	0.6	105.3	5.8	1.0

Source: Siqueira, O.J.F. de. 1980. Response of soybeans and wheat to limestone application on acid soils in Rio Grande do Sul, Brazil. PhD Thesis. Iowa State University, Ames, Iowa, USA.

**Table 2. Climatic parameters for the wheat-growing season, Passo Fundo, Rio Grande do Sul, Brazil, 1959 to 1979**

Month	Rainfall (mm)	Average temperature (°C)	Relative humidity (o/o)	Hours of sunlight
May	100	14.6	74	183
June	138	12.9	77	158
July	134	12.8	74	171
August	173	13.8	72	169
September	197	15.7	72	153
October	183	17.4	71	201
November	119	19.3	66	230
December	164	21.2	66	257

Source: Agrometeorological Bulletin 1983, 1984. Centro Nacional de Pesquisa de Trigo, Passo Fundo, Brazil. Pp. 2-31.

The soil in the Passo Fundo region is classified as dark red dystrophic latosol (oxisol). Data relating to some characteristics of a soil profile which is being used in a trial on lime dosage are given in Table 3. As can be seen, the pH is very low, and is slightly increased by lime applications. Aluminum and/or manganese levels are sufficiently high to cause either the death or great reduction in plant growth in cultivars which are susceptible to *crestamento* (toxicity caused by aluminum and/or manganese). Before creating cultivars resistant to this physiological disease, the area was considered inadequate for agriculture. Lime applications neutralize acidity, as well as aluminum and manganese, in the top layers, but the problem remains in the deeper layers, below 20 cm (Table 3). Cultivars susceptible to *crestamento*, when grown in these soils amended with lime, no longer show very evident *crestamento* symptoms, but are usually unable to compete in yield with resistant cultivars.

The genetic breeding of wheat in Rio Grande do Sul was initiated in 1914. The present breeding objectives are the development of germplasm with:

- Agronomic characteristics for high yield potential
- Short straw and/or high resistance to lodging
- Tolerance to *crestamento*
- Resistance to leaf rust (*Puccinia recondita tritici*)
- Resistance to stem rust (*Puccinia graminis tritici*)
- Resistance to septoria leaf blotch (*Septoria tritici*)
- Tolerance to glume blotch (*Septoria nodorum*)
- Tolerance to helminthosporium (*Cochliobolus sativus*)
- Resistance to mildew (*Erysiphe graminis tritici*)
- Resistance to scab (*Gibberella zeae*)
- Resistance to wheat mosaic virus
- Tolerance to barley yellow dwarf virus
- Resistance to sprouting
- Resistance to loose smut (*Ustilago tritici*)

**Table 3. Soil acidity and location in the soil profile of aluminum, calcium and magnesium, 11 years after the application of lime, Passo Fundo, Rio Grande do Sul, Brazil, 1984**

Soil depth (cm)	Amount of lime applied								
	0			12.4 t/ha <sup>a/</sup>			24.8 t/ha <sup>b/</sup>		
	pH	Al (me/100 g)	Ca + Mg (me/100 g)	pH	Al (me/100 g)	Ca + Mg (me/100 g)	pH	Al (me/100 g)	Ca + Mg (me/100 g)
0 - 1.25	4.5	2.5	3.5	4.8	1.0	6.4	5.2	0.4	7.7
1.25 - 2.5	4.3	3.2	2.9	4.7	1.4	5.6	5.2	0.6	7.0
2.50 - 5.0	4.2	3.6	2.6	5.0	1.2	7.0	5.0	0.8	6.9
5.00 - 10.0	4.3	3.6	2.4	4.7	1.6	5.6	5.3	0.5	8.1
10.00 - 20.0	4.3	3.9	2.3	4.6	2.2	4.4	5.0	1.1	6.3
20.00 - 30.0	4.4	4.2	1.9	4.4	3.3	2.9	4.9	2.7	3.6
30.00 - 40.0	4.4	4.0	2.2	4.5	3.2	2.8	4.6	3.0	3.4

<sup>a/</sup> The amount required to raise soil pH to 6.0 when experiment began in 1973

<sup>b/</sup> Double the amount of <sup>a/</sup>

- Resistance to shattering
- Variability as to cycle, preferably early maturity
- Tolerance to frost at the reproduction stage
- Efficiency in phosphorus use
- Resistance to greenbug (*Schizaphis graminum* R.)
- Good industrial quality

The information provided in this paper refers only to breeding in relation to soil problems.

### **Breeding Wheats Appropriate for the Problem Soils of Rio Grande do Sul**

#### **Tolerance to *crestamento***

Tolerance to *crestamento* was first identified in 1914, among wheats introduced by immigrants to Brazil (7). In that year, the cultivar Pollisu was selected for its exceptional growth in acid soils. This cultivar is part of the genetic background of nearly all varieties recommended for Rio Grande do Sul.

In 1948, Araujo (2) determined that *crestamento* was caused by the occurrence of exchangeable aluminum and iron in the soil, as part of its total absorption capacity; this constitutes what is called noxious acidity. In 1949, *crestamento* symptoms were reproduced by Oliveira after sterilizing the soil by heat, thus eliminating the presence of biological agents as possible causes of the disease.

The first information available concerning the genetics of the transmission of tolerance to *crestamento* is attributed to Beckman (1954), who indicated a gene as

responsible for tolerance, a dominant characteristic. Nodari (6), in genetic studies contrasting the tolerance of several cultivars to *crestamento* under field conditions, concluded that tolerance is controlled by two dominant genes.

Tolerance to *crestamento* involves several factors, including tolerance to toxic aluminum and to manganese. When interactions among these factors occur, the interpretation of results obtained in the field is difficult. The use of nutrient solutions has permitted the separation of cultivar reactions to each of these toxic factors. Using this methodology, Lagos *et al.* (5) determined that the tolerance gene to aluminum in the cultivar BH1 146 is located in chromosome 4D.

All wheat cultivars recommended in Rio Grande do Sul are tolerant to *crestamento*. Among them, BR6, CNT1 and IAC5 (Maringa) show the best resistance (8). The wheat-breeding program maintains such tolerance through plant selection in segregating generations (normally F<sub>2</sub> or F<sub>3</sub>) in soil areas where lime has never been applied. In this way, tolerant plants are easily identified and, in subsequent generations, they are screened in soils having better fertility. At the end of the selection process, tolerance to *crestamento* is confirmed by again growing the lines in soils with *crestamento*.

**Efficiency in phosphorus use**

The soils in the main wheat-producing region of Rio Grande do Sul are characterized by a low level of phosphorus availability. The interaction of plant response and aluminum and phosphorus absorption is well known.

Ben and Rosa (3), working with cultivars tolerant to *crestamento*, identified the cultivars Toropi and PG1 (a selection of Polissu) as having better development in soils with low phosphorus availability. These cultivars have a better (more efficient) utilization of phosphorus (natural or applied), indicating the possibility of encountering genetic variability for this character.

Koehler (4), working at Washington State University, USA, carried out experiments involving 1600 spring wheat accessions, with the objective of identifying accessions tolerant to phosphorus stress and learned how to select for this characteristic. His results identified various cultivars with good adaptation to soils with low phosphorus levels.

Attempts are being made at the National Wheat Research Center to transfer such phosphorus-use efficiency to other cultivars with better yield potential. The segregating generations are grown in soils with low phosphorus availability (around 3 ppm) and with toxic aluminum. It is expected that, by 1985, lines with better phosphorus utilization will be available for final evaluation.

**Conclusions**

Ecological conditions in Rio Grande do Sul vary greatly, as compared to those of the wheat-producing regions of Argentina or Mexico. Nevertheless, using the technology available at present, good farmers in the region have obtained average yields of 2,068 kg/ha over the last five crop years. They utilize a production system involving the use of the best cultivars, crop rotations to control root diseases and fungicide application to complement genetic resistance.

New cultivars developed jointly by EMBRAPA and CIMMYT will be made available to farmers in Rio Grande do Sul in 1985 [new lines of the cross IAS63/Alondra''S''//Gaboto/ Lagoa Vermelha (PF79765, PF79767, PF79780 and PF79782)]. It is expected that, with this material, these same farmers will be able to raise their yields to 3 t/ha within the next five years.

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## **Breeding and Disease Problems Confronting the Successful Cultivation of Wheat in the Cerrados of Brazil**

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### **Abstract**

*There are three systems of wheat production in the Cerrados, rainfed, irrigated upland and irrigated lowland. Important breeding points and the main diseases are discussed for each of the systems in the Cerrados area of Brazil, as well as information on climate and soils in relation to each of them. Wheat yields on farmers' fields and a comparison with other possible crops are presented.*

### **Climate and Soils of the Cerrados**

Brasilia will be considered here as representative of the the Cerrados region of central Brazil. It has two seasons, a rainy season and a dry one. The rainy season lasts from October to April, and the dry season from May to September. During the rainy season, the average monthly rainfall is 215 mm; during the dry season it is only 14 mm. From January to April, the total rainfall is 780 mm. During the rainy season, dry periods (veranicos) are frequent and can influence the wheat crop in two ways, by reducing plant growth and by favoring a serious pest, *Elasmopalpus lignosellus* Zeller.

The temperature in Brasilia is representative of that of the high plateau (1,000 meters); it is lower than that of the low-altitude Cerrados regions. The average temperature in the rainy season is 21.3°C and, in the dry season, 19.3°C; if the temperature of September (wheat harvest month) is not considered, the dry season average drops to 18.6°C. The relative moisture of the air is high during the rainy season and low in the dry season. Dew is frequent until 9:00 or 10:00 a.m. in May and June; there is little dew in July, August and September.

The Cerrados soils are acid, with high soluble aluminum content. They are very low in calcium and magnesium as well as in phosphorus; there is a strong fixation when phosphorus is applied as fertilizer. There is also a deficiency in micronutrients, mainly zinc and boron. Boron application at a rate of 1 kg/ha is needed to prevent male sterility, a limiting factor in wheat production that is also conditioned by climate. The physical properties of the soils are good for root development of the plants, but their water retention is poor. Soils in the paddy fields in the lowlands vary a great deal but, in general, have poor drainage which leads to waterlogging; they are more appropriate for rice production and flood irrigation than they are for wheat cultivation.

### **Systems of Wheat Production**

There are three systems of wheat production used by farmers in the Cerrados region, as a rainfed crop, sown in the middle of the rainy season (February) and harvested in the dry season (with total rainfall of 700 mm during the crop season), as an irrigated crop in the uplands and as an irrigated crop in the paddy fields. In the last two systems, the crop season is the dry season, May to September, with 273

hours of sunlight monthly. Although there are breeding and disease problems common to the three systems of production, there are others that are different enough to justify specific approaches for resolution, according to the production system.

### **Breeding and Diseases**

#### **Rainfed cultivation**

Important factors to consider in breeding wheat for cultivation under rainfed conditions are:

- Good growth patterns and the ability to tiller under warmer conditions
- Growth cycle of about 100 days
- Tolerance to aluminum toxicity, as roots must reach into the subsoil for water, especially in dry periods
- Resistance to drought
- Resistance to diseases

The efficient use of phosphorus and the C<sub>4</sub> type of photosynthesis are desirable characteristics for all of the systems of production.

Disease incidence is related to rainfall. Abundant rainfall leads to high incidence, especially when it takes place toward the end of the crop season. The main diseases are stem and leaf rusts and *Helminthosporium sativum*, which is the most important disease and is responsible for the heaviest losses. All of these diseases may be controlled through the use of fungicides.

Until now, the best germplasm has been the old Brazilian varieties, which are tall and have tolerance to aluminum toxicity. In the best locations during the last seven years, they have yielded from 900 to 1,700 kg/ha on farmers' fields; no crop failures have been reported. Wheat has been profitable in the locations where early soybeans yield well. The two-crop rotation of early soybeans followed by wheat, grown in the same field during the rainy season,

has given a higher return than land sown only to soybeans or only to maize. In areas where early soybeans do not yield well, wheat alone cannot compete with late soybeans (2.5 t/ha) or maize (4 t/ha), since these are crops which utilize the entire rainy season.

#### **Irrigated cultivation on the uplands**

The lower temperatures, relative humidity, and rainfall and the sufficient sunshine of the uplands are favorable to higher wheat yields and lower incidence of diseases. Wheat is irrigated by sprinkler and by corrugation. An adequate supply of moisture, combined with liming of the soil, permits the successful growing of the Mexican-type cultivars, with yields ranging from 2 to 3.5 t/ha.

The main disease problems are stem and leaf rusts and powdery mildew. It is possible that root rots and nematodes may become a problem after several years of cropping on the same site. *Helminthosporium* is not an important disease.

The use of cultivars which give better yields in warm climates would improve crop adaptation for the lower altitudes and result in higher yields. Higher tillering capacity, short, strong stems and resistance to lodging are important features of cultivars for use with irrigation. Efficient utilization of phosphorus is also important, and tolerance to aluminum toxicity would improve yield, making irrigation more efficient.

The wheat-growing season in the uplands is limited to the period from the middle of April to September, in order to avoid the rains occurring at the end of the crop cycle. This provides conditions leading to grain of high quality, high test weight and good milling quality.

During the dry season, it is possible to cultivate other crops, such as beans, soybeans, maize, potato and peas. At present, farmers are using the dry season for growing wheat, potato, beans and peas. The main problems are the high cost of sprinkler irrigation, due to high energy prices, and the farmers' lack of experience with irrigation and wheat cultivation. Increased corrugated irrigation would lower costs.

**Cultivation in the lowlands and in paddy fields**

The lowlands and paddy fields in the lower altitudes have warmer climates. Wheat has been cultivated successfully in areas with an altitude of 500 meters and above. These areas have problems of irrigation and drainage, because of the nature of the soil (low hydraulic conductivity) and the poor leveling of the fields. Waterlogging frequently

occurs and seedbed preparation is difficult. In addition to the characteristics mentioned previously for breeding wheat in the irrigated uplands, tolerance to waterlogging and to higher temperatures will be required in the lowlands. Disease problems are similar to those of upland irrigated wheat, but are more intense.

Wheat cropping is carried out in the lowlands when there is no risk of flooding, and when other agricultural activities permit. The crops competing with wheat are the same as those of the uplands.

The water needed by wheat is less than half of that required by flooded rice; thus, wheat is a good alternative when there is limited water in the rivers during the dry season. Farmers are obtaining yields in these areas of 2 to 3 t/ha, with no investment needed other than that for drainage improvement.

## Screening Wheats for Quality

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### Abstract

*Screening tests are simple methods that are used to eliminate undesirable materials from the breeding program; they can be made rapidly, using small samples of individual plants in early generations. In the case of quality, these preliminary screening tests help breeders to select materials with the type of gluten that is desirable for the preparation of various products. Seed-type selection is used in segregating material for eliminating all lines with poor kernel characteristics. After seed selection, other preliminary screening tests are performed, among them, the Pelshenke test which is used to separate bread wheats according to gluten strength. The microsedimentation or Zeleny test and the sodium dodecyl sulfate (SDS)/lactic acid sedimentation tests are other rapid methods for estimating gluten strength in bread and durum wheats.*

Good milling and baking characteristics can be selected for in the development of higher-yielding varieties. In CIMMYT's wheat program, improvements are being made in developing higher-yielding, broadly adapted varieties with improved disease resistance and improved milling and baking quality. Everyone working in wheat research, production, utilization and industrialization should be concerned with the quality required for the preparation of local products; it must be kept in mind that quality is a relative concept, depending on who is considering it.

For the grower, good quality means high yield potential; for the miller, quality means high flour yields, which partly depends on high test weight and uniform kernel size and shape. For the consumer, wheat quality means a good end-product. Therefore, for the preparation of sandwich bread, wheat with strong, balanced gluten is needed; for cookies, the best quality wheat has extensible weak gluten. White wheats with strong or medium-strong gluten are preferred by the whole wheat consuming countries, such as India and Pakistan, for the preparation of chapatis.

To have all these qualities available, the use of preliminary screening tests is very important. Screening tests should be simple, reproducible tests that can be made rapidly, and in large numbers, on grain samples from individual plants, in order to eliminate undesirable materials from the breeding program; they are not tests which would be used for choosing lines to be released as new commercial varieties. These tests have the advantage that they can be carried out beginning with the F<sub>3</sub> generation, allowing many inferior lines to be eliminated early in the program. In general, at CIMMYT, all screening tests are performed after segregating materials have been selected for seed type.

### Selection for Desirable Grain Types

Emphasis is given to grain classification in all wheat breeding programs at CIMMYT; all lines that have poor kernel characteristics, and thus are likely to result in low grain test weight, are eliminated. In grain tests, samples are evaluated for grain size, plumpness, texture and color.

After seed selection, some of the preliminary screening tests are performed on segregating materials in the breeding programs. In the case of bread wheats, the segregating materials are evaluated for gluten strength. The Pelshenke test, which separates wheats with weak gluten from wheats with strong gluten, gives an indication of the ability of the gluten to retain carbon dioxide gas which is formed during fermentation.

In this test, a 3-gram sample of grain from each plant is ground into whole meal, mixed with a standard yeast suspension and formed into a dough ball. The ball is immediately placed in a beaker of distilled water at 30°C, and the time in minutes until the dough ball disintegrates is a measure of gluten strength; this is called the Pelshenke value. Wheats with strong gluten have Pelshenke values of more than 100 minutes; ones with weak gluten have Pelshenke values of less than 60 minutes. Even though this test has some weaknesses, it is very useful in some breeding programs.

Microsedimentation or the Zeleny test is another method for estimating the strength of wheat gluten. Like the Pelshenke test, it takes only 3 grams of wheat from each plant to produce the

.64 grams of flour needed to perform the test. The flour is suspended in water in a graduated cylinder and treated with lactic acid. The volume of sediment, consisting principally of swollen gluten and occluded starch, which is measured after standing for five minutes, is the sedimentation value.

The sodium dodecyl sulphate (SDS)-lactic acid sedimentation test is another rapid method for estimating gluten strength in both bread and durum wheats. The test is simple and rapid, allowing for the evaluation of several hundred samples in one day; it also requires only 3 grams of wheat. The ground sample is mixed with the SDS-lactic acid solution in a graduated cylinder for a short period of time and, after a rest period of ten minutes, the volume of the sediment is recorded, as in the Zeleny test. Wheats with strong gluten have large sedimentation values, while those with weak gluten have small values.

There are other tests that can be used for the screening of segregating materials, but the ones mentioned here have been very important at CIMMYT for creating the quality variability required for the various countries where genetic materials from the CIMMYT wheat program are utilized.

## Wide Crosses and New Genes for Wheats for the Tropics

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### Abstract

*The benefits breeders have derived from alien species through the introgression of alien genetic material are best exemplified by the current CIMMYT IB/IR wheat lines. Several lines have been released by various countries as varieties because of their wide adaptation, yield stability, aluminum tolerance and resistance to Septoria tritici. Other institutions have made significant improvements in wheat through alien introgressions, specifically for resistance to the pathogens that cause stem rust, leaf rust, stripe rust, powdery mildew and wheat streak mosaic virus, as well as resistance to greenbug. There have been, however, only a limited number of alien species involved in the above-mentioned studies, Aegilops umbellulata, Agropyron elongatum, Agropyron intermedium and Secale cereale; considering the extent of alien germplasm available, the promise of future success is extremely high. The larger the number of alien genera that are combined with wheat and the larger the number of resulting hybrids that are advanced, the more diversified will be the environmental conditions under which wheat production can occur. This potential is the reason for CIMMYT's wide cross program.*

Conventional plant breeding has maintained its predominant role in crop improvement and has been remarkably influenced by the wealth of prevalent genetic information. This has provided the necessary genetic variability for use by plant breeders, and genetic advances have adequately demonstrated their consistent impact. Prevalent breeding procedures and genetic variability have so far permitted routine handling for each problematic situation that has surfaced.

Complementing research that contributed to the success of conventional programs was developed with great success in the 19th century in the disciplines of mutation breeding and interspecific and intergeneric hybridization. The latter two, in essence, have incorporated an undirected, modified genetic system or have exploited, to a limited extent, the unique gene pool of a few closely related or more distant relatives of cultivated crops. In both cases, new

genes have been identified that otherwise might never have been available through conventional genetic systems.

More recently, the exciting areas of tissue culture, multiple shoot formation technology, anther culture, somaclonal variation and the broadly designated area of DNA technology have emerged. It should be recognized, however, that these new methodologies are fanciful; they offer immense promise in theory but, for the budgetors of time, they can be classified as being of high risk and extremely futuristic. They do, however, definitely warrant continued research.

In the CIMMYT wheat program, agricultural demands have dictated a working methodology that has taken us from a stage of research fantasy to one of practicality and accountability. The majority of the disease resistance and stress tolerance objectives pursued have no demonstrable genetic association or

inheritance and, for a few, no genetic base of resistance has as yet been identified. Specific examples of this are the lack of potent karnal bunt resistance in *Triticum aestivum* and *T. turgidum*, the meager knowledge of salt tolerance gene/s and the lack of a copper efficiency gene in *T. aestivum*. To these may be added heat tolerance and drought tolerance; the list can undoubtedly be extended. In order to resolve this complex situation, research efforts need to be so directed.

In wheat wide crosses, there is an attempt to resolve some of the disease-resistance and stress-tolerance problems. The approach has been to incorporate into wheat (*T. aestivum* and *T. turgidum*) the genetic resistance of stress tolerance that abounds in the annual or perennial grass species of the alien genera *Aegilops*, *Agropyron*, *Elymus*, *Haynaldia*, *Hordeum* and *Secale*. The major problems limiting alien germplasm utilization lie in the difficulty in producing hybrids. These difficulties will always be present and are found at various stages in the ontogeny of the hybrid. These areas have attracted little attention, and advances in any or all of them have the potential of substantially increasing the range of wide hybrids that may be produced.

The phenotype of wide hybrids and their derived amphiploids mitigate against their commercial use; consequently, additional cytogenetic manipulations must be made before practical application becomes possible. In general, these manipulations are directed toward introducing the smallest piece of genetic material capable of controlling the desired phenotype without affecting the other essential attributes of the recipient species. An extensive list of hybrids

involving species of the Triticeae, and also many examples of desirable genes transferred from wheat relatives into *Triticum*, most of which are now in commercial varieties, has recently been published. Consequently, there can be little doubt as to the practicality of the introduction and usefulness of alien variation.

Since the introduction of the Lr9 locus from *Triticum*, most of the examples of the introduction of alien variation involve loci for disease reaction. The introduction of genes affecting protein content, from *T. dicoccoides* into *T. aestivum*, was recently described. There is a qualitative difference between the interactions of the two types of introduced genetic material that is of considerable significance. In all cases involving disease reactions, both the introduced genetic material and the genetic material of the pathogen are free to mutate; consequently, the durability of usefulness of the alien material is limited by the natural variation of the pathogen. This type of system can be described as dynamic. In a dynamic system, it is to be expected that the introduced variation would have a durability no greater than the genes available by intraspecific manipulation. In this respect, they are no different than other genes manipulated by conventional plant-breeding methodology. However, in the case of karnal bunt resistance, it would seem that there is no available source of resistance in the cultivated forms and, therefore, the loci located in the wild relatives have an increased desirability, even though their ultimate practicality will be limited by the constraints of a dynamic system (1).

The introduction of alien genetic material affecting physiological traits of the recipient species is free from this restriction; this is a static system. Consequently, manipulations introducing material of this type have the potential of producing breakthroughs in commercial production. It would be anticipated, for example, that, if it is possible to introduce genetic material providing drought resistance or tolerance, high protein content, protein quality, salt tolerance or various metal tolerances, it would allow the cultivation of wheat in areas where it is currently impossible.

As the demands for increased world food production increase, the value of introduced variation will also increase. It is not possible to predict the future

genetic demands that may be placed on wheats as new races of pathogens appear or as cultivation is extended into new areas. Consequently, a stock of alien genetic material introduced from wide hybrids may prove to be of great value.

It appears that the use of wide hybrids and the derived genetic material in the Triticeae will provide an expanding source of genetic variation for plant breeders which, in some cases, may even amount to quantum changes in either the production or distribution of the crop.

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## Wheat in West Africa

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### Abstract

*Although wheat has been grown in small amounts in West Africa for many centuries, it is only in the last 20 years that it has become an important food source for the increasing urban population. Because of this increasing demand, governments in the region are becoming interested in the possibility of growing wheat, a crop that should be successful, dependent on the development of adapted cultivars and appropriate agronomic practices. Also needed will be trained personnel for research and extension, and improved transport and marketing systems.*

Wheat came to West Africa many centuries ago through the salt trade routes. Later on, it was also brought in by Muslim pilgrims. It used to be grown in very small areas in many African countries, more for use in religious ceremonies than for human food. This situation, however, has changed dramatically during the past twenty years, and today wheat is an important source of calories for many of the West African countries. In fact, Sub-Saharan Africa has one of the highest growth rates in wheat consumption in the world, mainly utilizing imported wheat. Most of the wheat is consumed in urban areas and, since the urban population in these regions is continuing to expand, the upward trend in wheat consumption is also likely to increase. This rapid expansion in the consumption of wheat has prompted many governments in the region to consider the possibility of growing wheat.

The countries in the region having at least some potential for growing wheat are Senegal, Mali, Upper Volta, Niger, Nigeria and Chad. The socioeconomic difficulties related to producing wheat is different for each of these countries. However, agroclimatic patterns and varietal needs are similar for all of the countries of the region.

Almost all of the wheat grown in West Africa is irrigated, and is planted about mid-November and harvested in early March. Most of the soils are heavy clays with very low water infiltration. However, there are also a few areas with sandy soils in the region. Winters in general are mild, with high rates of evapotranspiration, thus necessitating frequent irrigation. Planting date and water management are the two most critical factors for a successful crop.

At present, Siete Cerros and its derivatives are the best-adapted wheat varieties for the region. Fortunately, disease is not a factor limiting wheat production.

### Country Situations

#### Senegal

With the exception of Mauritania, Senegal has the highest per capita wheat consumption in West Africa. In the 1975-1977 period, wheat consumption was 23 kg per capita per year. The government of Senegal, with the help of FAO/UNDP, had an excellent wheat research project in Guede in the Senegal River valley from 1976 to 1982. Researchers at the station have consistently obtained yields of 3 to 4 tons per hectare. The variety Mexipak has yielded an average of 3.6 t/ha over five years, with a maximum of 5 and a minimum of 3 t/ha. In farmers' fields, on commercial-sized plots, yields have

averaged about 2.5 tons/ha. However, wheat in Senegal is still an experimental crop. It is possible that, in the future, Senegal can grow wheat in the Senegal River basin.

#### **Mali**

Farmers in the Niger delta have grown wheat in small plots for hundreds of years. Recently, with the introduction of small irrigation projects along the Niger river near Dire and Timbuktu, the wheat area has expanded. There are three aid projects in operation in the region, one each by Belgium, France and the USA, and all are involved in various aspects of wheat culture. The local varieties grown are Hindi Tosson and Alkama Tireye.

#### **Niger**

Wheat cultivation in Niger is ancient. The main wheat area is in the Agadez region. Close to 1000 hectares of wheat are grown in this region, all of which is locally consumed. At present, attempts are being made to grow wheat in the area of the Konni Irrigation Project. Local varieties there are Bahause, Hayatang, Tawat and a recent reselection, Dambata. The varieties being planted experimentally at Konni are Florence Aurora and Danbata.

#### **Nigeria**

Among the West African countries, Nigeria has the greatest production potential and the largest wheat area. It is grown in three different states, Bono, Kano and Sokoto, in the large-scale irrigation projects. Mexipak and INIA 66 are the two most widely grown varieties. At present, more than 10,000 hectares are devoted to wheat, but the country has the potential for expanding this amount to 100,000 hectares in the future.

#### **Chad**

Wheat used to be a regular crop around Lake Chad. The area was being expanded in the mid-1970s, but there is little information presently available because of the civil war in the country.

#### **Conclusions**

Wheat can be grown successfully in many West African countries. The need for an intensification of cropping patterns, the lack of trained personnel to conduct production agronomy research and extension and the lack of transport and adequate marketing systems are the major problems facing wheat production in West Africa.

## Wheat Varietal Development Strategy in Bangladesh

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### Abstract

*Against a background of variable planting dates, water availability, and farmer preference for the variety Sonalika, white-seeded varieties need to be developed with flexibility in terms of yield response to a number of cropping situations. This challenge is being met by a national varietal improvement program, wherein material is advanced only if it demonstrates the ability to yield as well as Sonalika when planted late in the season and/or under dryland conditions; its yield must be consistently better when planted early and/or under irrigated conditions.*

A bird's-eye view of the Bangladesh wheat-growing areas would reveal a mosaic of differing crop stages and stands, largely defined by date of planting and water availability. In one area, farmers may plant their crop late in December; in another, in mid-November. Irrigated and dryland crops may stand side-by-side. Further, the patterns can shift annually, due to changing facilities and the vagaries of weather. A farmer who plants his crop exclusively on dryland one year may, as a result of buying a shallow tube well, irrigate a mixed pattern of rice and wheat the next. Due to excessive flooding during the monsoon season, a farmer is sometimes forced, against his usual practice of planting rice as early as possible, to plant late, thereby causing him to harvest late and, subsequently, to plant his wheat crop late as well.

The availability of time and water for the growth of wheat in Bangladesh is much less than that of more productive areas, such as the Punjab in India and Pakistan and the Yaqui Valley in Mexico. There are about 120 days in the crop cycle at best, and about 70% of the crop is planted under nonirrigated conditions.

The average national yield is about 2 t/ha; even under the most favorable circumstances, yields have not exceeded 4.5 to 5 t/ha in farmers' fields. Generally, mid-November planting is most favorable for production. On the average, yields are reduced about 1% for each day that planting is delayed after the end of November.

In order that no losses are incurred through shriveling, grains must fill by the first week of March at the latest; after that time, temperature and relative humidity rise rapidly. However, about 75% of the wheat area is planted in December, with about 60% around mid-December, effectively leaving only 90 to 100 days for the production of a crop. This situation has placed a premium on the development of short-duration varieties.

Sonalika, the predominant commercial variety, matures in about 95 days if planted in mid-December and produces large, white seed and consistent (good-as-can-be-expected) yields in a variety of cropping situations. However, Sonalika is fully susceptible to leaf rust (*Puccinia recondita*) and must be replaced or, at the very least, the area it occupies diluted with resistant varieties. Resistance to leaf rust is not a great selling point, however, since epidemics usually start very late and damage is generally insignificant; new varieties

must also demonstrate a yield advantage. Further, farmer preference for Sonalika is so pervasive that it is nearly considered synonymous with wheat.

Against this backdrop of variable dates of planting, water availability and varietal preference, white-seeded varieties must be developed which can be planted late and/or on drylands, while also responding favorably to early planting and/or irrigated conditions. In all probability, the perfect, miracle variety will not be found that these parameters suggest is needed; obviously, some compromises will be necessary.

The development of a number of different varieties, each with its characteristics favorable to a given situation, is always suggested. However, 75% of the annual wheat seed requirement is stored by farmers and, suprisingly, a good percentage of such seed survives the humid monsoon season with a high level of germination. They cannot store seed safely for more than six months, nor are they willing to store a number of varieties, selected for the different kinds of situations they may have on their own land (and which may change annually). Further, the national seed production program, although producing good quality seed, is not sufficiently sophisticated to efficiently grow and distribute a number of different varieties in sufficient quantities that demand requires. The present program, instead, is directed toward the selection of the maximum amount of flexibility in germplasm, in terms of its drought tolerance/favorable response to increased water availability, and tolerance to late planting/favorable response to earlier planting.

Material is available with maturities and drought resistance comparable to Sonalika, but with no particular yield advantage. Yields, of course, generally

decline with decreasing time-to-maturity. The probability of selecting a variety with similar duration and desirable characteristics of Sonalika, and with a consistent yield advantage, is quite low. Rather than to exclusively select for varieties that are similar to Sonalika, selection is also made for varieties which, under both irrigated and water-stress conditions, are of somewhat longer duration than Sonalika (but no more than a week longer). They must also be tolerant to heat-forced maturation while still maintaining a reasonable yield and seed quality and, if planted at a more favorable date, yield consistently better.

All pre-trial material, irrigated or dryland, is selected at a favorable date of planting (November 15 to 30) and a late date (December 15 to 30), at least once before being allowed to progress to the national screening nursery, the Bangladesh Screening Nursery (BSN). Individual plants from international and locally generated segregating material are alternately selected at favorable and late dates of planting up to the F<sub>6</sub> generation (e.g., plants are selected at a favorable date in the F<sub>2</sub>, F<sub>4</sub> and F<sub>6</sub> generations, and at a late date in the F<sub>3</sub> and F<sub>5</sub> generations). Lines may be cut in bulk if selected for the BSN starting with F<sub>6</sub>; the F<sub>7</sub> and F<sub>8</sub> generations are also planted at a favorable date. However, all F<sub>2</sub> material is first selected under irrigated conditions; seeds of selected plants are divided and the populations are thereafter tested at alternate dates, simultaneously under both irrigated and water-stress conditions.

Lines selected for the BSN are planted at seven locations; three of the sets are planted under water-stress conditions. Lines of good appearance, with leaf rust resistance, absence of physiogenic leaf and spike problems, and yielding well-formed, clean seeds in a majority of

locations, are selected for yield trials. Although the apparent ability of any given line to perform well under only irrigated or dryland conditions would not necessarily exclude it from further consideration, it would have to be selected at either all the irrigated or all the dryland sites.

Lines selected from the BSN are tested for three years in experiment station trials which are planted at both favorable and late dates of planting, and under both irrigated and dryland conditions. Selection criteria, in addition to those mentioned above, require that a line must perform as well as Sonalika at a late date of planting, and better if planted at a favorable date under irrigated and/or dryland conditions. Lines advanced through the third year of trials are grown the fourth year in large unreplicated plots on both farmers' fields and experiment stations. This stage is critical; for a line to be released by the National Seed Board, its good performance must be observed in the field by a committee selected by the Board.

This strategy may appear complicated; however, as a result of the stringent selection criteria, the number of lines advanced annually are diminished considerably, thereby reducing the amount of material that must be handled in trials. For example, in the third-year trials of 1984-85, only ten lines including checks will be entered. In any case, it is felt that this strategy is practicable, since it shows that germplasm with the required flexibility is available.

Recently released varieties, on the average, yield 10% more than Sonalika if planted at a favorable date, and as well as Sonalika when planted late. All have maturities of three to seven days later than Sonalika, and all perform as well and often better under water-stress conditions than Sonalika. These varieties, in fact, were developed without employing the above strategy; it appears, however, that the present program will streamline the selection process and make possible the early identification of appropriate material.

## II. Diseases and Disease Control

### Breeding Wheats for Resistance to Helminthosporium Spot Blotch

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#### Abstract

*Spot blotch caused by Cochliobolus sativus (Bipolaris sorokiniana, Syn. Helminthosporium sativum) is one of the most important diseases in a number of countries, such as Brazil, Paraguay, Bolivia, India, Bangladesh and Thailand. In recent years, breeding for resistance to this disease has been gaining importance. This paper discusses some of the principal aspects involved in breeding, including genetic variability in the pathogen populations, screening this for resistance (inoculum, inoculation and field trials), identification of sources of resistance in alien species and transfer of resistance to advanced lines or varieties. Information on some of the resistant lines presently available in wheat against B. sorokiniana is also provided.*

Spot blotch of wheat, commonly known as helminthosporium, is caused by the fungus *Cochliobolus sativus* Ito et Kurib *Bipolaris sorokiniana* Sacc. ex Sorokin, (Syn. *Helminthosporium sativum* P.K. and B). *B. sorokiniana* can attack all plant parts. It is considered important in a number of countries since the resulting losses in yield are appreciable. Severe epidemics of spot blotch are frequently registered in some tropical countries. Spot blotch epidemics in India and neighboring Bangladesh and Thailand have recently been reported (7). Spot blotch is also considered one of the most important diseases in Africa (14). In the USA, on the other hand, it is considered of secondary importance, although its generalized occurrence was registered in Minnesota in 1979 and 1980 (18).

In Latin America, the importance of spot blotch is restricted to Brazil, Paraguay and the Santa Cruz area of Bolivia (5). During the years 1979 to 1982, severe epidemics of the disease occurred in Paraguay, causing heavy yield losses. In Brazil, spot blotch is of great importance. The disease occurs every year in all of the wheat-growing

areas of the country, and severe epidemics were registered in the states of Parana, Sao Paulo, Mato Grosso do Sul and Brasilia, D.F. during the years 1976, 1979, 1980, 1982 and 1983 (9, 10). Under favorable conditions for the disease, the losses in yield can be between 30 and 80%; in some fields they can reach 100%. Because of its importance, chemical control measures for spot blotch are being applied in order to obtain stability in crop production. Another way to control the disease is through varietal resistance.

#### Genetic Variability

As a rule, in breeding for disease resistance, it is necessary to have ample genetic variability within the host populations, as well as within the pathogen populations. To exploit existing genetic variability in the host plant, it is important to determine the genetic variability of the pathogen populations. For this purpose, the different virulence strains of the pathogen must be identified.

Attempts to identify the races of *B. sorokiniana* were made as early as 1922 (3). Based on morphological and pathological characters, Christensen (3) identified at least 37 races of this fungus. Clark and Dickson (4), while working on *B. sorokiniana* on barley, reported that the isolates differed significantly in pathogenicity. Wood (19) strongly believed in the existence of physiological races within *B. sorokiniana* and reported that isolates of this fungus differed strikingly in their parasitic capabilities, regardless of the plant or geographical source. It is well known that *B. sorokiniana* is an extremely variable fungus; progenies from a single conidium may differ in pathogenicity. Constant mutation and saltation are other problems which make race identification still more difficult.

To distinguish between races or strains, it is necessary to establish a differential set of cultivars. Recently, Mehta (11) established a preliminary set of 13 differential cultivars and identified a total of 32 races. These races, when tested on adult plants, differed strikingly from each other as to spore production and lesion size (12). To determine variability in the pathogen population, a large number of monoconidial isolates had to be obtained from different locations, from different wheat varieties or from related plant species over a period of two to three years.

Mehta (11) reported that the reaction pattern of the races on the various cultivars was altered in most cases after the isolates had been stored eight to ten months. It is well known that the isolates change or even lose their pathogenic capability after a period of time. This is why the term "race" for *B. sorokiniana* has been questioned.

Once the standard differential set of cultivars is established, the strains with different virulences (races) can be identified at any time by using fresh monoconidial isolates. Such isolates can, in turn, be used for the identification of broad-spectrum resistance. Recent work in the IAPAR laboratory shows that the monoconidial isolates can be maintained in conidial form on sterilized filter paper discs (11) with fewer problems of mutation and loss of virulence for up to three years. Further work is necessary with the preliminary set of differential cultivars; it needs to be standardized so that it can be used by scientists in different countries.

### **Screening for Resistance**

Screening for resistance is an important step in breeding for disease resistance. Screening techniques must be reliable, so that the resistant material thus selected can be incorporated into the crossing blocks with confidence.

Screening for resistance is generally done in a greenhouse or in a walk-in cold chamber, but always under controlled conditions; all plant materials must be tested under standard and uniform conditions. Any change in the quality of inoculum, inoculation technique, incubation period and environmental conditions may alter the reaction pattern.

### **Inoculum preparation**

For screening purposes, a good inoculum must include a mixture of several virulence isolates and an appropriate and constant amount of viable conidia in the suspension. Inoculum of different virulence isolates can be multiplied separately on autoclaved sorghum seeds in Erlenmeyer flasks at room temperature (20 to 25°C). Over a period of three weeks, abundant spore increase can be obtained on the sorghum seeds. Fifty grams of such seeds are placed in a

beaker with 200 ml sterilized distilled water and shaken thoroughly. The conidial suspension is filtered through a cheese cloth; it can be diluted by adding more water or strengthened by adding more seed, so as to arrive at a concentration of 33,000 to 43,000 conidia per ml of water.

It is not necessary to count conidia in a hemocytometer. To determine concentration, the count can be made under a microscope with a magnification of 150 (15 ocular x 10 objective). If an average of 8 to 12 conidia are observed per microscopic field, then a concentration of 33,000 to 43,000 conidia/ml is assured. This method is not time consuming and gives uniform results. The conidial suspension of all the isolates at proper concentration is mixed together and, for every 200 ml of conidial suspension, a drop of sticker Sandovit, manufactured by Sandoz, is added. The resulting mixture is used for inoculation. Normally, germination tests for conidia are not necessary, but experience has shown that, if the flasks are incubated for over three weeks, a large amount of conidia lose their viability. This procedure is also used to inoculate the segregating populations and advanced lines in the field; the less diseased plants with smaller lesions are selected.

At research stations where laboratory facilities are not yet available, the inoculum for segregating populations may be prepared in a simpler way. Conidial dust may be collected from the combine soon after harvest, especially from fields heavily infected by *B. sorokiniana*. Such dust normally contains about 70 to 80% conidia. This dust is dried in a desiccator for 72 hours, kept in glass bottles and stored in the refrigerator. Experience shows that conidial dust can be stored in a viable form for over two years. To get genetic variability in the pathogen populations, it is necessary to collect conidial dust from several varieties and several locations. At time of inoculation,

the dust from different locations and varieties is mixed in equal proportions, and the segregating populations and advanced lines are sprayed.

### **Inoculation**

In the greenhouse, it is preferable that plant material be tested for resistance at two growth stages, at the seedling stage and also at the adult plant stage. To confirm the reaction pattern, the test should be repeated for each growth stage; it has been shown that seedling reaction does not necessarily correspond with adult plant reaction. Although adult plant resistance is always preferred, tests on seedlings help to determine lines that show resistant reactions at both growth stages. Such lines are of great interest in programs breeding for resistance.

For seedling tests, plants can be grown in soil in plastic trays (55 x 30 x 12 cm). One row with 10 to 12 plants of each variety is planted; a total of twelve varieties can be grown per tray. Twenty days after sowing, the seedlings are inoculated uniformly, using a small atomizer and a pressure pump. The inoculated plants are incubated in the dark for sixteen hours at  $20^{\circ} \pm 1^{\circ}\text{C}$  and at near 100% humidity. Later, they are incubated for seven days at  $20^{\circ}\text{C}$  in a walk-in cold chamber with fluorescent lamps for alternate cycles of twelve hours light and twelve hours darkness. Readings on infection are taken seven days after inoculation, using an appropriate scale for reaction score (11).

The adult plant test can be performed by growing the plants in earthen pots 25 cm tall and 20 cm in diameter. Normally, five plants are grown per pot; a total of ten plants per variety are used to determine variety reaction. Only the flag leaves are inoculated soon after emergence. They are washed with distilled water, gently rubbed between the fingers and then, while being held

upright, are given a quick spraying, from the top to the bottom of the leaf and then from the bottom to the top. The rest of the procedure is the same as that for the seedling test.

### Field trials

Although greenhouse tests are reliable, it is often necessary to conduct field trials to confirm varietal reaction under natural conditions. In institutions where controlled environmental conditions are not present, screening tests can be performed in the field with artificial inoculations. All of the resistant lines selected in the greenhouse are tested under field conditions over a period of at least two years. It is important that tests be performed at three to four hot-spot locations each year. It is worthwhile to include resistant and susceptible checks in the nursery, and it should be surrounded by a susceptible spreader. Inoculum is prepared in the same way as for greenhouse tests, and the conidial suspension sprayed on the spreader as many times as necessary to obtain a severe epidemic.

Disease ratings should be taken at least twice, once at the heading stage and once at the soft dough stage. However, if time permits, weekly readings are very useful. From the disease progress curve, the rate of infection can be calculated; the lower the rate of infection, the higher the degree of resistance (12). Agronomically desirable lines with low infection ratings are used as sources of resistance in the breeding program.

Through this process, some lines have been selected (Table 1). However, they need to be tested further at other research stations before being used for general breeding purposes. Table 2 indicates some lines resistant to *B. sorokiniana*, based on screenings made in Zambia, Brazil and Bangladesh in 1980-81 (13). In India, Adlakha *et al.* (1) tested 625 wheat lines and reported 16 lines resistant to *B. sorokiniana*; HD1927 was considered to be the best. They believe that sources of resistance are readily available in wheat.

**Table 1. Resistant lines to spot blotch (*B. sorokiniana*) based on field screenings, Londrina, Brazil, 1982-83**

Variety/cross	Resistance reaction <sup>a/</sup>		
	Londrina	Palotina	S. Miguel
Pamir "S" CM20834-A-7Y-501Y-502Y-OB	8 MR, 30 MS	30 MS	10 MS, 20 MR
PF7339=Sonora 64-SKE x LR64A/IAS49	12 S, 45 MS	8 MR, 20 MR	25 MS, 5 MR
Horizon	1 MS, 40 MS	5 MR, 20 MS	5 MR, 20 MR
Veery "S" CM33027-F-12M-1Y-3M-1Y-0M	TMR, 20 MS	8 MS	20 MS, 15 MS

Table 1. (Cont'd)

Variety/cross	Resistance reaction <sup>a/</sup>		
	Londrina	Palotina	S. Miguel
OCEPAR-9-Perdiz	TMS, 25 MS	--	25 MS
CNT1=PF11.10000-62-BH1146	TMR, TMR	3 MS, 5 MR/MS	5 MR, 5 MR
Frontana	15 MS	30 MS	20 MR
BH1146=Fronteira-Mentana x P.G.1	9 S, 40 MS	21 MS	8 MS, 20 MR
Jacui=S8-Toropi	5 MS	30 MS	5 MR
LD7815	20 MS	20 MS	10 MR
LD7821	10 MS	--	15 MR
LD8115=Alondra//CNT7/PF70354/ 3/PAT24/Bluebird/Kalyansona I19170-2L-25L-8L-0L	10 MR	--	25 MR
LD81151=IAC17/Alondra"S" I18314-0F-27L-10L-7L-0L	10 MS	--	15 MR
PAT7219	10 MS	--	10 MR
PAT7392	20 MS	10 MR	10 MR
BR8=IAS20-Tp x PF70100	--	20 MR	10 MR
Kinglet"S" CM33089-W-3M-7Y-3M-0Y	20 MS	--	15 MS
LD8032=PAT72195-Musala x TRM I13746-1Ld-12Ld-4Ld-0Ld	35 MS	--	20 MS
LD8038=JUP-Moncho I9312-1Ld-8Ld-7Ld-0Ld	30 MS	--	30 MS
LD8077=IAS55-Alondra"S" I18310-0F-30Ld-15Ld-0Ld	25 MS	--	20 MS
PEL73015	15 MS	30 MS	5 MR

<sup>a/</sup> MR = moderately resistant, TMR = trace to moderately resistant,  
MS = moderately susceptible, S = susceptible

**Table 2. Results of screening for resistance to *Bipolaris sorokiniana*, Mexico, Brazil, Bangladesh and Zambia, 1981-82**

Cross and pedigree	Resistance found to be present
Kavkaz-HD2009, SWM2984-1M-1Y-1M-2Y-0M-0M	x
CRT-Alondra"S", II14055-0M-7LD-5LD-1LD-0Y	x
CRT-Alondra"S", II14055-0M-7LD-5LD-2LD-0Y	x
CRT-Alondra"S", II14055-0M-7LD-1LD-0Y	x
CRT-Alondra"S", II14055-0M-19LD-25LD-1LD-0Y	x
TOB"S"/CN067-JAR x Kavkaz, CM20707-A-1Y-8M-1Y-0Y-2PTZ-0Y	x
TOB"S"/CN067-JAR x Kavkaz, CM20707-A-1Y-8M-1Y-0Y-4PTZ-0Y (TOB"S"-NPO x Correcaminos-INIA/CNO-NO66)SJ"S"	x
Tanager"S", CM30697-16Y-7M-1Y-0M	
Pewee"S", CM31630-H-3Y-1M-6Y-0M	
Kalyansona-Bluebird x CJ"S"/Alondra"S", CM32421-4M-1Y-2M-2Y-0M	
Banaquit"S", CM32556-3M-501Y-519M-0Y	
Harrier"S", CM33435-P-1M-1Y-0M	
CBC148/5/INIA/3/LR64*2/SN64//CC/4/CC/INIA"S"/6/VLD"S" CM33683-A-4M-1Y-1M-0Y	
TOW"S", CM34709-B-3M-1Y-1M-1Y-0M	
BJY"S"-Grajo"S"(LR64-SN64 x TZPP-AN64/BBxTOB-CNO) CM34742-E-2M-9Y-0M	
Fury-MO73, CM36732-16Y-15M-4Y-0M	
OLN-TRM, CM36820-10Y-1M-1Y-0M	
Bonanza-JUP73, CM36872-27Y-3M-2Y-0M	
BR74.72-COC75, CM36889-31Y-10M-0Y	
GOV-AZ67 x Musala"S", CM41257-1-8M-3Y-0M	x
ERA-MN69.146 x Pavon 76, CM52349-1MM-0MM	x
BH1146	
L2000.731	
MN72135	
PF69129	
PF71131	
PF7339	

Source: Rajaram *et al.* (13)

### Identification of Sources of Resistance

Sources of resistance to *B. sorokiniana* in species other than *Triticum aestivum* are of special interest in the breeding program. The use of alien gene pools for disease resistance has long been known (8). Breeding for specific resistance against *Phytophthora infestans* in potato started as early as 1949, when a gene pool for resistance was discovered in *Solanum demissum* (16). In recent years, there have been several reports on the use of gene pools for resistance to rusts, septoria and mildew in wheat from some closely related species (2,17). CIMMYT has been making some effort to incorporate alien resistance genes already in the wheat background (6). Recently, they have obtained some segregating lines resistant to *B. sorokiniana* from wheat combinations with *Aegilops elongatum* and *Elymus giganteus* (M. Kazi, personal communication).

Nevertheless, information on the sources of resistance to *B. sorokiniana* in species other than *T. aestivum* is still very scant, and attempts should be made to identify sources of resistance in as many alien species as possible. Such information would help for genetically combining different sources of resistance. Also, relatively little information is available about the underlying genetic mechanism of resistance. Adlakha *et al.* (1) reported that resistance in wheat to *B. sorokiniana* was conditioned by one or two dominant factors; similar conclusions were reached by Srivastava *et al.* (15). Further work may be necessary to understand more about the inheritance of resistance.

### Transfer of Resistance to Advanced Lines or Varieties

Until recently, very little emphasis has been given to breeding for resistance to *B. sorokiniana*. During the past ten years, much improvement has been made in wheat production, especially in the Latin American region, through the introduction of Mexican varieties with high yield potential and improved disease resistance, mainly to the rusts. Some of the varieties have failed to create an impact in some areas due to their susceptibility to *B. sorokiniana* and the local complexes of diseases. There are only a few examples of field resistance to *B. sorokiniana* within existing commercially grown varieties. Among them are the Mexican varieties Alondra and Cocoraque, which have shown reasonably good performance against spot blotch in farmers' fields. Alondra, a semidwarf wheat with a big spike, has become an important progenitor in numerous crosses with Brazilian wheats. Among the Brazilian varieties, BH1146, CNT1 and PAT7219 have the best resistance. Thus, due to the fact that a majority of commercial varieties are susceptible or highly susceptible to *B. sorokiniana*, breeding for resistance to *B. sorokiniana* has rapidly gained importance in recent years.

Once the sources of resistance in *T. aestivum* or alien species are confirmed, the problem of incorporating such resistance in agronomically desirable varieties arises. By and large, the pedigree selection method is followed by most breeders and pathologists. After passing through several field and greenhouse screening tests, resistant lines are tested for yield, included in the crossing block, and selections for resistance and agronomic

characters made in segregating populations. Heavy inoculum pressure is a prerequisite to testing and, during the process of subsequent selections, there is the danger that resistance will be lost. Nevertheless, if a particular source possesses a very high degree of resistance, it will be able to endure through the pedigree method. In Brazil, a high degree of resistance has not yet been found in *T. aestivum*. It is possible that, in most cases, resistance is polygenic and is governed by minor genes.

Quite frequently, a bulk or modified bulk system is used when desirable characters are obscured by unfavorable environmental conditions or other stresses. The backcross method also might be used with success to transfer resistance to *B. sorokiniana*. This method works best when resistance is governed by one or only a few major genes. The CIMMYT germplasm development program has used this method to incorporate disease resistance into acceptable plant types (M.M. Kohli, personal communication).

In case resistance to *B. sorokiniana* is governed by a large number of minor genes with low expression and low heritability, the best approach would be to use the recurrent selection method. The availability of some effective gametocides makes the method feasible and would help to establish a large number of genetic pools which could subsequently be combined. These genetic pools or recurrent selection populations could serve as a bridge for

transferring resistance without losing important characters such as yield and adaptation.

There is an urgent need to identify resistant sources in alien species. Transfer of resistance from such species to *T. aestivum* is a rather complicated and difficult task. Difficulties in making interspecific crosses is due mainly to differences in levels of ploidy (8). However, problems such as lack of chromosome pairing and crossing-over, failure of crosses after fertilization, difficulties in rearing hybrid plants and the lack of vigor and fertility of hybrid plants can be overcome by the use of various techniques and chemicals such as colchicine and gibberellin. Information on these points is given by Knott and Dvořak (8).

In general, the most important objective of breeding programs is to enhance yield stability through effective resistance to a complex of diseases. However, uniform screening procedures and techniques have not yet been fully implemented. Invariably, disease-screening hot spots are lacking, and artificial inoculation techniques vary among national programs. Although plant pathologists have begun inoculating selected materials to identify progenitors, segregating populations and advanced lines are still being selected under variable and natural disease pressure. Only uniform artificial inoculation can guarantee the successful screening of germplasm for resistance to *B. sorokiniana*. A network of hot-spot locations for this disease needs to be established within each country in order to permit uniform screening and, consequently, provide reliable information on resistance.

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## Breeding Wheats with Resistance to *Helminthosporium sativum* in Zambia

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### Abstract

*The Mexican wheat cultivars developed in the 1970s are unsuitable for production during the rainy season in Zambia, due to their susceptibility to foliar diseases and head blight caused by H. sativum. Several sources of resistance have now been detected in new germplasm from CIMMYT and in Brazilian wheats. Crosses are being made in Zambia to increase the level of resistance and adaptation. Selected lines yield up to 3 t/ha in tests, and the first variety has been released. The prospect for rainfed wheat production with resistant cultivars is good.*

Zambia has 6 million inhabitants, and a large percentage of them live in cities and towns; the annual requirement for wheat is 180,000 tons. Approximately 10% of this amount is produced locally as irrigated wheat during the winter. Although a yield of 6 t/ha is possible and the wheat price is US\$ 320/ton, the irrigated wheat area is not increasing. The participation of small-scale farmers in irrigated wheat production is difficult to envisage, but they could participate in rainfed wheat production, where little or no mechanization is required.

Rainfed wheat research and production started in the mid-1970s; however, more emphasis was placed on production than on research. The cultivars Jupateco and Sonora 64 were used for commercial production, but with very low, uneconomic yields, ranging from 0 to 800 kg/ha. The major reason for this failure was determined to be the susceptibility of the wheat cultivars to diseases caused by *Helminthosporium sativum*.

Natural epidemics of diseases caused by *H. sativum* start from the tillering stage, and usually develop quickly after flowering; very susceptible lines may be totally necrotic by flowering. All above-ground plant parts are attacked. The optimal conditions for development of *H. sativum* are present in Zambia

during the rainy season. Most locations in the country can therefore be considered as hot spots for this disease. In crop loss assessment tests, it was demonstrated that total crop loss could occur if susceptible cultivars were used. In the same tests, it was also demonstrated that yields of more than 3 t/ha could be obtained with good disease control.

Wheat cultivars with resistance to *H. sativum* had to be found, but no suitable variety for Zambian conditions was known to exist anywhere. Screening began with the support of CIMMYT; the search for "the needle in the haystack" had started. Through contacts with Passo Fundo, the first Brazilian lines arrived in Zambia in 1979. Parts of the World Collection were also screened, and nurseries from ICARDA were tested.

Very few sources of resistance were found at first, when only advanced generation nurseries were tested. However, better materials were subsequently found in the CIMMYT F<sub>2</sub> spring x winter populations and in the F<sub>2</sub> nurseries for aluminum tolerance. It is possible that an association exists between tolerance to aluminum toxicity

and resistance to *H. sativum*. This may explain the resistance to *H. sativum* found in the Brazilian lines.

After several seasons of field tests with many lines from abroad and local crosses, all introductions are now compared with susceptible and resistant check varieties, and certain selection criteria are followed. Selections are made, based on foliar infection, head blight, node infection, black point, maturity period, plant height, lodging tendency and agronomic characteristics. A single, best growth stage at which resistance can be identified has not yet been determined. Observations in two or three growth stages are still necessary because of fluctuations in disease pressure. The critical period for infection is the time between early dough and maturity. Observations during flowering provide a good indicator, but selections made before flowering are unreliable.

Low percentages of flag leaf necrosis and head blight during the soft dough stage are good measurements of resistance. It may be possible to express necrosis by spot type and lesion number. Entire spikelets of susceptible lines are quickly destroyed by *H. sativum*; restricted lesion development and few lesions on the spikes are required. Node infection expresses itself in stem-breaking at maturity; 100% stem-break is often recorded on susceptible cultivars like Jupateco.

Grain infection varies considerably, even among resistant lines. Late-maturing lines may escape infection and are often wrongly selected as resistant. Therefore, it is necessary to relate infection level to growth stage and to make comparisons to check cultivars. *H. sativum* may severely attack lodged plants, probably due to the creation of a favorable microclimate for disease development after lodging. Dwarf plants do not compete well with weeds, and they risk exposure to relatively high disease pressure.

The flag leaf size is another criterion that needs further investigation. Large flag leaves permit more inoculum production than smaller ones, and indirectly contribute to higher disease pressure. Smaller leaves, in general, contribute to a microclimate which is less conducive to disease development. Good tillering provides an effective weed-control mechanism, and may also be an expression of tolerance to aluminum toxicity and heat.

In yield tests in Zambia, *H. sativum* severity is scored during flowering and in the soft dough stage on a 0 to 9 scale. During flowering, the height at which the infection is found on the plant is recorded; during the soft dough stage, the flag leaf and the spike are scored; the infection is already high up on the plant by that time. A severity index for black point will be included in the scoring system.

The occurrence of other diseases, such as *X. campestris* and *Fusarium* spp., complicates the scoring of *H. sativum*. Scoring at flowering is often made difficult by the presence of lesions all over the foliage. Fluctuations in disease pressure by sudden changes in weather

conditions, whereby infection percentages change quickly, complicate the comparison between varieties which are in different growth stages. Under high disease pressure, the epidemic develops very quickly, and correct determinations of growth stages at scoring are necessary.

The standardization of scoring methods of *H. sativum* would be beneficial for the development of resistant varieties. Presently, the situation is such that interpretation of information on *H. sativum* from different countries is difficult. Cultivars labeled resistant in one country may be very susceptible in other countries, and vice versa.

The wheat germplasm with resistance to *H. sativum* which is now being used in Zambia originates from CIMMYT segregating nurseries, from Brazil and from local Zambia crosses. In the spring x winter wheat nurseries, some lines were selected in the following crosses: Predg-NAC, Predg-Kavco, KVZ-Tanori, KVZ-HD2009/TOB-CNO x TOB-Era and KVZ/3/CC-INIA//CNO/El Gaucho-Sonora 64. Unfortunately, these lines are not adapted to acid soil conditions. In the spring x spring wheat nurseries (F<sub>2</sub> helminthosporium, F<sub>2</sub> aluminum tolerance) several promising selections have been made, especially in the crosses with Brazilian wheats. Some of these lines have good adaptation to acid soil conditions as well. Lines from the following crosses are in various yield tests: PEL73280-Atr(Tzpp x IRN46-CNO67/Protor), IAS64-Aldan"S", PF7339-Hahn"S", PF7339-Veery"S", IAS58-Chat"S", Hork x CNO-Siete Cerros/IAS63, Kalyansona-Bluebird x Alondra"S"/Jacui and PF7339/Cndr-ANA x Cndr-Mustafa.

Most of the older Brazilian wheats are late maturing and very susceptible to rust diseases under Zambian conditions. Some of the selections which are presently in yield tests are PF7748, PF72640, B7901, B7903, B8005, BR6 and Mascarenhas; these lines are also well-adapted to various soil conditions. From the local hybridization program, the best lines which are now in F<sub>7</sub> originate from the following crosses: PF7748 x PEL73280-Atr(Tzpp x IRN46-CNO67/Protor), K4500 x Kalyansona-Alondra"S"/PF7748, PF72640 x PEL73280-Atr(Tzpp x IRN46-CNO67/Protor), Predg-NAC x PF7748, PF72640 x IAS64-Aldan"S", IAS64-Aldan"S" x PF7748 and PF7748/Predg-NAC x K4500.

With an accelerated generation-advancement program, it is now possible in Zambia to develop and screen relatively large numbers of entries in a short period of time. Crosses are made in July and August, immediately after the rainy season. F<sub>1</sub> seed can be harvested as early as one month after pollination, due to favorable environmental conditions. The F<sub>1</sub> is then seeded during September and October, and F<sub>2</sub> seed harvested in December. The F<sub>2</sub> is seeded in early January in the rainy season at one or more locations. The selections are harvested in April and May and reseeded under irrigation in May and June. F<sub>4</sub> seed is ready in October, in time for the rainy season tests. Large populations from each cross were space planted in the beginning, but it may be more efficient

to make a large number of crosses and prescreen them in a nursery as a bulk, after which intensive selection can be conducted in space-planted populations of the best crosses.

The wheat program has recently released the first rainfed wheat cultivar, Whydah. Its origin is the Brazilian selection PF7748 (ND81/IAS59//IAS58). This variety requires four months from seeding to harvest. It is tall, tillers strongly and has small spikes. Besides being resistant to *H. sativum*, it is also resistant to *Fusarium*, *X. campestris*, *P. recondita* and *P. graminis*; it also has good tolerance to aluminum toxicity. It is now used as the resistant check in the yield tests, along with the susceptible cultivar Jupateco. It constantly yields around 2 t/ha in yield tests under various soil conditions and different times of seeding, provided the

rainy season lasts long enough. The first commercial production took place during the 1983-84 season, with an average yield of 2.5 t/ha. The same yields were also obtained with PF72640 and Banu, but these were not released.

At present, several entries in the yield tests have equal or better yields than Whydah. Among them are several Brazilian lines and selections from the CIMMYT and Zambian crosses mentioned earlier. Some lines yield 3 t/ha. However, official release not only requires resistance to *H. sativum*, but also to several other diseases, as well as tolerance to aluminum toxicity. This combination is not always present.

Commercial rainfed wheat production is now possible in Zambia. The farming community is becoming interested in this new crop. Sufficient land for production is available, and 3 t/ha and more may be realized in the near future.

## **CIMMYT Methods for Screening Wheat for *Helminthosporium sativum* Resistance**

**L.I. Gilchrist, Wheat Program, CIMMYT, Mexico**

### **Abstract**

*Helminthosporium sativum* is one of the most aggressive and virulent pathogens found when breeding wheat in tropical climates. To screen for genetic resistance at CIMMYT, seedlings at the two-leaf stage are sprayed with inoculum in the greenhouse, and then placed in a mist chamber; evaluation for resistance is made between the fifth and seventh day after inoculation. Selection under field conditions is accomplished in Poza Rica, where optimum environmental conditions for the development of *H. sativum* prevail. Usually four to six readings are taken of foliar damage, depending on the maturation of the lines being tested. Grain damage is evaluated for severity, based on the percent of infection of each grain.

Among the pathogens that most strongly affect wheat yields in tropical areas is *Helminthosporium sativum*, which causes seedling blight, spot blotch and black point. One of the control methods that is being investigated currently is the screening of genetic material for desirable resistance levels. This paper presents the methodology used for selecting genetic material from CIMMYT's bread wheat and wide cross programs under greenhouse and field conditions.

### **Handling Fungus in the Laboratory**

#### **Pathogen isolation**

The isolates are obtained from leaves of different wheat varieties and lines. In 1984, various samples were taken at Poza Rica. The diseased leaves were cut into small pieces, disinfected with 5% calcium hypochlorite for 60 seconds and transferred to Petri dishes with potato dextrose agar (PDA).

#### **Maintaining the isolates**

The isolates are maintained on sterilized wheat grain. To prepare the sterile grain media, the grains are first soaked in distilled water for 24 hours. Then the excess water is drained off, and the grain is sterilized in an

autoclave at 120°C for two hours. The isolates are kept in this media under refrigeration (4°C) until required.

#### **Inoculum increase**

When an increase in the inoculum is desired, the infected grains are transferred to Petri dishes with PDA and kept in a growth chamber at 22 to 24°C. After seven or eight days, the inoculum is ready for use.

#### **Inoculum preparation**

A spore suspension is prepared by washing the PDA plates with distilled water and filtering the spore suspension through gauze. The spore concentration is then standardized to 60,000 spores per/ml, using a hemocytometer.

#### **Inoculations under Greenhouse Conditions**

##### **Preparation of test material**

Ten to twelve seeds of the materials to be tested are placed in envelopes made from glassine bags lined with absorbent paper towels. They are then arranged in two rows in 22 x 30 cm trays with strings to separate and support the 60 envelopes. Each tray is then filled with distilled water, supplying the humidity needed for germination and plant development.

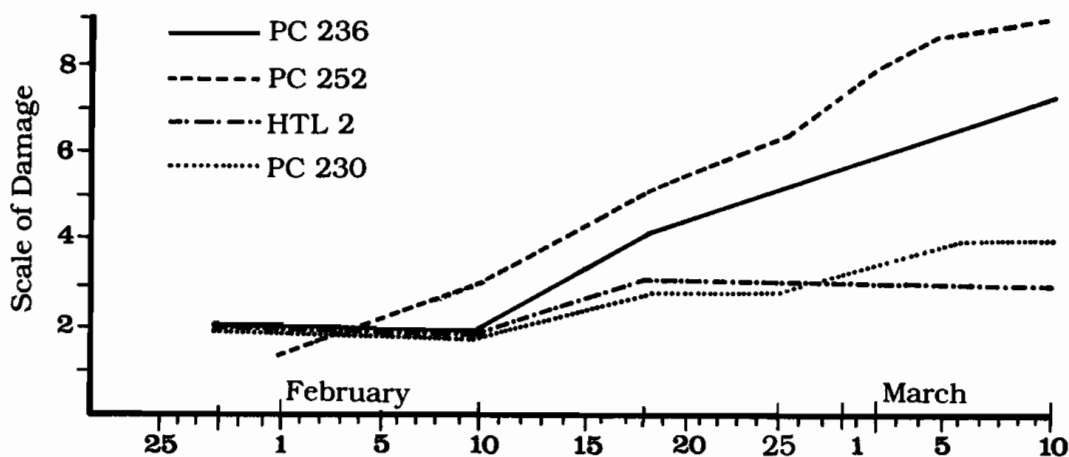
### Inoculation

Inoculation is done at the two-leaf growth stage (about eight to ten days after germination), using a hand sprayer. Each tray receives approximately 100 ml of inoculum. Inoculated plants are then kept in a mist chamber, with two hours of continuous misting, and then 15 minutes of misting every two hours thereafter for 24 hours. Later, the seedlings are transferred into a chamber and kept at 22° to 24°C and 75 to 80% relative humidity for five days.

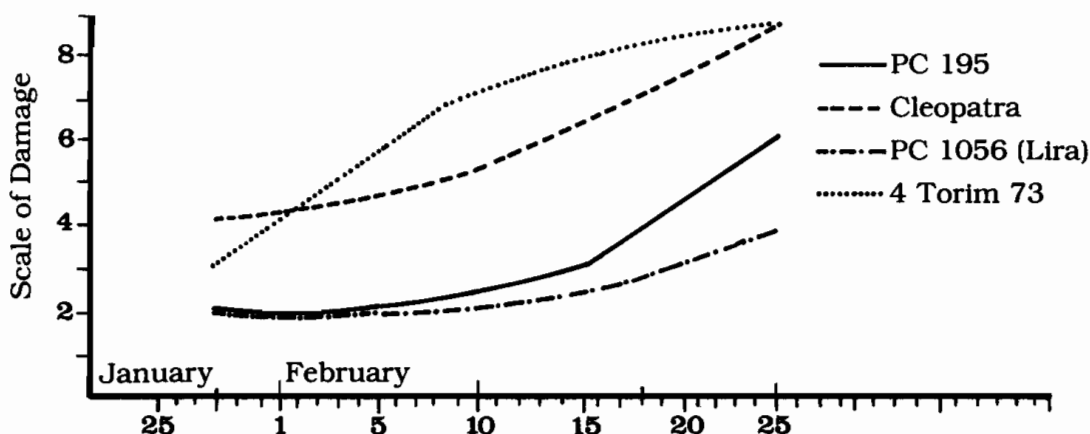
### Evaluation and selection of material

Inoculated materials are evaluated after five to seven days, according to the following 1-to-5 scale:

- 1 = a few small black lesions on leaves
- 2 = more black lesions, some with small chlorotic halos
- 3 = lesions surrounded by chlorotic halos, many of which start converging; some drying effects at leaf tips
- 4 = broad lesions with ample necrotic zones; drying over a large part of the leaf
- 5 = large lesions; drying of the whole leaf



**Figure 1. Disease development on four late-maturing wheat varieties, from flowering to milk stage, January 25 to March 10, Poza Rica, Mexico, 1983-84**



**Figure 2. Disease development on four early-maturing wheat varieties, from flowering to milk stage, January 25 to February 25, Poza Rica, Mexico, 1983-84**

### Selection under Field Conditions

During the 1983-1984 cycle, conditions were optimum for the development of *H. sativum* in Poza Rica. Relative humidity was recorded as between 90 and 100% for more than 95% of the growing cycle. This high relative humidity resulted from daily early morning and afternoon fogs, with less than five hours of direct sunlight per day recorded during most of the cycle. The optimum average temperature for the development of the fungus (18 to 24°C) was also recorded during approximately 75% of the growing cycle. These conditions allowed good selection pressure for the program. Four foliar evaluations were made for the early-maturing lines and six for the late-maturing materials. A 1 to 9 scale was used for scoring, allowing the noting of more variations in levels of disease presence.

Figure 1 shows the development of the disease on four late-maturing materials. The advanced lines Cook-Veery''S'' x Dove''S''-Veery''S'' (PC236) and AI Fong4-Yaco''S'' x Tanager''S''-Pewee''S'' (PC252) gave susceptible responses, while the lines F371-TRM (HTL2) and Yaco''S''-Phoebe''S''/Calidad-CHKW x Veery''S'' Calidad-

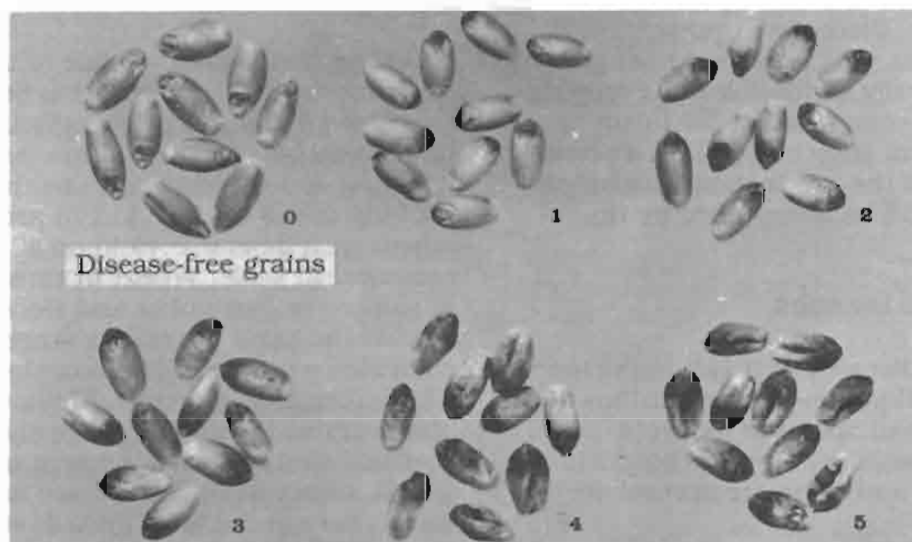
CHKW x Veery''S'' (PC230) showed slow development of the fungus and high disease tolerance.

Figure 2 shows the development of the disease on four early-maturing materials. Torim 73 and Cleopatra showed a susceptible response. Line Antbird''S''-Yaco''S'' (PC195) exhibited slow development at the start, but reached a high level of infection by the end of the cycle. Line Lira''S'' (PC1056) displayed good resistance, exhibiting a low level of infection during the entire cycle.

In addition to field evaluation, 50 spikes of each selected line were harvested at maturity and the percentage of diseased grain and the severity of the damage was evaluated, according to a 1-to-5 scale (Figure 3). The best lines selected at CIMMYT with this methodology are presented in the paper by Villareal *et al.* (these proceedings).

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**Figure 3. One-to-five scale used at CIMMYT for scoring severity of disease damage on wheat grains**

## **Insect Pests and Diseases of Wheat in the Philippines**

**D.B. Lapis, Institute for Plant Breeding, University of the Philippines, Los Baños, Philippines**

### **Abstract**

*For the Philippines, producing wheat would be an ideal approach for reducing wheat importation and for saving foreign exchange. Insect pests and diseases are two of the constraints to its production and to crop acceptability by the farmer. Based on observations in areas where wheat is being targeted for commercial production, helminthosporium seems to be the most limiting factor to producing wheat with desirable yield on a commercial scale; foot rots are observed only occasionally and sporadically. Work on wheat pests has only begun in the Philippines; principal research efforts will be in breeding for resistant cultivars to control the pests and diseases of primary economic importance.*

Although wheat was under cultivation in the Philippines as early as 1664, commercial production is still in its infancy, with only about 69 hectares of commercial production in the 1983 cropping season. However, a great deal of wheat is consumed in the Philippines. In 1983, wheat importation amounted to about US\$ 20 million, second only to petroleum, and thus constituted a tremendous foreign exchange drain.

Even though producing wheat would be an ideal approach for reducing wheat importation and saving foreign exchange, there are at present constraints which make wheat growing economically unfeasible. The crop does, however, offer promise for future production. Insect pests and diseases are two of the production constraints which limit its acceptance by the farmer.

### **Wheat Diseases**

The two diseases of major importance in the Philippines are helminthosporium leaf spot and foot rots. Leaf spot is caused by *Helminthosporium sativum*, and there are several other

reported helminthosporium species. Foot rots are caused by *Sclerotium rolfsii*, *Rhizoctonia solani*, *Fusarium roseum*, *Phythium* spp., *Phytophthora* spp. and *H. sativum*.

Several species of *Helminthosporium* are suspected of causing leaf spot, leaf stripe and net blotch, which are presently attacking wheat. It is obvious that they are caused by different species, because of the observed differences in the characteristics of the lesions present on the diseased plants. The different root rot pathogens infect plants, either alone or in combination.

Based on observations made at the different areas where wheat is being targeted for commercial production, the disease caused by the *Helminthosporium* spp. is believed to be the most limiting factor in the effort to produce wheat with desirable yield on a commercial scale. Wheat in those areas is planted in November and December, so that the early vegetative stage coincides with the cooler months (December and January). Previous observations in the field have shown that leaf spot is always present on wheat, but usually the disease becomes severe only at the later growth stages, between late January and late

February. Environmental conditions are often favorable for quicker and more severe helminthosporium infection when temperatures of 25 to 28°C and relative humidity of 70 to 84% occur from January to March, coinciding with the critical stage of plant growth.

Further complicating the management of the disease is the year-round presence of host plants of helminthosporium, including various grasses and broadleaf weeds, such as *Commelina diffusa*, *Chloris barbata*, *Dactyloctenium aegyptium*, *Eleusine indica*, *Cyperus difformis*, *C. fimbriatus*, *Imperata cylindrica*, *Cynodon dactylon*, *Paspalum conjugatum*, *Leptochloa chinensis*, *Rottboellia exaltata*, *Brachiaria distachya*, *B. mutica* and *Echinochloa colona*.

Foot rots, although only occasionally and sporadically observed in the different areas, are also considered of importance. The areas targeted for wheat are the rainfed areas, with insufficient irrigation for a second rice crop. *Sclerotium* and *Rhizoctonia* are common soil-borne pathogens, and the sclerotial bodies left in the field after rice harvest serve as an inoculum source for the wheat. The situation is further aggravated by pre-sowing irrigation and the existence of high temperatures and high relative humidity, favoring germination of and infection by these soil-borne pathogens.

Other foot rot pathogens, such as species of *Pythium* and *Phytophthora*, are observed only occasionally; *H. sativum* is more common. It is probably seed-borne, as indicated by the fact that 20 to 25% of the seeds taken from fields severely infected with helminthosporium leaf spot show the

presence of black point. This is further supported by a preliminary study in which seeds, previously disinfected with 1:1000 mercuric bichloride solution, soaked for five minutes in a spore suspension of *H. sativum* and planted in sterile soil, gave only 30% germination; uninoculated seeds had 92% germination. Those seedlings that survived showed symptoms of helminthosporium five days after emergence.

To date, the only studies conducted on wheat diseases in the Philippines have been on the etiology of helminthosporium leaf spot (1966), which was identified as *Helminthosporium sativum* Pammel King and Bakke, and on head blight, which was identified as *Fusarium roseum* (Cke) Snyder and Hansen.

### **Insect Pests**

The principal insect pests on wheat in the Philippines are:

- Seedling maggot - *Antherigona* spp.
- Semilooper - *Chrysodeixis chalcites*
- Pink stemborer - *Sesamia inferens*
- Corn earworm - *Helicoverpa armigera*
- Aphids - *Rhopalosiphum maidis*

Current observations indicate that the first four pests appear in succession during the cropping season.

At present, no details on genetic resistance to the different wheat pests can be given since work only started on July 1, 1984. The main research efforts in the Philippines will continue to be a search for resistant cultivars, in order to control those pests and diseases of primary economic importance.

## The Effect of Early Foliar Infection by *Helminthosporium sativum* on Some Yield Components of Two African Wheats

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### Abstract

*Early foliar infection by helminthosporium reduced the kernel dry weight per ear of two African genotypes, in particular the number of kernels per ear. Reduction in kernels per ear was high at moderately high air temperature and humidity, but moderate at high air temperatures and moderately high humidity; under those conditions, yield was low anyway. Research is proposed for studying yield loss due to early foliar infection in the field. For areas with high air temperature and humidity, breeding for tolerance to high temperatures seems to demand a higher research priority than breeding for helminthosporium resistance. Genotypic variation apparently permits selection for incomplete resistance to helminthosporium.*

Foliar infection by helminthosporium (*Helminthosporium sativum* Pammel, King and Bakke) of wheat (*Triticum aestivum* L.) occurs in hot humid areas, for example, in parts of Africa and Asia (10), but also in cool humid areas (3,4). During the hot rainy season in Zambia, foliar infection of wheat can become very severe (6,7); in the cool, dry season, however, severity remains low (1). The economic importance of helminthosporium is unknown for many areas (5,8,9,11). Crop-loss studies have been performed in the field (Raemaekers, these proceedings), where the effect of helminthosporium on yield is confounded with other factors, such as temperature, soil and interplot interference. To study the effect of helminthosporium on yield components, trials were performed under controlled conditions with artificial inoculation. Conditions in the growth chamber corresponded as much as possible to field conditions in Zambia and to other countries in the tropical belt.

### Materials and Methods

Two trials were performed in a walk-in growth chamber at the Department of

Phytopathology of the State Agricultural University, Wageningen, Netherlands. Trial 1, performed in 1982, had high air temperature and moderately high humidity (Table 1); in Trial 2, performed in 1983, both air temperature and humidity were moderately high (Table 2). A 12-hour day was used in 1982 and a 13-hour day in 1983; light intensity in both trials was moderate.

In 1982, inoculations with helminthosporium were made before mid-flowering (mid-flowering = decimal code (DC) 64) (13). In 1983, they were made before heading (heading = DC 50).

The cultivars used were Tokwe and MILO4-21, short-cycle, early-maturing wheat genotypes. Tokwe is a dwarf cultivar for irrigated conditions (2,12), which is susceptible to helminthosporium in the field. MILO4-21 is a medium-tall line from the Horizontal Resistance Breeding Program (1); it has moderate susceptibility to helminthosporium in the field and relatively good yield in the warm rainy season at Mazabuka, Zambia (15°45'S latitude, 27°56'E longitude, 985 m altitude).

Each trial had two replications with two blocks for inoculation and two genotypes randomized within the blocks for inoculation. The block for inoculation contained at least eight pots with two plants each. The 1982 trial was harvested 104 days after the start of germination, and the 1983 trial after 101, 108, 115 and 122 days from germination. Kernels were dried at 80°C for 42 hours, and number of kernels and dry weight of kernels per ear were determined.

## Results

In Trial 1, kernel dry weight per ear of the first tiller was relatively low

(Table 3). Foliar infection significantly influenced kernel dry weight per ear, but genotypes differed in response. In Tokwe, infection was lowest, with no difference between inoculated and uninoculated plants. MILO4-21 had a loss of about 38%, due to a loss in number of kernels and some loss in kernel dry weight.

In Trial 2, kernel dry weight per ear of the first tiller was good in uninoculated plants (Table 3). Foliar infection significantly influenced kernel dry weight per ear. Tokwe, with the lowest value for untreated plants, had the highest loss in kernel dry weight per ear. In both genotypes, loss in kernel

**Table 1. Climatic conditions used in growth chamber trials to study the effect of *Helminthosporium* on yield, Netherlands, 1982 and 1983**

Condition	Trial 1, 1982		Trial 2, 1983	
	Light (12 hr)	Darkness (12 hr)	Light (13 hr)	Darkness (11 hr)
Air temperature (°C) at 70 cm	27	20	24	18
Relative humidity (o/o)	63(80) <sup>a/</sup>	80(96)	(80)	(90)
Light intensity at planting (lux)	24,500	—	24,000	—

<sup>a/</sup> Figures in brackets = set value of growth chamber

**Table 2. Regime followed for inoculating wheat with *Helminthosporium sativum* to study effect on yield, Netherlands, 1982 and 1983**

Trial	Inoculation regime		
	Days after germination	Mean development stage (DC)	Spore density (spores/ml)
Trial 1 (1982)			
Inoculation 1	48	42	6 × 10 <sup>4</sup>
Inoculation 2	51	45	1 × 10 <sup>5</sup>
Inoculation 3	64	59	5 × 10 <sup>6</sup>
Trial 2 (1983)			
Inoculation 1	35	28	1 × 10 <sup>6</sup>
Inoculation 2	40	36	1 × 10 <sup>6</sup>
Inoculation 3	52	50	1 × 10 <sup>6</sup>

dry weight per ear was caused mainly by a severe reduction in the number of kernels per ear.

### Conclusions

Early foliar infection by helminthosporium reduced the kernel dry weight per ear of both African genotypes. Foliar infection between development stages 30 and 50 DC of the plant inhibited kernel production, but did not appear to influence dry weight per kernel. Foliar infection between development stages 40 and 65 DC of the plant, however, could affect both number of kernels per ear and dry weight per kernel. The results suggest that the development stage at which the infection occurs is of importance for the number of kernels produced. The degree of inhibition was high, particularly at the moderately high air temperature and humidity. Under irrigated conditions, as in Zambia, helminthosporium occurs on the leaves before anthesis; the experiments suggest that helminthosporium may then cause significant yield loss. The amount of yield loss found in these experiments justifies yield loss studies with fungicide applications before anthesis, and screening for genetic variation in resistance to early infection.

At high air temperatures and moderately high humidity, the effect of temperature on kernel dry weight per ear was larger than was the effect of helminthosporium. This indicates that, in areas with high air temperature and humidity, breeding for tolerance to high temperature should have priority over breeding for resistance to helminthosporium.

In both trials, kernel dry weight per ear differed between genotypes; it was highest for MILO4-21, which was selected under warm, rainy-season conditions in Zambia. Under those environmental conditions, MILO4-21 had a higher yield than Tokwe. Genetic variation appears to allow selection for incomplete resistance to helminthosporium but, without good tolerance to high temperature, this resistance may have little practical value.

### Acknowledgements

The authors wish to thank CIMMYT for providing the opportunity for presenting this paper, the Department of Phytopathology of the State Agricultural University, Wageningen, Netherlands, for providing the facilities to perform the trials, M. Kelfkens and M. Krot for carrying out the 1982 and 1983 trials, respectively, and W. Hoogkamer for providing technical assistance.

**Table 3.** The effect of foliar infection by *Helminthosporium sativum* on yield components of first tillers for two African wheat genotypes grown in a growth chamber, Netherlands, 1982 and 1983

Yield component	Trial 1, 1982 (genotype and effect)				Trial 2, 1983 (genotype and effect)			
	Tokwe	Effect of inoculation <sup>a/</sup>	MILO4-21	Effect of inoculation <sup>a/</sup>	Tokwe	Effect of inoculation <sup>a/</sup>	MILO4-21	Effect of inoculation <sup>a/</sup>
Kernel dry weight per ear (g)								
No inoculation	0.14		0.53		0.68		1.28	
Inoculated	0.14	0	0.33	.38	0.25	.63	0.80	.37
Number of kernels (-)								
No inoculation	5		19		21		43	
Inoculated	6	—	15	.21	8	.62	28	.35
Kernel dry weight (mg)								
No inoculation	29		28		35		30	
Inoculated	25	.14	24	.14	35	0	30	0

<sup>a/</sup> Effect of inoculation = 1.00-(+/-)

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## Wheat Breeding for Scab Resistance

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### Abstract

*Scab or head blight of wheat caused by Gibberella zeae (Fusarium graminearum) is an important yield-limiting factor in tropical/subtropical regions; the main damage occurs as shrivelling of grain and flower abortion. Immunity has not been reported, but some Asian cultivars have shown stable and transmissible resistance. Selections in segregating material should be done at locations with a high natural disease incidence and/or by using measures to increase disease spread, such as artificial inoculum production and inoculations. Changes in seeding date, sprinkler irrigation, rotation with corn or the use of susceptible borders should be utilized to enhance the epidemic. The most reliable methods of disease assessment must be used to determine the percentage of shriveled kernels and of flower abortion. In this paper are presented aspects of inoculum production, inoculation methods, environmental conditions which facilitate testing, identification of resistance and breeding for scab resistance.*

Scab or head blight, caused by *Gibberella zeae* (Schw.) Petch, with *Fusarium graminearum* Schw. as an anamorph, is an important factor limiting wheat yields, especially in areas having mild winters and warm, humid springs. These conditions frequently occur during the winter wheat season in the Southern Cone of South America, southern Africa, Australia, eastern and western Europe and North America (5,6,10,13,30,33,34,71,73).

The main damage occurs as kernel shriveling and floret abortion due to infections of the anthers and ovaries, but *F. graminearum* is capable of attacking the whole wheat plant (10,13,24,30,34,48,67). *F. graminearum* survives from one season to another as mycelia, conidia and/or ascospores in the soil, on crop debris and on seeds. Infections in other hosts, such as barley, corn, oats, rice, rye, sorghum and grasses, e.g., species of *Alopecurus*, *Agropyron*, *Bromus*, *Digitaria*, *Echinochloa*, *Lolium* and *Poa*, may also be important inoculum sources (3,5,7,10,13,24,30,34,48).

The variability within *F. graminearum* is high, at least in cultural characteristics (11,48,55,70), and immunity to head scab has not been reported in wheat. However, lines with high levels of resistance have been found, especially among material from China, Japan and southern Brazil (23,30,34,50,58). Unfortunately, these sources usually have poor agronomic type.

The nature of resistance to scab is not completely understood. Schroeder and Christensen (56,57) observed two different types, resistance to initial infection and resistance to spread within the spike. The resistance to initial infection might be related to the opening of the floret for a shorter time (Nakagawa, personal communication), and to not trapping anthers when the glumes close (48,51,60,61,62,63,64,66), as well as to other factors. The resistance to disease spread within the spike is probably of a biochemical nature, and Nakagawa has tried to correlate it with sugar and phosphorus level (38,39,40,41,42).

Although differences in the level of resistance have been observed in both Brazil and Japan (such as in

Shinchunaga and descendants), several materials have shown good resistance over all localities during the few decades that they have been tested (29). This fact has encouraged breeders and pathologists to attempt the difficult task of breeding for resistance to a disease caused by a pathogen with a high variability, high rate of multiplication, various means of dispersion and survival in the absence of the host. Breeding programs for scab resistance are in progress now in China, Japan and Brazil. In order to select for resistance to scab, methodologies to assure the occurrence of the disease and to evaluate resistance are essential.

### Artificial Inoculation

#### Inoculum production

Several culture media can be used to isolate and increase inoculum of *F. graminearum* (7,72). Pieces of corn stalk with nodes, autoclaved with a small amount of water (25), constitute an inexpensive media that produces high amounts of conidia and/or ascospores, and allows several harvests of inoculum; this method is now in use in Brazil. Cultures grown at 25°C under continuous fluorescent light give good production of conidia. Ascospores are produced by some isolates kept under natural conditions.

#### Inoculation methods

Sprays of a suspension of mycelia, conidia and/or ascospores are similarly effective in inducing disease when environmental conditions are favorable (48,66,67,68,69). The concentration of spores in successful inoculations reported varies from  $4 \times 10^3$  to  $8 \times 10^6$  conidia/ml (1,14,55,56,72). In the tests conducted in Brazil, a spore suspension with  $10^6$  conidia/ml is applied, under both field and greenhouse conditions, with a conventional sprayer.

Injections of spore suspensions (300 to 400 conidia per drop) in a central floret are very useful for testing resistance to

spread within the spike. As the most damaging infections occur between anthesis and the milk stage, i.e., the period of highest susceptibility (1,2,8,10,11,12,34,54), the inoculation should be made at flowering or a little later. In Brazil, mixtures of fifty or more isolates from different localities are normally used, in order to assure a pathogenic population representative of the one that occurs naturally in the field.

#### Environmental conditions

In greenhouses with temperatures around 25°C and relative humidity over 85% during the inoculation period (flowering to milk stage), the development of scab is very good. In Pelotas, a marginal region for wheat production in Brazil, the warm, windy, humid spring weather provides natural conditions for a high incidence of the disease in the field almost every year, as can be seen in Table 1.

**Table 1. Natural occurrence of scab in wheat plots under field conditions, Pelotas, Brazil, 1979**

Cultivar	Scabbed grains (o/o)
Abura	19.65
Inayama	2.07
Nobeoka Bozu	3.98
Nyu Bay	6.39
Pekin 8	10.18
Toropi	8.18
PEL73007	23.20
PEL73022	20.40
PEL73157	5.51
PEL73175	16.20
FB5163	93.33
Jaral	81.81
Super X	91.17
PV-Indus	95.28

In localities where scab occurs only sporadically, several arrangements can be made in order to increase the possibility of the uniform occurrence of the disease. These include changes in seeding date to make flowering coincide with the period of higher humidity, the use of sprinkler irrigation, crop rotation with corn, leaving corn stubble within and around plots, the use of highly susceptible borders (triticale, durum wheat, rye and some wheat varieties), and leaving inoculated or naturally infected wheat or corn straw along the edges of the plots (3,4,24,43,46,47, 65,74,75).

#### Identification of resistant plants

Since the main damage caused by scab is kernel shriveling and floret abortion, the most reliable method for disease assessment must involve these two parameters. Individual threshing of spikes (or a known number of spikes) and counting shriveled and healthy grains is necessary. The number of plump kernels per head, grown under conditions of high scab incidence,

compared with the normal number of plump kernels per head under healthy conditions is the best indication of the degree of resistance or susceptibility of a cultivar. With segregating materials, since a healthy check is not possible, an estimate of the number of kernels per head, based on spike size, is necessary (Table 2).

The percentage of damaged grains alone, overlooking flower abortion, has been used in several programs (7,8,9, 14,16,28,37,72), and has proven useful in most routine screening work. Visual grading of kernels for plumpness and shriveling is also used. Whenever resistance scoring through kernel observation is employed, threshing should be done by hand or with a thresher without forced ventilation, since shriveled grains tend to be eliminated in normal threshing. Observation of symptoms in heads can also be made in preliminary selections (37), always watching out for those cases where glume symptoms are not correlated with grain infections (28). The score for a plant should be the score of the most infected head (Table 3).

**Table 2. Modified Japanese scale for scab resistance, according to percent of scabbed grain**

Scale	Scabbed grains (o/o)	Resistance level
0	0	Completely resistant
1	Less than 8	Resistant
2	9-11	Moderately resistant
3	12-20	Moderately susceptible
4	21-50	Susceptible
5	More than 50	Highly susceptible

**Table 3. Modified Japanese scale for scab resistance, according to head symptoms**

Scale	Necrotic area of head (o/o)	Resistance level
0	0	Completely resistant
1	1-5	Resistant
2	5-25	Moderately resistant
3	25-50	Moderately susceptible
4	50-75	Susceptible
5	More than 75	Highly susceptible

### Wheat Breeding for Scab Resistance

The main sources of resistance to scab used in the Brazilian breeding programs are descendants of Asian cultivars, such as Nobeoka Bozu, Pekin 8, Nyu Bay, Minami Kyushu 69, Abura, Inayama, Tokai 66 and others (7,9,14,15,16,17,18,19,20,21,22,32,35,36,44,45,52,53). Local cultivars, especially Toropi and Encruzilhada, are also being used because, even though they are moderately susceptible in greenhouse tests, they show some resistance under field conditions (26,27,28,31,59).

Crosses followed by genealogical selection have been used in attempts to combine resistance to scab with other traits of local interest, such as yield, quality and resistance to other diseases. The EMBRAPA National Wheat Research Center at Passo Fundo has a

special program for transferring resistance to scab, via back crosses, to several cultivars of good agronomic type (49).

Selection for scab resistance should start with a preliminary selection of F<sub>2</sub> plants or, if entries are to be tested under heavy inoculum in the field or greenhouse, in the F<sub>3</sub> and/or F<sub>4</sub> generations. According to Nakagawa (personal communication), selection in the F<sub>4</sub> and F<sub>5</sub> generations are more effective. In localities where scab does not occur every year, testing should be repeated over several generations until reliable data can be obtained.

Table 4 presents the percentage of scabbed (shriveled) kernels of susceptible and resistant cultivars and

**Table 4. Percentage of scabbed kernels of various resistant and susceptible cultivars and crosses after greenhouse inoculations, Pelotas, Brazil**

Cultivar or cross	Generation	Scabbed kernels (%)	
		Cultivars <sup>a/</sup>	Selected plants
Nyu Bay		9.3	
Nyu Bay x Lagoa Vermelha	F <sub>3</sub>		15.7
Lagoa Vermelha		53.7	
IAS54		70.2	
IAS54 x Nobeoka Bozu	F <sub>4</sub>		86.8, 5.0, 4.7, 8.0, 7.3, 12.5, 11.1, 8.7, 16.8, 7.9, 9.1, 15.4, 8.8, 10.8
Nobeoka Bozu		10.8	
Toropi x Nobeoka Bozu	F <sub>6</sub>		6.6, 7.1, 7.4, 10.1, 8.6, 4.5, 9.0, 8.3
Toropi		32.0	
IAS20 x Toropi	F <sub>6</sub>		22.6
IAS20		50.3	

<sup>a/</sup> 5-year average

their descendents after tests in the greenhouse, with relative humidity kept over 90% by automatic mist. The plants were given two inoculations per week, from flowering to maturation, of a spore suspension comprising over 70 isolates (29).

Table 5 presents the number of resistant plants selected under severe greenhouse tests. These were derived from F<sub>3</sub> and F<sub>4</sub> populations, from crosses involving more than one resistance source (53).

**Table 5. Number of resistant plants from segregating populations subjected to greenhouse scab inoculations, Pelotas, Brazil**

Cross	Number of plants	
	Population	Selected
Toropi-Nobeoka Bozu x Abura-Siete Cerros	114	8
IAS52-Toropi x Avanzado Ecuador L17-Nobeoka Bozu (IAS 49-Minami Kyushu 69 x IAS49-IAS20) x IAS 54-Nobeoka Bozu	268	23
Abura-Mazoe (Gabo) x IAS54-Nobeoka Bozu	286	40
Nobeoka Bozu-IAS54 Sel21 x PF7225	296	8
Lagoa Vermelha-Nobeoka Bozu x PF6968	176	7
IAS20-Toropi x Nyu Bay-Nadadores 63	224	10
Pekin 8 x IAS50-Sheridan/IAS20-PEL8685-62 x IAS20-Tokai 66	116	9
	128	3
Several other crosses	--	55

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## Head Scab Screening Methods Used at CIMMYT

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### Abstract

*One of the most important methods for selecting adaptable and resistant wheat plants under adequate planting conditions is the disease-screening technique. CIMMYT techniques have been developed and improved in order to reduce unnecessary effort on the part of cooperators and farmers around the world when seed is sent to them. From a wide array of germplasm, selections were made for scab resistance from 220 lines screened from 1980 to 1982 in Toluca and El Batan, 21 highly resistant lines from China and 5 highly susceptible ones selected from 1978 to 1980. Fusarium-infected wheat spikes were collected for pure spore isolation and fresh inoculum preparation. Two inoculation methods, using cotton or using a spray, have consistently proved effective. The cotton method, in which a tuft of cotton permeated with fusarium spores is placed between the glumes of the spike, is the most precise, but both methods are extremely effective and give well-defined results.*

Disease screening is one of the major tools of plant breeders in selecting desirable plants with better and wider adaptation. There are a number of different disease-screening methodologies in operation for handling different diseases. However, as diseases that were once unimportant become more important (3), new screening techniques need to be developed or existing ones improved.

The question is not only one of screening against diseases, but also of reducing the number of breeders' materials. For ensuring better and wider adaptation, the selected materials have to be tested against diseases over a much wider area and under different conditions. Preliminary testing in breeders' plots is necessary to reduce the amount of germplasm before it is sent out to cooperators for testing in hot spots.

Although a naturally occurring epidemic is one of the tools of screening, it frequently fails to occur in a continuous pattern due to changes in climatic conditions that favor either the host or the pathogen. In this case, the flow of disease information received by the breeder can lack continuity. In order to assure disease development

annually, conditions must be available and methods continually created to assure that screening processes function properly. Thus, the host is tested in the presence of the pathogen.

### Materials and Methods

On May 31, 1983, 962 advanced bread wheat lines were planted in Toluca in the State of Mexico. These same entries were planted on June 22, 1983, in Patzcuaro, Michoacan. While the bulk of the material was from the Crossing Block and the 17th International Bread Wheat Screening Nursery, the group also contained 220 lines that were identified as scab resistant in tests in Toluca and El Batan from 1980 to 1982. Also, 21 highly resistant lines from China and five highly susceptible lines were included in the plantings as controls.

Both at Toluca and at Patzcuaro, plantings were made in two one-meter rows. Five grams of seed were planted in each plot to assure enough heads for inoculating by two different inoculation methods. Although the weather pattern is similar at the two places, soils and pathogens differ greatly. In Patzcuaro, the soil has a low pH (J.K. Ransom, personal communication), and there is

an extremely high incidence of natural scab infection. However, by taking advantage of both natural and artificially inoculated fusarium, both locations are excellent sites for scab screening (1).

#### **Fusarium isolation and culture preparation**

Fusarium-infected wheat spikes, for pure spore isolation and fresh inoculum preparation, were collected from Toluca and Patzcuaro. Spore isolation and purification were made on corn meal agar (CMA) (2) in the laboratory at El Batan. For individual-spike and mass inoculation (spikes in one-meter single rows), a large volume of fusarium isolates were multiplied on CMA and mungbean extract (W.Y. Zhong and W.S. Jun, personal communication).

#### **Preparation of fusarium spore inoculum**

To prepare the fusarium inoculum, cultures grown on CMA are placed in a disinfected food blender, and blended for one minute to make a thin puree. The CMA-culture puree is then passed through several layers of sterilized cheese cloth to obtain a clear filtrate. When mungbean extract is used as the culture medium, the culture is blended for only a few seconds and filtered as above. In both cases, the concentrated clear filtrate is then diluted with sterilized distilled water until a desired spore count per cc of water is attained. Thirty to fifty thousand spores per cc of water are suitable for CIMMYT conditions.

#### **Inoculation methods**

Two different inoculation methods were developed and modified at CIMMYT for controlled scab screening. These methods are suitable both in the greenhouse and in the field under Mexican conditions. They are:

- The cotton method—With this method, a tiny tuft of cotton (cotton

swab for laboratory and hospital use) is permeated with the distilled water containing fusarium spores in suspension. One-fourth of the cotton swab, the size of an outer wheat glume, is pushed between the glumes and placed in contact with the anther in a wheat floret. Sharp-pointed tweezers of the kind generally used for emasculation purposes are used for separating the cotton tufts and for inoculating. A glassine bag is then placed over the inoculated wheat head to prevent damage by wind, dust or excess humidity (rain or dew). This cotton method is the most precise for controlled scab study in the greenhouse and in the field.

The method is comparable to that of inoculation by injection with a syringe. However, unlike the injection method, the cotton method places the inoculum at a specified inoculation point without injuring plant tissue. With the syringe method, the water suspension can drip, contaminating other parts of the spike. Also there is the possibility of applying less inoculum with syringe applications because, when the needle is pushed through the spike, a portion of the inoculum may be discharged into the air. The needle also injures the wheat tissue.

- The spray method—With this method, fusarium spores suspended in water are sprayed on wheat heads, using various types and sizes of hand garden sprayers with various nozzle attachments. Also, a back-pack motor-driven sprayer can be used. For CIMMYT's advanced wheat line screening study, a small hand atomizer (commonly used as a garden pesticide sprayer), with a meter long, hard-walled plastic tube, is used. Inoculum is placed in one-liter plastic containers, and the tube from the spray nozzle is immersed in the container.

Wheat spikes are spray-inoculated from a distance of 10 to 15 cm until they are soaked with spore suspension.

#### **Crop stage for inoculation for maximum disease development**

For maximum scab development, wheat heads are inoculated at flowering or at anther protrusion stage. Young, plump and yellow anthers (not white and dry) are good indicators of the right stage for inoculation as are flowering wheat heads with one to three protruded anthers at the mid-point of the spike(s). In this study, a cultivar was considered ready for inoculation when 5 to 10% of the extruded anthers appeared in a plot of wheat plants. It is critical that this growth stage is used at all times. Any inoculation at pre or post-flowering (especially at post-flowering when extruded anthers are white and dry) results in poor scab development.

#### **Inoculating the wheat plant in the field**

Wheat plants in plots of two rows one meter long were inoculated with fusarium spore suspension by both the cotton and the spray methods at Toluca; only the spray method was used in Patzcuaro. In Toluca, ten spikes in one row of each plot were inoculated with the cotton method, and each inoculated spike covered with a glassine bag. The remaining single row in Toluca and one row in the plots in Patzcuaro were spray inoculated. Spray-inoculated wheat spikes were not covered with bags. After inoculation, plants were checked periodically for disease development.

#### **Disease development and scoring**

Scab disease developed differently on early and late-maturing cultivars, both at Toluca and Patzcuaro. In spite of differences in inoculation time, disease development occurred between 35 and 45 days after inoculation. Disease developed more rapidly in early-maturing lines than in later ones.

Therefore, disease scoring was done 42 days after inoculation, using a 0 to 5 scale.

Disease development was excellent with both inoculation methods. With the cotton method, spikes remained clean and bright (straw color), since they were protected by the glassine bags. The movement of fusarium infection was well-defined; it started at the point of inoculation and progressed either up or down the spike from where the cotton was placed. Since there was no dripping of the liquid inoculum, the disease remained localized and then spread to other spikes in a continuous pattern, without skipping spikelets. This type of disease development was not obtained in previous studies when the syringe injection-inoculation technique was used (unpublished data).

With the spray method, head scab development was also excellent at both Toluca and Patzcuaro. Differences between susceptible and resistant lines and between inoculated and uninoculated portions of the plots were well defined. Susceptible lines showed bright pinkish-orange sporodochia filled with fusarium conidiospores. Infected spikes (rachis, glumes and seeds) of susceptible lines were permeated with fusarium mycelium and filled with spores. In most cases, seed formation was aborted or replaced by sporodochia. Symptom development was good with both techniques. However, with the spray method, there were a large number of infection points in each spray-inoculated spike and disease development was much greater, spreading over the full length of the infected spikes.

Both inoculation methods were found valuable in identifying 198 highly scab-resistant lines from the 962 lines tested. All of these 198 selected lines showed resistance both in Toluca and in

Patzcuaro. Among those selected lines, certain sister lines appeared repeatedly in the list, including several sister lines

of Veery and combinations with Veery (VEE"S"), Bobwhite (BOW"S"), Alondra (ALD"S"), Dove, Kavkaz (KVZ) and Passo Fundo (PF) lines (Table 1).

**Table 1. Some advanced wheat lines with low scab infection, identified in tests at Toluca and Patzcuaro, Mexico, 1983**

Lines and crosses	Disease score <sup>a/</sup>	Lines and crosses	Disease score <sup>a/</sup>
Veery"S" CM33027-D-1M-2Y-1M-1Y-1M-0Y	1	JUP-Alondra"S" CM36867-18Y-17M-3Y-0M-1PTZ-0Y	1
Veery 8 CM33027-F-12M-1Y-1M-1Y-1M-0Y	T - 1	Siskin"S"-Canario"S" x Alondra"S" CM62319-3Y-1M-1Y-2M-2Y-1M-0Y	1
Veery 9 CM33027-F-12M-1Y-12M-1Y-2M-0Y	2	Tanager"S"/TI-TOB x Alondra"S" CM64340-4M-1Y-1M-2Y-1M-0Y	2
Veery"S"-Cuckoo"S" CM58882-0Y-0M-0Y-1M-5Y-1M-0Y	T - 1	PF7339	1
Veery"S"/Kalyansona-Bluebird x TQFN"S" CM67412-17Y-2M-5Y-2M-0Y	T - 1	PF71131	1
Siskin"S"-Veery"S" CM58831-3M-2Y-2M-2Y-1M-0Y	T - 2	PF70354-Alondra"S" CM47090-14M-1Y-1F-703Y-10F-705Y-2Y-0Y	1 - 2
Tucan"S"-Moncho"S" x Veery"S" CM62001-6Y-1M-2Y-2M-1Y-1M-0Y	T	PF70354-Alondra"S" CM47090-13M-1Y-1F-701Y-1F-704Y-6Y-0Y	1
Redpoll-Ani"S" x PVN-Veery"S" CM68735-1-4Y-1M-3Y-1M-0Y	1 - 2	PF70354-Alondra"S" CM47090-1M-110PR-1T-0T	1
Cook-Veery"S" x Dove"S"-Veery"S" CM69279-C-2Y-1M-1Y-1M-0Y	T - 2	PF70354-Moncho"S" CM67934-1Y-1M-1Y-3M-0Y	T - 1
Bobwhite"S" CM3203-K-9M-9Y-4M-4Y-1M-1Y-0M	1 - 2	PF7619-Dove"S" x CEP7670 B25813-A-1M-4Y-1M-1Y-1M-0Y	1
Bobwhite"S" CM3303-K-9M-33Y-1M-500Y-0M-1J-1J	1	Kavkaz-Siete Cerros SWN4064-6Y-4M-3Y-1M-1Y-3M-0Y	T
Bobwhite"S" x YR-Trifon"S" CM64684-2Y-2M-1Y-1M-0Y	T - 1	Kavkaz-Sapsucker x Moncho"S"-TSI CM68651-C-1Y-1M-1Y-1M-0Y	T - 1
YR-Trifon"S" x Bobwhite"S" CM68336-1Y-1M-1Y-2M-0Y	T - 1	Kavkaz-CJ	T - 1
Tanager"S"-Bobwhite"S" CM68381-8Y-1M-2Y-2M-0Y	1 - 2	Moncho"S"-Kavkaz SWN-3720-6Y-3M-1Y-2M-1Y-0M	1 - 2
Teeter"S"-Bobwhite"S" CM58857-2M-1Y-1M-3Y-1M-0Y	1	Dove"S"-Buckbuck"S" CM58808-6M-5Y-1M-1Y-1M-0Y	T - 1
Alondra"S"-PVN"S" CM49901-14Y-2Y-1M-1Y-0M	T - 1	Dove"S"-Buckbuck"S" CM58808-27Y-2M-7Y-4M-0Y	2
Alondra"S"-PVN"S" CM49901-14Y-2Y-6M-4Y-0M	1	Dove"S"-INIA 21B-1Y-1M-0Y	2
Alondra"S"-COC CM50351-9M-2Y-1Y-4M-1Y-0M	1	Dove"S"-INIA 55B-2Y-3M-0Y	T - 1

<sup>a/</sup> Scoring scale 0 to 5 (0 = immune, 5 = completely susceptible, T = trace)

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## Recent Advances in Research on Wheat Scab in China

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### Abstract

*Wheat scab (head blight) caused by Gibberella zeae (Schw.) Petch is one of the most serious wheat diseases in South China, especially in the middle and lower reaches of the Yangtze River, where there is a high frequency of incidence causing considerable loss in yield. Scab is estimated to occur on 6.7 million hectares in China and, in years of severe epidemics, losses range from 10 to 40%. Comprehensive research has been carried out on causal organisms, resistance of wheat varieties and tests for resistance, including inoculation methods, epidemiology and integrated control measures.*

Wheat scab (head blight), caused by *Gibberella zeae* (Schw.) Petch, occurs in almost all of the humid and semi-humid regions of the tropics, the subtropics and in certain temperate zones of the world. It is one of the most serious wheat diseases in South China, especially in the middle and lower reaches of the Yangtze River, where the disease has a high incidence and frequently causes severe losses. During the 28 years from 1957 to 1984, there were four years of severe epidemics and 15 years of moderate epidemics in this region: the average frequency of epidemics was about 68%. In years of severe epidemics, the rate of infected spikes reached more than 50%, and yield loss ranged from 10 to 40%; in years with moderate spread, the rates of infected spikes and yield loss were 20 to 50% and 5 to 15%, respectively. It is estimated that wheat scab occurs in an area that covers more than 6.7 million hectares in China (7,8). Besides the direct losses caused by the disease, the pathogen also produces mycotoxins, which can cause mycotoxicoses in humans and domestic animals (19,20). Therefore, there is a great need to study and control wheat scab.

In 1974, a cooperative research team involving scientists from 12 provinces and cities was organized by the Chinese Ministry of Agriculture. Comprehensive research has been carried out on causal organisms, resistance of wheat varieties to scab, epidemiology and integrated control measures; significant advances have been achieved.

### Scab-Producing Organisms

#### *Fusarium* spp.

In 1955, Yu Da-Fu (25) reported that the wheat scab-causing species of *Fusarium* along the Yangtze River were *F. graminearum*, *F. moniliforme*, *F. culmorum* and *F. avenaceum*. From 1976 to 1980, the cooperative research team (1,22,28) collected 2,450 samples of diseased wheat heads from 21 provinces and cities. Eighteen species and varieties of *Fusarium* were isolated, identified and classified as to high, moderate or low levels of virulence on wheats.

The species and varieties with high virulence were:

- *F. graminearum* Schwabe
- *F. camptoceras* Wr. and Rg.
- *F. equiseti* (Corda) Sacc. var. *compactum* (Wr. Joffe)
- *F. sulphureum* Schlecht.
- *F. culmorum* (W.G. Smith) Sacc.

The species and varieties with moderate virulence were:

- *F. avenaceum* (Cda. ex F.) Sacc. var. *graminum* (Cda.) Sacc.
- *F. avenaceum* (Cda. ex F.) Sacc. var. *herbarum* (Cda.) Sacc.
- *F. tritinctum* (Corda) Sacc.
- *F. acuminatum* Ell. et Ev.
- *F. nivale* (Fr.) Ces.

The species and varieties with low virulence were:

- *F. equiseti* (Corda) Sacc. var. *longipes* (Wr. and Rg.) Joffe
- *F. sporotrichioides* Sherb. var. *chlamydosporum* (Wr. and Rg.) Joffe
- *F. sporotrichioides* Sherb.
- *F. equiseti* (Corda) Sacc.
- *F. concolor* Rg.
- *F. moniliforme* Sheld.
- *F. semitectum* Berk. and Rav.
- *F. oxysporum* Schlecht.

Among these, the predominant species in China was determined to be *F. graminearum* (*Gibberella zeae*), which represented 94.5% of the total samples.

Chen Hong-Kui and Ling Xun-yi (3) reported that *F. fusarioides*, *F. lateritium* and *F. oxysporum* var. *redolens* belonged to the low virulence group; they caused decay and sterility of floral organs, but could not induce the typical symptoms of head blight. Therefore, it is generally agreed that these types of species could not be regarded as scab-causing pathogens for wheat, and only ten *Fusarium* species with high and moderate virulence would be considered as causal organisms.

#### **Variations of *Gibberella zeae* (*Fusarium graminearum*)**

*Gibberella zeae* is one of the species with great variation, not only in cultural characters, but also in virulence. Xu Yong-gao (personal communication) studied four isolates of

*G. zeae*, collected from Mexico, Sri Lanka, Indonesia and China, and pointed out that there were remarkable differences among them. As compared with the Chinese isolate, the growth rate of the isolate from Sri Lanka was slower, aerial mycelia were sparse, the red pigment on the substrate was very dark and no macroconidia were produced on potato dextrose agar (PDA). The Mexican isolate was capable of producing macroconidia on PDA, but the formation of perithecia on wet sand was slower and the ascospores slightly longer. The Indonesian isolate was similar to the Chinese isolate, with the exception of growth rate.

The work by Li Qing-Xi and Wang Zhang-ming (10) indicated that differences in both cultural characteristics and virulence were found in most of 17 wild and cultured isolates of *G. zeae*, collected from different parts of Jiangsu province. A few of these isolates varied significantly after being transferred three times, i.e., the growth rate was reduced, the formation of conidia and septa either slowed, decreased or stopped altogether, perithecium production was sparse or absent and virulence was weakened.

Based on the results of testing 43 isolates collected from 27 provinces and cities on 20 wheat varieties, Xu Su-zhen and Lu Jin-tu (personal communication) showed that the isolates of *G. zeae* could also be divided into three types, high, moderate and low virulence. Xu Yong-gao and Fang Zhong-da (23) and other workers obtained the same results. Chen Hong-zao and Li Ke-chang (4) tested the virulence of the three types by inoculating 11 wheat varieties, and concluded that there was a specific relationship between isolate and wheat variety. Li Qing-xi and Wang Zhang-ming (9) pointed out that isolates of

*F. graminearum* from Jiangsu differed significantly in virulence, as did resistance of wheat varieties to *F. graminearum*, but interaction between the virulence of the pathogen and the resistance of the wheat variety was not present. Wang Yu-chung (14) confirmed that isolates of *F. graminearum* from Jiangsu differed significantly from one another in virulence, but that there was no significant difference in average virulence among isolates from different counties. Xu Yong-gao and Fang Zhang-da (23) further suggested that single ascospores isolated from a culture differed as to virulence, as did those from an ascus. Owing to the fact that the variation of *G. zeae* is very complicated, it has been difficult to classify the isolates of *G. zeae* in China into different physiological races.

Based on the comparative study of virulence of the four isolates collected from Mexico, Sri Lanka, Indonesia and China on 7 Chinese and 28 Mexican wheat varieties, Xu Yong-gao (personal communication) concluded that the Chinese isolate of *G. zeae* was more virulent than the Mexican isolate on both Chinese and Mexican varieties.

### **Resistance of Wheat Varieties to Scab**

#### **Types of resistance**

In the early 1960s, Schroeder and Christensen (11) and Takegami (12) reported that the resistance of wheat varieties could be divided into two types, based on whether the resistance was to initial infection or to the spread of the infection. Many Chinese pathologists have confirmed scab resistance to be to hyphal spreading within wheat, but there has not been agreement as to resistance to initial infection (15,23,27). Through field observations over many years, many Chinese workers have indicated that

the difference in the rate of disease spread within the spike when infected at the same flowering stage indicates the difference in resistance to initial infection. Twenty wheat varieties were tested for resistance to initial infection at the heading stage by keeping single spikelets moist for two days by spraying with a spore suspension. Xu Yong-gao (personal communication) found that the variety Zhen-mai 7495 showed a lower level of diseased heads (23 to 40%); the rest of the varieties reached 100%. It was suggested that Zhen-mai 7495 might be resistant to initial infection under certain conditions, but that it did not exhibit any resistance to initial infection in the flowering stage or after being kept moist for four days. Resistance to initial infection seemed to be affected by environment.

#### **Testing for resistance**

The following methods are generally used for testing resistance to wheat scab in China:

- Scattering diseased wheat grains on the soil surface—This method of inducing epidemics in the field is similar to natural conditions (19). The fields are kept moist by sprinkler irrigation.
- Dripping spore suspension into the floret—With a syringe, the fusarium spore suspension is dripped into a single floret in the middle of the spike (15,17,23). This method is precise and reliable, because the inocula can be applied quantitatively.
- Cutting the glume with scissors dipped in spore suspension—With this method, developed by Wang-Yu-chung and Yang Xin-ning (15), the inocula is introduced into one of the spikelets in the middle of a spike by cutting the glumes with scissors that have been dipped in the spore

suspension. This method has proved to be reliable in testing for resistance against hyphal spread.

- Spraying spore suspension on the flowering spikes—This method is used in testing for resistance either to initial infection or to hyphal spread.

It is very important that suitable moisture and temperature be maintained for all of the above methods of inoculation.

#### **Resistance assessment**

The method for assessing resistance using the rate of hyphal spread was developed by Takegami (12) and has been refined by a number of Chinese workers (4,9,13,23). The following scale of 1 to 5 would seem to be reasonable:

- 1 = disease restricted to infected spikelet; does not spread to spike axis
- 2 = disease spreads from infected spikelet to axis; does not invade parts near spikelet
- 3 = disease spreads along axis; invades nearby spikelets
- 4 = disease spreads to the head above the infected spikelet; upper part of head wilts
- 5 = disease spreads throughout the head; entire head wilts

These ratings do not represent the degree of resistance of a variety; they only reflect the course of disease development. The resistance of varieties can be assessed by the following reaction index:

- Resistant (R) (1 to 2 on the scale)
- Moderately resistant (MR) (2.1 to 3 on the scale)
- Moderately susceptible (MS) (3.1 to 4 on the scale)
- Susceptible (S) (4.1 to 5 on the scale)

The reactions of resistant (R) and susceptible (S) varieties are relatively stable and independent of the severity of the epidemic; however, the reaction index of MR and MS varieties varies with the epidemic conditions.

#### **Testing of varietal resistance to scab**

From 1974 to 1982, over 30,000 wheat varieties and materials were tested in the field by the cooperative research team led by the Shanghai Academy of Agricultural Sciences. The tested materials included 32,618 common wheats (varieties and lines), 1557 materials of rare species belonging to 21 races and 26 species of three related genera. The following conclusions were drawn:

- All of the materials tested were more or less affected by the disease, but differed greatly in degree.
- Among common wheats, there was a group of varieties with high and stable resistance, which always showed a lower percentage of infected spikelets and scabby heads and less disease spread along the axis. This was true for different years, different localities and under different epidemic conditions. The Chinese varieties, Su-mai 3, Wang-shui-bai and Nanjing 7840 all belong to this group of resistant varieties.
- Sources of resistance to wheat scab are distributed over various regions of the world where scab is endemic. The middle and lower reaches of the Yangtse River, which is one of the epidemic regions, has abundant sources of resistance to scab.
- Resistant and moderately resistant varieties were not found among the rare species of *Triticum* tested; however, some species of the genus, *Secale*, showed moderate resistance to scab.

### **Inheritance of resistance to scab**

Schroeder and Christensen (11) reported that the resistance of wheat to head scab was a quantitative character controlled by polygenes. In recent years, Chinese workers have also shown that resistance of wheat to colonization by *G. zeae* is controlled by polygenes (27). The resistance of  $F_1$ s tends to resemble the resistant parent, and exhibits obvious heterosis. Backcrossing with resistant parents tends to increase resistance. Xia Sui-shing, Zhou Chau-fei and Quia Cun-ming (personal communication) studied the inheritance of scab resistance in Su-mai 3 and Wang-shui-bai and obtained similar results. Yu Yu-jin (26) studied the inheritance of resistance of Su-mai 3 by monosomic analysis; results indicated that at least five pairs of genes which determine resistance to hyphal spread were located on chromosomes 1B, 2A, 5A, 6D and 7D.

Chen Chu-huo (2), using a 4 x 4 half-diallel scheme with two resistant and two susceptible parents to study the inheritance of resistance in wheat, suggested that Su-mai 3 and Wangzhou Hong-he-shang (Red Monk) might have more dominant genes for controlling resistance; they demonstrated high general combining ability for reducing the rate of diseased spikelets in their progenies. It appears that the inheritance of resistance to scab is mainly governed by additive genes, but non-additive genes also have a significant effect. The genes controlling resistance were partially dominant. It was found in diallel crosses that there was a significant positive correlation between resistance and plant height or spike length, and a significant negative correlation between resistance and spikelet density in  $F_2$  populations. Various workers have suggested that the heritability of resistance of wheat to scab is low.

### **Sources of resistance to scab**

The studies of the cooperative research team have demonstrated that sources of scab resistance come mainly from common wheats. Some Chinese varieties with high and stable resistance have been the best available sources of resistance among the world collection; the resistance in exotic varieties has not exceeded the resistance of these varieties. Su-mai 3 has been introduced into many countries of the world, and there has been no report that its resistance is equal to or better than local varieties in those countries. Nanjing 7840, a new source of resistance, is derived from crosses of (Aurora x Anhui 11)  $F_2$  x Su-mai 3, and many resistant varieties or lines with good agronomic characters have been derived from it (29).

Crosses between moderately resistant and susceptible varieties may yield hybrids with higher resistance than their parents. The well-known resistant variety Su-mai 3 was bred through the hybridization of the moderately susceptible varieties, Funo and Taiwan wheat. The crossing of the moderately resistant varieties, Jingzhou 1 and Su-mai 2, also produced progenies with high and stable resistance.

Some materials of the genus *Secale* are another source of resistance. Jingzhou 1 was derived from the hybrid of Nanda 2419 and Jingzhou rye. Jingzhou 66 (MS-MR) was derived from the combination (Funo x durum) (Nanda 2419 x rye). Jingzhou 1 has been adopted as a common parent in the breeding programs for resistance to scab in South China.

### **Epidemiology**

#### **Occurrence of scab disease in the field**

A rice-wheat cropping system is found in most of the regions of the middle and lower reaches of the Yangtse River. The initial inocula of scab usually comes from the perithecia on rice stubble.

How the pathogen oversummers and overwinters after the wheat harvest and how the perithecia reproduce are important factors for forecasting scab epidemics. Xu Run-cheng and Huang Zhen-xing (21) suggested that *G. zeae* can only survive for a short time under flooding; therefore, the organism cannot oversummer on the soil surface in paddies after rice has been harvested, although it can survive on the plant base, leaf sheaths and rice grains and then be transferred to the soil (5). Liang Xun-yi and Wang Qing-sheng (personal communication) have confirmed that the pathogen can oversummer on rice, on dry soil surfaces, on the shady side of piles of wheat straw and on the remains of wheat stems and grains scattered over the threshing ground, as well as on rice straw and withered rape stems in fields.

Research of the Hunan Agricultural College suggests that the pathogen affects not only wheat and barley, but also such crops as corn, sorghum and cotton. It may also infect weeds, such as *Cynodon dactylon* (L.) and Pers, and produces perithecia on the debris.

The Shanghai Academy of Agricultural Sciences (1975 to 1977) and the Suzhou Institute of Agricultural Sciences (1977 and 1980) made a series of observations on the dissemination of mature ascospores. The results indicated that aerial ascospores could be trapped throughout the year. This indicates that infected rice stubble, grains and wheat debris remaining in fields and aerial ascospores which have fallen on the soil are all sources of inoculum, causing perithecia formation on rice stubble early in the spring. The pathogen overwinters as mycelia on rice stubble.

Ye Hua-zhi (24) studied the biology of *G. zeae* and showed that the temperature for perithecial formation ranged from 5 to 35°C and, for ascospore production, 13 to 33°C, with an optimum of 25 to 28°C. The

discharge of ascospores is controlled by moisture and precipitation. The number of ascospores released is greater at night (8 p.m. to 8 a.m.) than by day (8 a.m. to 8 p.m.), and is greater on rainy days. The peak for spore discharge is from 10 p.m. to 8 a.m. and, more specifically, from midnight to 6 a.m. Germination of ascospores occurs at 4 to 35°C, with an optimum of 25 to 28°C. Germination percentage may reach more than 90% within 4 to 8 hours at a temperature of 25 to 30°C. The ascospore can germinate without free water, but germination is markedly inhibited when relative humidity is low; it doesn't occur below 81%.

#### Forecasting

Various mathematical models have been established in China for forecasting scab epidemics over different areas. The best is the one proposed by the workers in Hubei Province (6). After having qualitatively analyzed the key factors causing epidemics, and having quantitatively defined the relationship between the degree of epidemic and the key meteorological factors in Guangji County over a period of 21 years, the cooperative group suggested that epidemics depend on the interaction of the pathogen and the host with four meteorological factors, rainfall (R), days of rain (Rd), relative humidity (Rh), and sunlight hours (S). The statistical model for calculating the incidence of disease was established as:

$$Y = [\sin (47.72 \lg Q - 33.64)], \text{ where } Q = RRdRh/S$$

This indicates that the outbreak of epidemics varies according to climatic and atmospheric conditions, but these meteorological factors can be utilized to forecast epidemics for a province or for a certain area.

From 1975 to 1981, short-term forecasting of scab epidemics was done by the Shanghai Academy of

Agricultural Sciences, through the statistical analysis of the relationship among meteorological factors, the number of ascospores present on wheat heads at the milk stage and the preliminary incidence of the disease. Satisfactory results were obtained with this program.

#### **Integrated control of scab**

A reasonable strategy for the integrated control of scab should involve the utilization of resistant varieties, proper cultural practices and the application of chemicals in the critical growth stage.

In the early 1950s, many resistant varieties, such as Wan-nan 2, E-mail 6, Hua-zhong 2133, Xiang-mai 1, Zhen-mai 7495, Jingzhou 1 and Jingzhou 66 were bred and released. In recent years, still more resistant varieties with good agronomic characters, such as Yangmai 4, Nanjing 8017 and Nanjing 8026, have been released.

In the beginning of the 1970s, many workers reported that Benzimidazole (BMZ) was an efficient systemic chemical for controlling wheat scab. Since 1978, a series of rapid and efficient techniques have been developed, such as those of the Jiangsu Academy of Agricultural Sciences (15,16), to improve the effects of BMZ. These include the use of a BMZ-suspensoid, soluble agent, which is a micronized powder, instead of wettable powder. Also, a new type of atomizer has been produced to change the application of the chemical from high volume to low, and the spray from fine to atomized. This increases chemical coverage and enhances adhesion to the wheat heads to prevent its being washed off by rain.

This combination of new resistant varieties and new methods of applying fungicide has brought the level of integrated control to a new high.

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## Reflections on Foot Rots of Wheat in Warmer, Nontraditional Wheat-Growing Climates

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### Abstract

*Information is presented on Sclerotium rolfsii, Rhizoctonia solani, and Helminthosporium sativum foot rots in warmer areas. It is noted that the facultative nature of most foot rot pathogens may facilitate their moving from rotation crops to wheat in tropical areas. Effective control may require the integration of breeding for resistance or tolerance, appropriate agronomic practices and chemical or biological control.*

The introduction of wheat as a possible commercial crop in warmer or tropical climates has been increasing in recent years (8). The difficulty of achieving economic yields should not be underestimated; there are a myriad of problems inherent in transposing a temperate climate crop to tropical areas. One of the principal problems will be the unique diseases encountered in these nontraditional areas and how to control them.

Foot rot is one of the diseases of wheat that may have to be confronted and controlled in subtropical or tropical areas. Wheat scientists must be aware of the type of pathogens they are dealing with, and that the ecological or host-pathogen relationships in the hotter, humid areas may be quite different from those prevailing in temperate climates. An exhaustive review of the literature of foot rots of wheat in the tropics is not presented; indeed, very little published information exists. What little is cited shall serve only as examples.

Fungal pathogens constitute the focus of this paper, with some mention also made of nematode diseases, since they may be of some importance. However, it should be noted that bacteria, viruses and related organisms could become problems also. The fungal organisms causing foot rots are, without exception,

facultative parasites that spend most of their life cycles as saprophytes in the soil or on plant debris. Plant parasitic nematodes generally are obligate parasites that feed and reproduce only on their living hosts. Nevertheless, although they are obligate parasites, in many cases they do not appear to have developed high levels of pathogenic specificity, and so often the same species can attack many diverse types of plant hosts (10).

As noted, fungal facultative parasites primarily exist as saprophytes and become parasitic when the appropriate conditions are met. These parasites have a minimum of pathogenic specialization and probably have evolved to a level of species compatibility, rather than cultivar specificity or compatibility (5). Since they are not as fastidious as the fungal obligate parasites, they may, if given the opportunity, become parasitic on a nontraditional crop when it is introduced into an area. It can be expected that cropping patterns and husbandry practices may have an important impact on foot rots of wheat. Diseases of rice and soybeans, for example, might be important on wheat, and vice versa. This would also hold true for the facultative, foliar pathogens. This must be kept in mind when considering present foot rot problems, diseases of potential importance in the future and suggested control strategies.

### Documented Foot Rot Diseases in Warmer Climates

Based on personal observations, discussions with colleagues and searches of the literature, there is little doubt that the main wheat foot rot pathogen in tropical areas at present is *Sclerotium rolfsii* Sacc.; reports from southern India, as well as from Brazil, have been published (6,7). *S. rolfsii* has been observed on wheat in Ecuador, Peru and Bolivia, and it has been noted in many countries of Southeast Asia (E.E. Saari, personal communication). *Sclerotium rolfsii* is an omnivorous, soil-inhabiting organism with worldwide distribution, attacking more than 500 species in over 100 plant families (2). It survives as sclerotia in the soil for long periods of time and, although the organism has been the object of a great deal of research, few control measures exist other than rather costly chemical treatments (2). Due to its polyphagous nature and longevity in the soil, this organism will be difficult to control without chemical means.

*Rhizoctonia solani* Kuhn is another widespread soil pathogen that has been observed on wheat in the semitropical areas of Brazil (7). As wheat is tested and grown in warmer areas, and as pathologists begin making more intensive observations, *R. solani* will surely become more obvious. Better progress has been made in breeding for resistance to *R. solani* than to *S. rolfsii* but, overall, resistance breeding has not been very successful. One reason may be that *R. solani* is made up of genetically distinct groups and, thus, *R. solani* is not a single species but consists of diverse populations that may be recognized through anastomosis grouping (1). As more pathologists and breeders take this into consideration, progress may be made in breeding for disease resistance.

*Helminthosporium sativum* P.K. and B. causes a severe foot rot problem in many areas of Brazil (7). Up to now, major efforts in more tropical areas have dealt with the foliar disease caused by *H. sativum*, but closer examination of roots and crowns may indicate the presence of the foot rot phase of this organism as well.

The above examples point to some of the foot rot organisms that pathologists and breeders will have to deal with in different areas. The foot rots are caused by some of the most difficult pathogens to control in temperate climates. Due to suboptimal growth conditions for the host, coupled with optimal conditions for the pathogens in tropical areas, the achievement of economic control measures may be difficult to obtain.

### Diseases of Possible Importance in the Future

Based on the nature of the foot rot organism, pathogens that attack rotation crops may become problems in wheat. Two examples may be sufficient to illustrate this point. Recently, *R. oryzae-sativae* Sawada has increased in severity and incidence on rice in California; there is an apparent correlation between this and the increased use of semidwarf cultivars (4). Three factors might indicate the possible importance of an *R. oryzae-sativae*-type organism in tropical areas. First, wheat-rice rotations will be important; second, the organism is adapted to warm climates and, third, it attacks many hosts. Thus it not only might attack wheat, but could become increasingly important on rice.

A second example is related to a wheat-soybean rotation in Indiana where *Gaeumannomyces graminis* (Sacc.) Arx and Oliv., normally infecting wheat and grasses, was isolated from

immature, field-grown pods of six soybean cultivars. The soybean isolates were able to produce typical take-all symptoms on wheat roots and stems. This could have a significant effect on take-all disease in that area (9).

In regard to nematodes, examples of possible pathogens might be the root knot nematodes, *Meloidogyne* spp., and the cyst nematodes, *Heterodera* spp., both of which occur on cereals, including rice, in warmer climates (3, 10). Once again, the introduction of wheat into an area may provide an appropriate host for these or other nematodes.

These are only a few examples of the possible disease syndromes that could occur. However, many groups of soil fungi might become relatively more important in warmer climates as, for example, the fusaria and the water molds.

### **Possible Avenues of Control**

As better understanding of the epidemiology and genetics of foot rot organisms is achieved, resistance and tolerance will become more useful tools for breeders. When dealing with more tropical conditions, obtaining adequate resistance or tolerance becomes even more elusive due to the predisposition of the host in those climates. It is probable that, for a long time to come, an integration of resistance or tolerance, appropriate husbandry practices and chemical or biological control will be critical to procuring adequate, economical control measures of foot rot organisms. Breeders and pathologists should be aware that, in

some warmer areas, it may be impossible to obtain high levels of disease control, due to the nature of the environment and the condition of the host.

However, there is no need for pessimism either; a possible scenario for attaining adequate control of *S. rolfii* can be used as an example. To date, some progress has been made in southern India with chemical seed treatments, such as Carboxin, PCNB and Guatazine, for controlling *S. rolfii* through the seedling stage (6). These seed treatments have a dual advantage since they also control loose smut and common bunt. The next step might be to find some level of resistance or tolerance in wheat that would increase the level of control. Mechanical resistance has been found in *Lycopersicon pimpinellifolium* where, after six weeks, phellem development prevents penetration of *S. rolfii* (2). Perhaps analogous types of resistance could be found in wheat or related genera. Finally, a multipronged attack might include planting rotation crops that reduce sclerotial formation, or PCNB might be applied to the soil to reduce inoculum potential. The point to keep in mind is that no single control measure may be adequate. To have the best chance of success, pathology and breeding will have to be fully integrated.

Although the literature is meager relating to foot rots, some examples of foot rot organisms have been presented that are problems at this time, as well as others that could become problems, with the hope of making breeders and pathologists aware of the greater complexity of controlling facultative parasites in tropical areas as compared to temperate zones. Control methodologies may also have to be more complex, and levels of control may never approach immunity.

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## A Review of Major Wheat Diseases in Tropical Environments

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### Abstract

*The major wheat diseases in tropical environments are not always the same as those of temperate environments. In the warm and humid tropics, the major diseases are leaf rust (Puccinia recondita), leaf spots (Helminthosporium sativum, H. tritici-repentis, H. giganteum and Fusarium nivale), root rot and seedling blights (H. sativum, Fusarium spp., Rhizoctonia spp., Sclerotium rolfsii and Phytium spp.), head scab (Fusarium spp.) and loose smut (Ustilago spp.). Less common diseases are downy mildew (Sclerophthora macrospora), bacterial diseases (Xanthomonas campestris) and barley yellow dwarf (BYD). Karnal bunt (Neovossia indica) has not been reported.*

Traditionally, wheat cultivation has been confined to the more temperate climatic areas of the world, and the diseases which attack the crop in these traditional wheat areas are well known and fairly well documented. Recently, interest has grown in producing wheat in the warmer and more humid tropical areas, where it is grown during the cooler part of the year and often in rotation with rice or maize. While it is recognized that yields equal to those in the more traditional areas cannot be attained, wheat appears to be a viable alternative crop for some countries in the tropics. These countries are found in Southeast Asia, Western Africa, Southern Africa, Central America and parts of South America. However, when wheat is promoted in these regions, a number of problems appear that can limit the introduction and/or production of wheat.

Diseases are often a major constraint, particularly in the warm and humid areas. When speaking of the tropics, one often visualizes warm and wet conditions; there are, however, also areas of the tropics where the environment can be classified as warm and dry. In these areas, such as Sudan and Nigeria, diseases are not a problem.

However, with expanding areas under wheat, it is expected that diseases will become more of a problem in the future.

In the warm and humid areas of the tropics, diseases play a major role in determining whether wheat can be successfully grown. The major diseases in those areas are leaf rust, leaf spots, root rots and head scab.

Leaf rust, caused by *Puccinia recondita*, is by far the most important of the rust diseases in the tropics. Stem rust is seldom seen, and stripe rust only in the highlands and cooler areas. In Southeast Asia, leaf rust is found in most countries, but usually attacking only the older cultivars, indicating that the races of the pathogen are primitive and that adequate resistance is available. However, as the area under wheat cultivation expands, it is possible and probable that races with additional virulence will begin to appear. The epidemiology of the rusts in the tropics is not well understood but, if they behave as they do in the more temperate regions, arrival of more virulent inoculum can be expected. When the virulence of the leaf rust populations in India and Bangladesh are examined, it is found that only a few of the major genes are effective

against leaf rust by themselves, indicating a potential danger to Southeast Asia, as the subcontinent is the build-up area.

The major leaf spot of wheat in the warm and humid tropics is caused by *Helminthosporium sativum* and is currently found in almost all of the areas of the tropics where wheat is being grown or introduced. This organism can attack many members of the *Gramineae* family. The role of inoculum build-up on collateral hosts needs to be investigated further. Resistance is available, but it is not as clear-cut as in the rusts. Several of the papers being presented here will deal with this subject. Resistance to this disease will be necessary, possibly supplemented by fungicides, before successful wheat cultivation can be attained in many tropical areas. Several other fungi, such as *H. tritici-repentis*, *H. giganteum* and *Fusarium nivale* are also found to be causing leaf spots in wheat. Many of these pathogens are seed-borne or survive and multiply on crop debris in the soil.

Root rots and seedling blights caused by *H. sativum*, several *Fusarium* spp., *Rhizoctonia* spp., *Sclerotium rolfsii* and *Phythium* spp. are more often found in the tropical environments than in the more traditional wheat areas. More investigation into seed treatment fungicides, along with substantial improvement in resistance screening research, is needed. Again, several papers in the following sessions will deal with this topic. However, there must be an awareness of this group of diseases and their potential in the warm and humid areas of the tropics.

Head scab is caused by several species of the fungal genus, *Fusarium*. It is considered severe in southern China, parts of Brazil, Zambia and most countries of the warm and humid tropics. Losses can be total in very bad years, rendering the grain produced

unsafe for consumption. No highly resistant cultivars are in commercial production, but a number of cultivars have moderate resistance. Major cooperative research programs are underway between Brazil, China and CIMMYT.

Loose smut may pose a threat to future advances of wheat if proper seed-testing treatment and production procedures are not followed.

Karnal bunt is presently not found in the warm and humid tropics, but is confined to the Indian subcontinent and to Mexico. More research is necessary to ascertain whether the organism *Nevossia indica* could survive under the warm and humid conditions of the tropics. India and Pakistan, as well as CIMMYT, have major research programs searching for resistance, as well as determining effective chemical control measures.

Downy mildew can be a localized problem whenever management practices allow water to stand in wheat fields; it should be watched.

Bacterial diseases such as those caused by *Xanthomonas campestris* can be a problem when wheat is grown under warm, wet and humid conditions. However, the use of clean seed and good management practices can minimize losses.

Barley yellow dwarf virus (BYDV) has the potential to cause serious problems in the tropics. Barley yellow dwarf is an aphid-transmitted disease found in most wheat-growing countries. Resistance in wheat and chemical control of the vector are the principal means of control.

In summary, the better-known diseases of wheat in the more traditional areas of wheat cultivation are not always the most important diseases in tropical environments. Disease research has

been centered in the traditional wheat areas; consequently, very little is known about wheat diseases in the warm and humid tropics and much more research is necessary.

## **Distribution and Importance of Root Rot Diseases of Wheat, Barley and Triticale in South and Southeast Asia**

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### **Abstract**

*Wheat and barley are cultivated under a wide range of environments in South Asia, and the climates vary from temperate to tropical. In Southeast Asia, wheat, barley and triticale are experimental crops. There are a number of rotations involved, as cropping intensities are generally greater than one crop in both South and Southeast Asia. The influence of environment and cropping system has a pronounced effect on soil-borne diseases, with a number of common pre-emergence and post-emergence diseases reported; a few unique soil-borne diseases are found in the more tropical environments. Most of the research on soil-borne diseases has been descriptive; there is relatively little information on either losses or control.*

Wheat and barley are traditional crops in the South Asian countries of Pakistan, India and Nepal. The climatic conditions in these countries vary widely, depending upon latitude and altitude. The majority of the acreage, however, is cultivated on the plains of northern India and Pakistan, and on the plains of Nepal bordering on India. There is a small area cultivated in the mountainous areas of all three countries, and some acreage in central and southern India which can be classified as subtropical to tropical.

The cultivation of wheat has been expanding into new areas in the past 15 years (9). The most notable increase in acreage has been in Bangladesh, southern and eastern India and, more recently, Burma. There has been an increasing awareness and interest in the possibilities of wheat cultivation in the countries of Southeast Asia as well. Wheat as a possible crop in these nontraditional areas has developed mainly as a result of the closing gap in the production of the basic food crop, rice. The growing level of wheat consumption and imports, with its implications for foreign exchange, is also contributing to the question of wheat cultivation. There is interest in

the possible cultivation of wheat for crop diversification and intensification during the dry season in these areas.

The climate of South and Southeast Asia is typified by a monsoon season. The duration of the rainy season varies, depending upon several factors, but it is characterized by high rainfall, humidity and warm temperatures. Rice is the main crop in the lowlands or wherever water can be contained for a flooded paddy. In well-drained soils, numerous upland crops are available. The monsoon season is generally followed by a drier, cooler season. The dry period is defined as those months with less than 100 mm of precipitation. The average temperatures are the coolest during this period of the year, and relative humidity is lower. In the northern hemisphere, December and January are generally the coolest and driest months.

Historically, few crops have been cultivated during this period, unless irrigation is available. In areas with limited irrigation, vegetable crops or other high cash-value crops are generally grown. Where irrigation is

readily available, a number of crops are possible. If temperatures are mild, an additional rice crop may be grown or, in cooler regions, an irrigated wheat crop can be sown. The rainfed areas are not cultivated in many instances, although the soil moisture situation is often saturated or at field capacity after the rainy season crop is harvested. There are some farmers who broadcast a short-cycle crop, such as mungbean, to utilize residual moisture.

The cropping patterns, climate and agronomic practices involved have a profound effect on soils and their microbiology. This combination of factors also has a strong influence on disease-causing organisms. Organic matter decomposes rapidly during the monsoon period, so crop debris produced in the dry season does not serve as a source of inoculum for the following wheat, barley or triticale crop. Paddy rice cultivation creates an anaerobic situation, and the flooded condition is detrimental to the survival of most plant pathogens. The cultivation of another crop species in the monsoon season constitutes a rotation, which generally reduces inoculum of disease-causing organisms, unless that organism has the capacity to cause disease in both crop species.

The disease surveillance programs conducted in Pakistan, India, Nepal and Bangladesh have recorded most of the known diseases of wheat, barley and triticale (5,10,13,18,25,28). The soil-borne diseases have been considered as minor in relative importance compared to the other commonly occurring diseases. There are occasional fields which are seriously affected, but overall economic losses have not been established except for some notable exceptions.

At the higher elevations, and in remote areas where chemical seed treatment is not feasible, the soil-borne bunts (*Tilletia* spp.) can be serious diseases of wheat. Flag smut (*Urocystis agropyri*) is soil-borne and endemic in the northern plains of Pakistan and India, and the cultivation of susceptible varieties has brought about an increase in the frequency of this disease (10). Karnal bunt (*Neovossia indica*) has become much more prevalent in the past few years in these areas (12). The dramatic increase in this disease probably reflects a combination of factors. Most of the new varieties released during the past decade are considered highly susceptible. The spread of the wheat-rice rotation may also be a factor that has contributed to the current increase in disease prevalence. There are also several nematodes reported, but *Heterodera avenae* (*Globodera* spp.), the oat cyst nematode, is the most serious.

In the tropical and subtropical environments of Southeast Asia, wheat, barley and triticale are not grown commercially. The introduction of these three species into the cropping system has been primarily experimental. The higher mean temperature and relative humidity changes the relative importance of some of the diseases, as compared to the semi-temperate areas of South Asia (3,4,8,24).

### **Foliar Diseases in More Tropical Environments**

Leaf rust of wheat (*Puccinia recondita*) has been observed, but only on older varieties known to have little or no resistance. Consequently, it appears that primitive race forms must be coming from some grasses and that, with the expansion of wheat cultivation, new virulences undoubtedly will arise which can attack the cultivated varieties. No leaf rust on barley or triticale has been observed.

Surprisingly, little or no stem rust (*P. graminis*) has been recorded, although the environment must be considered ideal for the disease (4,24).

Helminthosporium leaf blight (*Helminthosporium sativum*), also known as *Bipolaris sorokiniana* and *Drechslera sorokiniana*, with the perfect stage *Cochliobolus sativus*, is a serious and sometime limiting factor to wheat and barley cultivation in tropical environments. Severe leaf blight, spike and seed infections are common (4,8,14,17).

### Soil-borne Diseases

In Southeast Asia, the soil-borne diseases of upland crops can be divided into pre and post-emergence diseases, damping off and root and stem rots (19). A survey by the International Rice Research Institute in the Philippines of disease problems of upland crops sown after wetland rice indicates that specialized pathogens are suppressed by flooding, rotation and certain tillage operations. The unspecialized pathogens with a wide host range, such as *Sclerotium rolfsii*, *Pythium* spp. and *Rhizoctonia solani* (19,28), are provided an advantage and become important pathogens in the system.

Observations from experimental plots of wheat, barley and triticale in farmers' fields suggests that the main damping off and root or stem rot-causing organisms are *Sclerotium rolfsii*, *Helminthosporium sativum* and *Fusarium* spp. (3,4,14,24, personal observation).

*S. rolfsii* predominates in the heavier soils of the paddy rice-wheat, barley or triticale rotation (9,27). Warm temperatures and high moisture conditions are associated with the establishment of the disease. Infection occurs at all stages of plant growth, or at least the death of plants can occur at

any stage of development (27). Drought stress often results in premature death and numerous "white heads" in the field. These probably reflect incipient infections which are manifested by the drought stress. The post-damping-off stage is easily recognizable, and occurs commonly in the rice-based rotation. The establishment of a proper plant population is often affected. Information on pre-emergence damping off in wheat is not readily available.

Roots and crowns of infected plants are usually covered with a fluffy white mycelium and, if the surface of the soil is damp, mycelium will radiate out from the stem on the surface of the soil. Sclerotial bodies form readily on the surface of the plant tissue and even on the soil surface. Young sclerotia are white in color and darken to brown-black with age. The fungus survives either on alternative host species or as sclerotial bodies in the soil.

There are numerous species of helminthosporium in Asia, and several are reported to be pathogens of wheat (20). The species *Helminthosporium sativum* appears to be the predominant pathogen in South and Southeast Asia on wheat, barley and triticale. On numerous isolations from leaf samples from the tropical and subtropical areas of Southeast Asia, *H. sativum* has been identified in more than 90% of the samples; many grass species are also hosts for *H. sativum* (8,17, E.E. Saari, unpublished data).

Helminthosporium leaf blight is a serious disease of wheat, barley and, to a lesser extent, triticale (3,4,8,14). The disease can be sufficiently severe in areas with high relative humidity that it becomes a limiting factor to the cultivation of wheat and barley; temperature also seems to play an important role in the case of wheat (21).

At higher altitudes or latitudes, where minimum temperatures are cooler, wheat becomes less susceptible than barley.

The amount of spike or kernel infection by *H. sativum* in the tropics can be significant. If severe leaf infection is present and some rain occurs after heading, the percentage of grain infection may exceed 50% (personal observation). This high level of kernel infection has major implications on seedling blight or damping off if the grain is used for seed. Both pre and post-emergence damping off will be at a high level, and root infections, which can lead to dryland foot rot, will also be present. In lighter soil areas and upland cropping sites, *H. sativum* can be readily identified from the roots of unhealthy plants and dead plants that have white heads. *Helminthosporium* as the cause of damping off and root rots in wheat and barley has been established, but the extent of losses caused by *H. sativum* as compared to other root diseases is not known.

The *Fusarium* spp. are known to cause seedling blights and root rots of small grain cereals wherever wheat or barley is cultivated, and it has also been identified as a root rot of wheat and barley in the nontraditional areas of Southeast Asia (3,4). *Fusarium* is found more commonly in the upland rotations, particularly with maize. The rotation of maize with wheat and barley is known to favor *Fusarium graminearum* (*Gibberella zeae*). In areas with high humidity or rain at heading time, the presence of head scab disease is often a serious problem. The situation in Southeast Asia is different in that heading occurs at the driest period, which often approaches drought conditions; consequently, scab has not been of importance except at high altitudes where rain occurs (E.E. Saari, unpublished data).

There are three species of *Fusarium* reported, *F. graminearum*, *F. culmorum* and *F. moniliformi* (3,4); in one report, *F. moniliformi* was the fungus most frequently isolated from root samples (3). Other fungi have been reported, but their pathogenic capacities have not been established.

The role of nematodes and their possible synergistic effects on root rots have not been examined. The rice flooded conditions are known to be detrimental to plant pathogenic nematodes, but the upland situation is different. The addition of one crop sown immediately after the harvest of another provides a bridge in some cases and a possible break crop for others. Two reports involving nematodes from Thailand identified root knot (*Meloidogyne* spp.) and stubby root (*Paratrichodorus* spp.) nematodes at levels high enough to cause damage to cereal crops (4, D. Saunders, unpublished data).

### **Disease Control Possibilities**

#### **Resistant varieties**

The development of resistant varieties would be the ideal solution for control; however, the resistance to root rots caused by *S. rolfsii*, *H. sativum* and *Fusarium* spp. in wheat, barley and triticale is not clear (4,14). Observations by the author and others suggest that resistance to *S. rolfsii* probably does not exist, at least in a readily usable form. Differences in relative susceptibility does occur between bread wheat and barley (4); barley seems far more susceptible, according to preliminary observations. Triticale has not been tested to the same degree, so the relative differences have not been established.

There are reported differences in resistance to *H. sativum* in the foilar phase of the disease (1,4,14). Wheat appears to be more tolerant than barley and even resistant at cooler

temperatures, but this difference is vastly reduced in the humid tropics. Differences in resistance in the bread wheats are perceivable, but are small under such conditions (4,14). The possible use and value of this difference needs further evaluation. It is possible that the resistance in barley to *H. sativum* may also disappear in the humid tropics, but this subject has not received sufficient attention. Triticale seems to have a greater degree of resistance, but it has not been tested as extensively as the bread wheats. The durum wheats appear not to be well adapted, and so have received little attention in the tropical environments. These differences recorded in resistance to the foliar phase of the disease may or may not apply to the seedling blight and root rot phase. No comparative work has been done on this subject in these environments, but there is some evidence that tolerance and degrees of resistance to the root-attacking phase is operative from temperate environments (26).

The inoculum potential of *H. sativum* in tropical environments is severe, and it is found in abundance on numerous grass species (4,8,14,17). The role of inoculum potential in overcoming resistance in temperate climates has been described (26) and, obviously, also will be an important factor in tropical environments.

Information on the possible resistance to fusarium root rots is limited (26), and there is none currently available for tropical environments. The prospects for resistant or tolerant varieties appears to be limited.

#### **Agronomic practices**

There are no established cultural practices that can be recommended with confidence at this time for limiting seedling blights or root rots in tropical environments. A number of possibilities exist, but they require careful evaluation. For example, *S. rolfstii* is

favoured in saturated soil-moisture conditions. Even small differences in drainage and root aeration appear to have major effects on the growth and health of wheat and barley. There is a question of whether sowing on ridges might be beneficial to reducing root rots. It has been observed that wide-row spacing has an effect on the development of the foliar phase of *H. sativum*, but it is not known if this has a carry-over effect on the root rot phase. The implications of weed control, soil tillage, ridging, sowing depth, date of sowing, irrigation practices, rotation and no-tillage have not been critically evaluated, although field observations suggest they may be extremely important in certain root disease situations (6,7,11,23).

#### **Chemical control**

Limited information is available on the effectiveness of chemical treatments on root rots and seedling blights in more tropical environments. An initial evaluation on fungicide treatment made in 1984 at Central Luzon State University in the Philippines was of limited success. Seed treatment reduced infections by 53% over the control plots, but the level of infection was still high in the treated plots (27). The use of systemic fungicides or ones with a greater fungal specificity may provide better control (2,22).

A seed treatment combined with one, or possibly two, foliar applications, to provide control of soil and seed-borne pathogens and to reduce the foliar disease-infection phase, appears to have merit (4,16). Its combination with agronomic practices to reduce predisposition of wheat and barley to root diseases could further enhance the effectiveness of chemical seed and foliar treatments.

The development of resistant varieties is a possibility for the future. Even a small degree of resistance combined with proper agronomic practices and critical chemical treatments could have major effects on reducing seedling blights and root rots. The combined effort could also have an effect on the other disease phases which have been mentioned here.

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## Chemical Control Measures for the Major Diseases of Wheat, with Special Attention to Spot Blotch

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### Abstract

*Spot blotch, rusts, and scab are some of the most important diseases in many tropical countries. Frequently, more than one disease appears at the same time. Success in chemical control of a disease complex depends on the use of an appropriate spraying schedule which takes into consideration 1) appropriate fungicide and dosage for the diseases and the variety in question, 2) time of first spraying, 3) number of sprayings and 4) the interval between sprayings. For a disease complex, Maneb or Mancozeb should always be used in a fungicidal mixture. Spot blotch is well controlled by three to four applications of Maneb or Mancozeb or three applications of Propiconazole.*

Although yields by some farmers in tropical areas, and more particularly in Latin American countries, exceed 3,000 kg per hectare, the average yields during the past ten years have varied between 1,000 and 1,200 kg/ha. The primary causes of such low yields are probably adverse climatic conditions and severe disease epidemics.

One of the major problems for wheat production in most tropical countries is the severe disease complex. Such a disease complex may include major diseases like leaf rust (*Puccinia recondita* Rob. ex Desm.) spot blotch (*Bipolaris sorokiniana* Sacc. ex. Sorokin, syn. *Helminthosporium sativum* P. K. and B.), and head blight or scab (*Fusarium graminearum*) Schwabe (*Gibberella zeae* (Schw.) Petch. These diseases can be controlled by the use of resistant varieties; nevertheless, until resistant varieties are available, chemical control should receive due priority.

At present, there are more than 20 different fungicides available for the major wheat diseases, and new ones are constantly being introduced into the

market. When considering fungicide use, economic aspects must be taken into consideration. The success of chemical control depends mainly on an appropriate spraying schedule, and consideration must be given to 1) appropriate fungicide and dosage for the disease and the variety in question, 2) time of first spraying, 3) number of sprayings and 4) the interval between sprayings.

An appropriate spraying schedule has been established for Brazil and Paraguay, and it is being used with good success; the schedule needs to be further established on a regional basis. However, considering the common disease complex problem among Latin American countries, the existing spraying schedule can be used in other countries with some modifications, if necessary.

### Fungicides and Dosage

Fungicides are normally selected and recommended as a result of yield differences between treated plots and check plots. During the past several years, more than 30 fungicides with different active ingredients have been tested on the most popular varieties in Brazil, either alone or in combination.

According to a new criterion established for the selection and recommendation of fungicides for foliar diseases, a fungicide that does not maintain the infection level at less than 50% at growth stage DC (decimal code) 83 (2) is not selected or recommended for the disease in question. All fungicides selected, using this criterion, have led to statistically higher yields as compared to check plots.

The degree of efficiency of a particular fungicide depends on the cultivar. Contact fungicides are less expensive but are also less efficient than systemic fungicides and, for this reason, they should be used for less susceptible or slow-rusting cultivars. Systemic fungicides, on the other hand, should be used on fully susceptible cultivars, to obtain reasonably good disease control and guarantee economic returns. Among the systemic fungicides, the most efficient ones for leaf rust are Triadimefon and Propiconazole; they also give some protection against stem rust (Table 1). For spot blotch, there are only a few fungicides which offer reasonably good control, i.e., Maneb, Mancozeb and Propiconazole. The efficiency of Propiconazole (1.0 lt/ha) against spot blotch has also been seen in some experiments.

The efficiency of Maneb and Mancozeb as protection against several fungal diseases has long been known. Experimental data from the past several years indicate that three to four applications with one of these fungicides give good control of spot blotch. A fungicidal trial against spot blotch was conducted in 1983, to confirm once again the efficiency of some Dithiocarbamates and some new systemic fungicides. Propiconazole at a reduced rate (0.5 lt/ha) was still effective, but not superior to Maneb or Mancozeb. However, it is gaining in importance, since it also offers good control for other diseases, such as powdery mildew, septoria and leaf rust.

Therefore, it has been concluded that propiconazole should only be used when more than one foliar disease is present. When only spot blotch is present, Maneb or Mancozeb alone give good results.

Scab is another important disease in Latin America. Existing varieties are susceptible, and chemical control measures have not been efficient. It is believed that fungicides of the Benzimidazol group are the only ones effective against scab. Detailed studies on the chemical control of this disease were carried out, but showed no clear evidence of any efficiency difference between Methyl Thiofanate, Thiabendazol and Benomil; the tentative conclusion is that none of these fungicides are highly efficient against scab. Sensitivity monitoring of the fungal populations for resistant strains needs to be carried out.

#### **Time of first spraying**

The timing of the first spray application is of primordial importance in the spraying schedule. Under normal conditions, the disease epidemic starts 45 to 55 days after sowing, at least under Brazilian and Paraguayan conditions. The first spraying should be done soon after the first appearance of disease symptoms. It is recommended that, for early-maturing cultivars (such as Anahuac and Cocoraque), the first spraying should take place 45 to 55 days after sowing and, for medium or late maturing ones (such as Alondra 4546 and PAT7219), 50 to 55 days after sowing. If the disease epidemic only starts 80 days after sowing, then the first spraying should be done then and not before. If an interval of 15 days between sprayings is maintained, initiating the spraying at 45 to 55 days after sowing will protect the crop up to the soft dough stage. After that, it is not necessary to control leaf diseases, since yield losses will be almost negligible.

**Table 1. Fungicides and spraying schedule for control of the major wheat diseases, Brazil**

<b>Fungicide</b>	<b>Mode of action<sup>a/</sup></b>	<b>Dosage (kg or lt/ha)</b>
<b>Application no. 1</b> (45-55 days after sowing)		
One of the following:		
Chlorothalonil	C	2.5
Maneb or Mancozeb	C	2.5
Propiconazole	S	0.5
Propineb	C	2.5
Pyracarbolide +Maneb	S + C	1.5 + 2.5
Triadimefon	S	0.5
Triforine	S	1.5
Triphenyltin acetate	C	2.0
<b>Application no. 2</b> (15 days later)		
Any of the above fungicides and dosages		
<b>Application no. 3</b> (15 days after the second)		
One of the above fungicides plus one of the following fungicides to control scab:		
Benomyl	S	0.5
Carbendazin	S	0.5
Thiabendazin	S	0.5
Thiophanate-methyl	S	0.5

<sup>a/</sup> C = contact, S = systemic

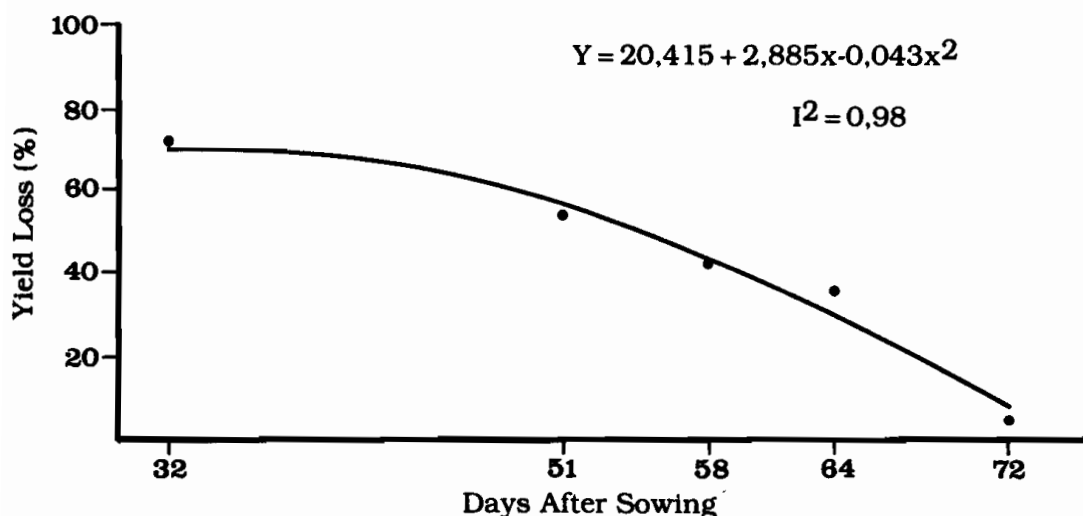
**Note:** Powdery mildew is not of general occurrence and is not considered important. However, under conditions favorable for the disease, one of the following fungicides should be added in the second application: Ethirimol (1.0 lt/ha), Pyrazophos (1.0 lt/ha), Oxythioquinox (0.5 lt/ha) or Tridemorph (0.5 lt/ha). Use of these fungicides is not necessary if Propiconazole or Triadimefon is used in the second application.

Loss in yield is directly proportional to the time when the epidemic starts. Yield losses of the cultivar Jupateco were assessed by controlling the start of the epidemic, using appropriate fungicides. When the epidemic started as early as 30 days after sowing, loss in yield was 70%; when the epidemic started 51, 58, 64 and 72 days after sowing, losses were 54, 44, 40 and 4%, respectively (Figure 1).

The timing of the first spraying is so important because, after the epidemic has become established, chemical control of the disease is uneconomical. Starting fungicidal spraying soon after the start of an epidemic either paralyzes it for 30 to 40 days or substantially reduces the rate of infection, depending on the type of fungicide used. The objective is not to obtain 100% control of the disease, but to maintain its level below 50% up to the soft dough stage. For this reason, systemic fungicides should be used for susceptible cultivars to delay the start of the epidemic, and protectant fungicides for less susceptible cultivars (slow-rusting cultivars) to reduce the rate of infection.

#### Number of sprayings

Normally three sprayings are recommended but, with spot blotch, there may be a need for four. The experience in Brazil indicates that, if the disease epidemic starts 45 to 55 days from sowing, at least three sprayings are necessary to obtain economic returns. Nevertheless, with prolonged dry periods (40 to 50 days) after tillering, two sprayings may be enough. Spot blotch is a very fast-growing disease, especially under warm, wet conditions, and it can attack the spikes as well as the leaves. Under such conditions, the disease can only be controlled with at least three to four sprayings with Maneb or Mancozeb or three sprayings with Propiconazole. Three or four applications not only reduce the rate of infection of the disease on the leaves, but protect the spikes from becoming infected. Since weather conditions are very changeable in Latin America, the exact number of sprayings cannot be predetermined.



**Figure 1. Loss in yield in relation to the start of the leaf rust epidemic on the cultivar Jupateco, Brazil, 1978**

**Interval between sprayings**

The fourth important aspect of the spraying schedule is the interval between fungicidal applications. Experience indicates that the interval should be about 15 days, regardless of the kind of fungicide used. With special reference to spot blotch, when protectant fungicides like Maneb or Mancozeb are used, and when weather conditions are very favorable to the disease, the interval should be reduced to 10 to 12 days.

Maneb or Mancozeb are broad-spectrum fungicides and, as a rule, should be used for complex disease situations. Besides being very economical, their use minimizes the danger of creating resistant strains of the pathogen.

Although the establishment of an appropriate spraying schedule is of utmost importance before any control measure is employed, no hard and fast rules can be laid out. On-the-spot modifications are quite often necessary, and the wheat variety, weather conditions and the intensity of the disease must be considered.

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## Chemical Control of *Helminthosporium sativum* on Rainfed Wheat in Zambia

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### Abstract

*Significant rainfed wheat yield losses due to diseases caused by Helminthosporium sativum were measured during three seasons in field tests with Mexican wheat varieties in Zambia. It was demonstrated that high rainfed wheat yields could be obtained with chemical disease control. Triadimefon and Fenitacetate-maneb controlled foliar infections and head blight better than other chemicals in field experiments. Triadimenol effectively controlled seedling infections caused by H. sativum and other pathogens.*

Zambia annually requires 180,000 tons of wheat to meet an ever-rising demand for bread; most of this is imported. Approximately 10% of the annual requirement is produced locally, as irrigated wheat during the winter. Although the yields are high, the area under irrigation is not increasing. Therefore, production of rainfed wheat is now being encouraged in Zambia. There is plenty of suitable land throughout the country and, with adapted cultivars and the participation of large and small-scale farmers, local production could increase significantly in a short period of time.

However, diseases, especially those caused by *Helminthosporium sativum* (syn. *Drechslera sorokiniana*; *Bipolaris sorokiniana*) are a major problem on rainfed wheat in Zambia. Throughout the country, the climatological conditions during the rainy season are optimal for the development of the fungus. Grasses are considered as the main source of inoculum, and natural epidemics occur each year. Infections start from tillering onwards, and may develop very quickly after flowering, depending on weather conditions. All above-ground plant parts and grain can become infected. The combination of spot blotch on the leaves, head blight, stem infection and black point may result in severe crop losses.

During previous years, several tests were carried out in Zambia to determine crop losses caused by *H. sativum* and to assess the effectiveness of various chemicals to control foliar infections, head blight and seedling infection (damping-off). Ten crop loss assessment tests were done over three seasons, with two dates of seeding per year. Mexican wheat cultivars were used, which are susceptible to foliar diseases and head blight, caused by *H. sativum*; resistant wheat cultivars were not available at that time. Since different weather conditions occurred each season, the conditions for the development of *H. sativum* and the disease pressures on the crop varied. Moderate and high crop losses were recorded.

In order to measure crop losses, three different disease levels were always maintained in the tests. Although it was not possible to have disease-free plots, near total disease control was obtained with fungicides, such as various Dithiocarbamates, Chlorothalonil, Captafol and Triadimefon. Sometimes two to three applications per week were necessary. The natural epidemic was allowed to develop in the unsprayed plots, and a third disease level with moderate

infection was obtained with less-frequent fungicide applications. Spot blotch and head blight were scored weekly. The average crop loss, as calculated from all tests for the different seasons, was 45% of the yield of the healthy plots; the maximum crop loss was 85% of the yield of healthy plots. For all practical considerations, this was a total crop loss. Severe foliar necrosis and head blight was recorded in plots which were exposed to the natural epidemic. Yields of more than 3 t/ha were obtained in disease-free plots, with a maximum yield of 3.6 t/ha recorded. Such yields are an indication of the potential for rainfed wheat production in Zambia if *H. sativum* is controlled, either genetically and/or by fungicide applications.

Rainfed wheat production with frequent fungicide use is certainly out of the question, due to economic considerations. If the input of a fungicide is going to be considered, it would have to be a highly effective chemical with very good persistence at a maximum of one or two applications.

Fungicide tests were carried out with the Mexican wheat cultivars. An orientation trial with the variety Sonora 64 showed that plots which received two applications of various standard contact fungicides did not have yields different from those of the unsprayed plots. The objectives were changed and, instead of concentrating on the number of applications, the emphasis was placed on finding an effective formula. Nine chemicals were evaluated on the variety Mexipak during the 1978 season. Two spray intervals were used, with spraying starting from the first signs of visible infection, which was one month after seeding. Eight sprayings at weekly intervals were applied, compared to three sprayings at intervals of three weeks. Above-average rainfall was recorded during the post-flowering period, providing the right conditions for the development of the

*H. sativum* epidemic in the plots and, consequently, for proper screening of the chemicals. The fungicides which were tested were Captafol, Tridemorph-maneb, Triadimefon, Fentinacetate-maneb, Mancozeb, Metiram, Maneb, Benomyl and Methylthiophanate. The unsprayed control plots yielded only 0.2 t/ha under high disease pressure conditions. Fentinacetate-maneb and Triadimefon were the most effective chemicals in slowing down the epidemic. Plots which were sprayed with these chemicals at intervals of once every three weeks yielded 0.8 t/ha. Plots sprayed with Fentin at weekly intervals yielded 1.7 t/ha versus 1.0 t/ha for plots sprayed with Triadimefon; a significant reduction of foliar infection and head blight was recorded for both. Head blight and node infection (stem break) were better controlled by Fentinacetate-maneb than by Triadimefon.

These two chemicals were compared during the next season with three new products, RH2161, EL228 and Imazalil, and also with a tank mix of Fentinacetate-maneb with Tridemorph-maneb. Four sprayings with each chemical were applied at intervals of two weeks, from flag leaf appearance onwards. The high disease pressure of the previous season did not occur, and the hand-harvested control plots yielded 1.9 t/ha. Plots sprayed with Triadimefon, Fentinacetate-maneb and the tank mix yielded 3.4 t/ha, 2.8 t/ha and 3.2 t/ha, respectively; these yields were not significantly different from each other. Plots which were sprayed with RH2161 also yielded significantly better than the control plots, but the yields were lower than those of the Triadimefon plots; perhaps a higher dosage of RH2161 could have bridged this gap. EL228 and Imazalil did not control the disease sufficiently, and plots which were sprayed with these chemicals did not have yields different from those of the unsprayed control plots. The efficacy of Triadimefon and Fentinacetate-maneb for the control of

*H. sativum* on foliage and heads of wheat was confirmed. Black point occurrence was recorded in this test; it was highest in the plots with the highest yield.

The next test was initiated to compare one and two applications of the tank mix Triadimefon-captafol with that of Fentinacetate-maneb and with the new product, Propiconazole. The improved variety Kavkaz x Kalyansona-Bluebird, with a better resistance to *H. sativum* than Mexipak, was by then available. Captafol was added to Triadimefon to improve the control of head blight. Due to insufficient rainfall after heading, the epidemic did not develop well and the plants suffered from drought stress. The plots which were sprayed with Triadimefon-captafol yielded 1.8 t/ha, but this yield was not significantly different from the yield of the unsprayed control plots.

Damping-off is also a problem in rainfed wheat in Zambia, especially when periods of prolonged drought stress occur soon after emergence. A complex of *H. sativum*, *Rhizoctonia solani*, *Rhizoctonia* spp. and *Fusarium* spp. are usually found on the roots, crowns and coleoptiles of infected plants. Laboratory experiments were carried out to test seed treatment formulations for the control of these soil-borne diseases. The variety Jupateco was used in these tests, since no varietal resistance to damping-off was thought to exist. Selected seeds were treated with dry formulations of the following chemicals: Thiram-malathion (standard seed treatment in Zambia), Thiram-malathion-carbendazim, Carboxin-thiram-lindane, Triadimenol, Furmecyclox-captan, Furmecyclox, Imazalil-bird repellent, Carbendazim and Chlorothalonil. The seeds were germinated in water agar in wide test tubes. Each test tube had one seed, and five seeds made up one "plot." Seven days after seeding, a plug of agar with mycelium was deposited near the

germinated seed. Three fungi were tested separately, *H. sativum*, *R. solani* and *F. graminearum*. The coleoptile infection was scored ten days after inoculation. The only chemical seed treatment which controlled all three diseases effectively was Triadimenol. It was also the only chemical which controlled *H. sativum*. *R. solani* was also controlled by Carboxin and Furmecyclox; *F. graminearum* was controlled equally well by Carbendazim and Triadimenol. Rainfed wheat seed in Zambia is already being treated with Triadimenol, although these results have not yet been confirmed in field tests.

These test results show that there are effective systemic and contact fungicides for the control of foliar infections and head blight caused by *H. sativum* on wheat. The input of these chemicals in wheat production can be considered if the environmental conditions are conducive to moderate disease pressure only. Under such conditions, susceptible cultivars can be protected. However, under conditions during which severe epidemics of *H. sativum* can be expected, the risk of growing susceptible cultivars cannot be neutralized by relying on chemical disease control.

In Zambia, the development of resistant cultivars which will yield well under different weather conditions and different disease pressures of *H. sativum* will be the ultimate research goal. For rainfed wheat to become an acceptable crop to large and small-scale farmers in a developing country, it should not require the input of chemicals to control foliar diseases and head blight. Seed treatment of rainfed wheat, on the other hand, is recommended to prevent seedling diseases caused by soil-borne pathogens. Systemic chemicals such as Triadimenol may also control early air-borne infections.

## Chemical Control of Wheat Diseases in the Philippines

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### Abstract

*Commercial production of wheat has only been attempted in the Philippines in the 1980s. This has been triggered by the release of two varieties, Trigo 1 and Trigo 2. These cultivars have agronomic adaptation to the environmental conditions of the country, but lack resistance to the major diseases. As the development of resistant cultivars takes time, chemicals have been evaluated for disease control when applied as foliar sprays, for frequency and rates of application for leaf spot control, as well as for seed treatments for protecting against and eradicating soil and seed-borne pathogens. Foliar sprays tested under nursery conditions have shown that Tilt 250 EC is the most effective chemical for controlling helminthosporium leaf spot. Some chemicals have also shown promise as protectants and eradicants of seed-borne diseases; Homal, Vitavax-thiram, Vitavax-captan and Arasan are effective against Sclerotium rolfsii, Rhizoctonia solani and Fusarium moniliforme, as well as for seed-borne fungi.*

Although the Philippines has a long history of wheat cultivation, dating back as early as 1664, recent commercial production has only been attempted in the 1980s. This attempt was triggered by the release by the Philippine Seed Board of two wheat varieties, UPLW<sub>1</sub> and UPLW<sub>2</sub> (Trigo 1 and Trigo 2), with good adaptation to the environmental conditions of the country. Unluckily, the two wheat varieties lack resistance to major diseases present in the Philippines. Faced with this situation, and realizing that the development of resistant cultivars would be the most logical and economical approach to disease control, a breeding program has been begun. Since the development of resistant cultivars takes time, as an emergency measure chemicals were evaluated for disease control in 1984. They were tested for use as foliar sprays and for

frequency and rates of application for leaf spot control, as well as for seed treatments for protecting against and eradicating soil and seed-borne pathogens.

Foliar sprays of chemicals under nursery conditions, using the microplot technique, showed that the fungicides Caltan F, Manzate D, Manzate 200, Orthocide 50 WP and Vinicur, at their recommended rates, and Tilt 250 EC, at 0.4 and 0.6 lt/ha formulated product (FP), were effective both as protectants and as eradicants, compared with the control. Among these chemicals, it appeared that Tilt 250 EC at the rate of 0.6 lt/ha FP was the most effective chemical for controlling helminthosporium leaf spot, with 24 and 14 mean lesion counts, as a protectant and an eradicant, respectively (Table 1). This was further corroborated with field experiments; Tilt 250 EC at 0.6 lt/ha FP gave 65% control and a yield of 1.5 t/ha versus the yield of the control at 0.9 t/ha (Table 2).

**Table 1. Mean number of lesions of helminthosporium leaf spot on wheat variety UPLW<sub>2</sub> with protectant and eradicant methods of spray applications under nursery conditions, Los Baños, Philippines, 1984**

Fungicide	Application rate (FP/ha) <sup>a/</sup>	Lesion count, according to application method <sup>b/</sup>	
		Protectant	Eradicant
Tilt 250 EC	0.6 lt	24 (25)	14 (56)
Orthocide 50 WP	1.0 kg	26 (19)	20 (37)
Caltan F	1.0 kg	27 (16)	25 (21)
Manzate D	2.0 kg	27 (16)	17 (47)
Manzate 200	2.0 kg	28 (12)	19 (41)
Tilt 250 EC	0.4 lt	29 ( 9)	21 (34)
Vinicur	1.0 lt	30 ( 6)	20 (37)
Control	--	32 ( 0)	32 ( 0)

<sup>a/</sup> FP = formulated product

<sup>b/</sup> Figures in brackets = percent control

**Table 2. Yield and percent control of helminthosporium leaf spot of wheat variety UPLW<sub>2</sub> sprayed under field conditions, Los Baños, Philippines, 1984**

Fungicide	Application rate (FP/ha) <sup>a/</sup>	Yield (t/ha)	Percent control
Tilt 250 EC	0.6 lt	1.5	65
Manzate D	2.0 kg	1.3	56
Manzate 200	2.0 kg	1.4	54
Caltan F	2.0 lt	1.5	53
Orthocide 50 WP	1.0 kg	1.2	43
Vinicur	1.0 kg	1.4	13
Control	--	0.9	0

<sup>a/</sup> FP = formulated product

Results from this field experiment also indicate that the weight of seeds with black point per 50 grams of seed was less with Tilt 250 EC, which gave 3.63 grams of seeds with black point, as compared with 16.44 grams for the control (Table 3).

The preliminary experiment on the effect of rate and frequency of chemical applications showed a smaller number of lesions after spraying with Dithane M-45, as compared with Fungitox-sprayed plants and the control. Furthermore, there was no difference in disease development with one or two spray applications, or at any rate of application; an interaction between rate and frequency was only observed when Dithane M-45 was applied three times.

Fungitox seemed to have no effect on helminthosporium leaf spot development (Table 4).

Homai and Vitavax-thiram, when used as slurry at 2 g/kg of seed, and Vitavax-captan and Arasan at 4 g/kg, all seem promising for protecting seeds against *Sclerotium rolfsii*, *Rhizoctonia solani* and *Fusarium moniliforme*, as compared with the control (Table 5).

Tests on the eradication of the more common seed-borne fungi, such as *F. moniliforme*, *Curvularia* spp., *Aspergillus* spp., *Helminthosporium* spp., *Penicillium* spp., *Rhizopus* spp. and *Alternaria* spp., using the same chemicals, rates and method of application as above, showed that all of the chemicals tested were effective in eradicating these seed-borne pathogens on wheat seeds (Table 6).

**Table 3. Presence of black point on seeds of wheat variety UPLW<sub>2</sub> according to fungicide treatment, Los Baños, Philippines, 1984**

Fungicide	Application rate (FP/ha) <sup>a/</sup>	Seeds with black point (g/50g seed)
Tilt 250 EC	0.6 lt	3.6
Vinicur	1.0 lt	4.5
Orthocide 50 WP	1.5 kg	5.3
Caltan F	2.0 lt	6.1
Manzate 200	2.0 kg	6.1
Manzate D	2.0 kg	11.5
Control	--	16.4

<sup>a/</sup> FP = formulated product

**Table 4. Effect on leaf spot infection of two fungicides applied at different rates and frequencies on wheat variety UPLW<sub>2</sub>, Los Baños, Philippines, 1984**

<b>Fungicide</b>	<b>Application rate (FP/ha)<sup>a/</sup></b>	<b>Number of applications</b>	<b>Lesion count</b>	<b>Percent control</b>
Dithane M-45	0.5 kg	1	23.3	62.6
		2	22.0	63.1
		3	8.9	85.7
	1.0 kg	1	22.0	64.7
		2	13.4	78.5
		3	3.7	94.1
	1.5 kg	1	23.9	61.6
		2	14.7	76.5
		3	3.0	95.2
Fungitox	0.5 kg	1	76.9	-23.5
		2	57.2	8.1
		3	53.5	14.0
	1.0 kg	1	62.7	- 0.6
		2	55.8	10.4
		3	71.9	-15.5
	1.5 kg	1	101.3	-62.6
		2	84.5	-35.6
		3	67.2	- 8.0
Control	--	--	62.3	0

<sup>a/</sup> FP = formulated product

**Table 5. Protective effect of fungicides against three soil-borne pathogens, Los Baños, Philippines, 1984**

Fungicide	Percent germination of treated seeds		
	<i>S. rolfsii</i>	<i>R. solani</i>	<i>F. moniliforme</i>
Homai	43.3	44.9	45.1
Vitavax-thiram	44.4	43.9	44.5
Vitavax-captan	41.4	43.3	44.1
Arasan 75	42.8	40.9	43.5
Control	36.9	38.7	38.9

**Table 6. Eradicative effect of fungicides on seed-borne pathogens on seeds of wheat variety UPLW<sub>2</sub>, Los Baños, Philippines, 1984**

Fungicide	Pathogen-free seeds <sup>a/</sup> (%)
Homai	46.8
Vitavax-captan	29.2
Vitavax-thiram	14.2
Arasan 75	9.0
Control	0.0

<sup>a/</sup> Pathogens commonly encountered on untreated seeds are species of *Fusarium*, *Curvalaria*, *Helminthosporium*, *Alternaria*, *Penicillium* and *Rhizophus*

### III. Agronomy

## Physiological Limitations to Producing Wheat in Semitropical and Tropical Environments and Possible Selection Criteria

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#### Abstract

*"Tropical" wheat environments are characterized by short winter photoperiods (11 and 12.5 hours) with high temperatures, the mean temperature for the coolest month varying from warm (15°C) to hot (20°C) to very hot (25°C). Diurnal temperature range, solar radiation, vapor-pressure deficit and water supply (irrigated or rainfed) vary considerably between regions; frosts and hot winds constitute meteorological hazards in some locations. In such environments, wheat may establish poorly because of high soil temperatures. More seriously, development is accelerated (approximately in proportion to temperature), while growth rate is stable or may decline, so that leaf size, tillering, spike size and yield potential suffer, even under irrigation. Excessive respiration and possible direct effects of high temperature on sink formation may further reduce potential, while kernel filling is curtailed by hastened development and/or carbohydrate shortage. There is little physiological experience with wheat at high temperatures, but some other plant genera show remarkable thermal adaptation. It is possible to lengthen the seeding-to-flowering interval in wheat with daylength and cold-sensitivity genes, thereby increasing biomass production. Selecting in such material for harvest index (currently very low) would seem a rational physiological approach for improvement of yield potential. In order to avoid high temperatures at critical stages, and to maximize water-use efficiency, it is desirable to have seeding date and cultivar maturity class such that flowering is around the coolest point of the year and, if the crop is rainfed, subsoil moisture reserves are fully exploited.*

Crop research comprises the complementary activities of adapting environments to plants, and adapting plants to environments. At first glance, there is not much that agronomists can do about the thermal regimes of the tropics, but genotypic adaptation to such conditions may offer possibilities to plant breeding. Genotypic adaptation to superoptimal temperatures is also of interest to physiologists; eco-physiologists already recognize many adaptations to hot regimes in other plants (37). The tropics being a new environment for wheat, it might permit easier prediction of advances than the well-trodden field of genetic improvement in more temperate areas.

In this paper, important features of wheat climates in the tropics and of yield determination in wheat will be summarized, before passing to specific physiological problems of tropical wheat and possible genotypic adaptations. Possible selection criteria and interactions with agronomy will also be discussed. Disease and weed-free conditions and adequate fertility will be assumed. The indulgence is asked of researchers in the tropics for the author's having ventured from temperate agriculture into a field in which he has had little research experience.

## Climatic Considerations

Table 1 is a summary of wheat climates in the region within 23 degrees north and south of the equator and below 1500 meters in altitude; Dhaka (24°N latitude) is included because of the importance of wheat in Bangladesh. It is assumed that wheat is grown in the winter and that the temperature in January (or July in the southern hemisphere), almost always the coolest month, is the simplest and most relevant climatic feature. Thus, January mean temperatures above 22.5°C are considered very hot, those between 22.5 and 17.5°C hot, and those between 17.5 and 12.5°C warm, giving three regimes with mean temperatures of about 25, 20 and 15°C, respectively. These are further divided, according to January atmospheric humidity, into humid (with estimated average leaf-to-air vapor pressure deficit (VPD) being below about 10 mb) and dry (VPD above 10 mb); dew is unlikely to form in the latter case. A fourth high-latitude warm regime (25 to 30°C), is included because several major traditional low-latitude, wheat-growing regions are represented and are relevant to this conference.

The range between mean maximum and mean minimum temperatures is given in Table 1, for it may be directly relevant to crop growth and can be used to calculate mean minimum temperatures, which is relevant to vernalization, and which some studies suggest may be more closely correlated to crop performance than mean temperature (25, C.E. Mann, personal communication). The temperature

range tends to be least at humid coastal locations. Information on solar radiation is, unfortunately, not always available or accurate; January radiation decreases with distance from the equator, with cloudiness (in humid locations) and with dust haze (e.g., northern Nigeria). Seasonal changes in temperature, radiation and vapor-pressure deficit for October to April (April to October in the southern hemisphere) are shown for representative locations in Figure 1.

Winter rainfall totals in Table 1 are an inadequate description of water supply to the crop. In few places is there sufficient rainfall during the crop season for viable cropping (e.g., possibly in Indonesia, southern China, Paraguay and southern Brazil). More generally, crops rely on soil water stored from the summer wet season in deep retentive soils (e.g., central India, Bangladesh, Thailand and Queensland, Australia), and/or on irrigation. Irrigation is essential in places like Sudan and Nigeria and, for reasons of soil type, in central Brazil. Thus, water-supply regimes dominated by irrigation, stored soil water or, less commonly, rain on the crop need to be distinguished.

This brief discussion of climate has not taken into consideration several meteorological factors of lesser importance to tropical wheat. These include sun angles and mid-day radiation intensity, potential or pan evaporation rates, the sharpness of the post-January air-temperature rise and the incidence of frost and severe dry winds. Frost occurs only in the warm regime; this can be quite significant in southern Brazil and Queensland. Severe atmospheric drought is apparently significant at locations bordering the Sahara.

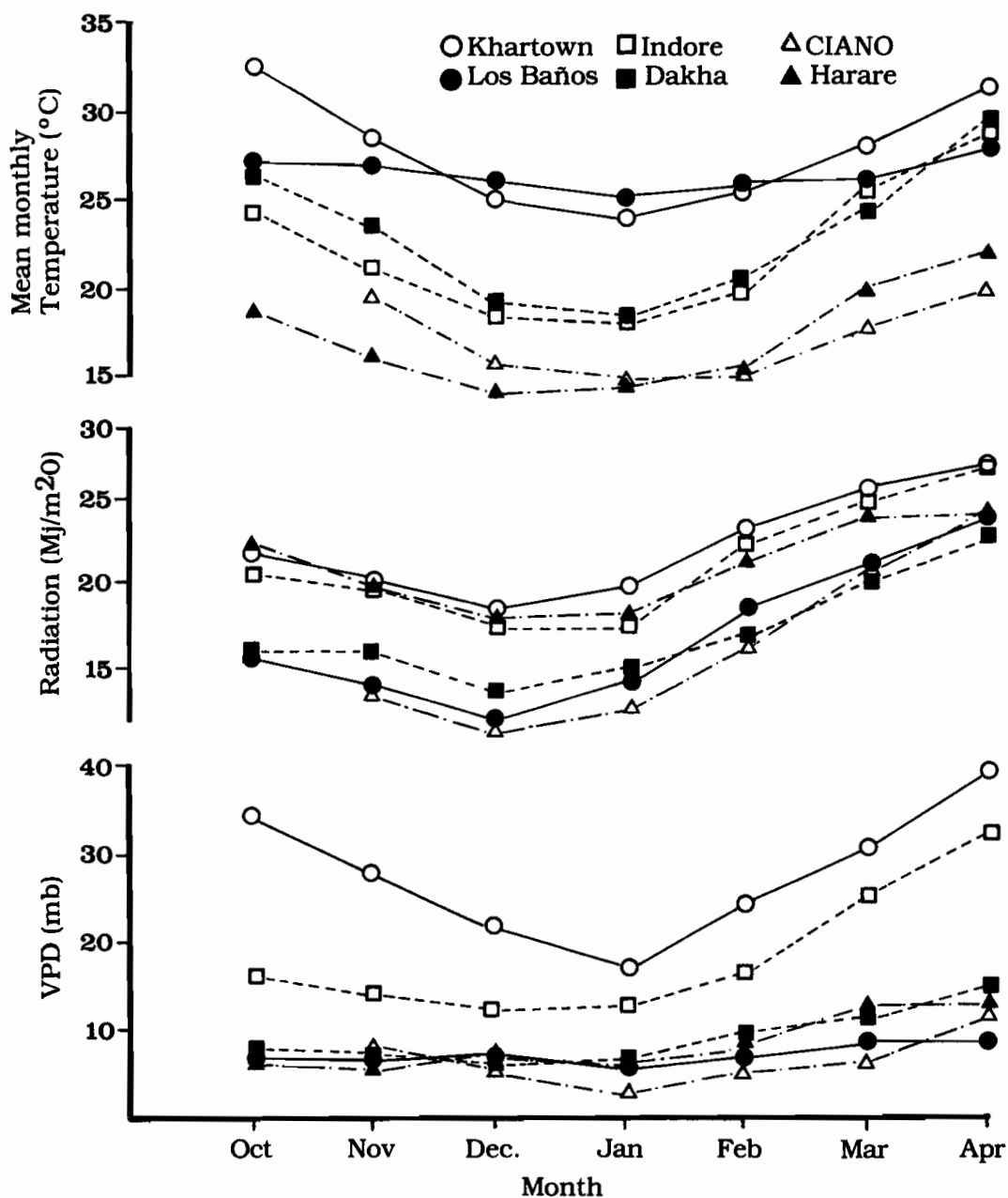
**Table 1. Actual and possible wheat-growing locations in and near the tropics, and principal features of their temperature and humidity regimes in the month of January (July in the southern hemisphere)**

Thermal and humidity regime	Location	Latitude	Altitude (m)	Mean daily January weather				Total rain		Locations with approx. similar wheat climates
				Mean temp. (°C)	Temp. range (°C)	VPD (mb)	Solar radiation (MJ/m <sup>2</sup> /d)	Dec.-Feb. (mm)	Annual (mm)	
Very hot, humid	Los Baños, Philippines	14°N	40	24	5	6	15	230	2040	Jakarta, Indonesia
	Phitsanulok, Thailand	17°N	50	25	14	8	—	32	1354	
Very hot, dry	Khartoum, Sudan	16°N	380	24	16	22	20	0	164	
	Kununurra, Australia	17°S	30	23	17	19	21	5	745	
Hot, humid	Chiang Mai, Thailand	18°N	313	21	16	6	—	28	1246	Mandalay, Burma Poza Rica, Mexico Villa Guede, Senegal Santa Cruz, Bolivia Asunción, Paraguay
	Dhaka, Bangladesh	24°N	8	19	14	6	15	51	1928	
	Formosa, Brazil	16°S	911	19	14	8	—	17	1595	
Hot, dry	Kano, Nigeria	12°N	470	22	17	20	21	1	873	Hyderabad, India (1) Taiz, Yemen Rep. Tlaltizapan, Mexico
	Indore, India	23°N	555	18	17	12	18	16	876	
Warm, humid	Lima, Peru	12°S	11	15	4	1	21	5	10	Lusaka, Zambia Londrina, Brazil Matamoros, Mexico
	Emerald, Australia	23°S	179	15	16	5	—	108	591	
	Harare, Zimbabwe	18°S	1470	14	15	7	18	9	868	
	Canton, China	23°N	18	14	9	4	—	126	1720	
Warm, humid (25-30° lat.)	Riyadh, Saudi Arabia	25°N	594	15	14	6	—	42	105	New Delhi, India Kufra, Libya Cairo, Egypt
	Ciudad Obregon, Mexico	27°N	40	15	16	3	13	40	267	
	Passo Fundo, Brazil	28°S	750	13	—	—	—	445	—	

### Yield Determination in Wheat

Table 2 outlines an approach to understanding yield determination in wheat. This emphasizes crop and spike growth (dry matter accumulation in

terms of  $g/m^2$ ) in a critical period (spike-growth period) leading up to anthesis as the key to determination of grains/ $m^2$ ; little importance is given to traditional numerical components of grain number (17).



**Figure 1. Long-term mean monthly temperature, daily radiation and estimated leaf-to-air vapor pressure deficit (VPD) for key tropical locations (VPD was estimated assuming the leaf was at the mean daily temperature). Months for Harare, Zimbabwe, should read April to October.**

**Table 2. Wheat yield determination and the influence of environment and genotype in the absence of nutrient limitation**

Components and subcomponents	Controlling factors <sup>a/</sup>	
	Major	Minor
1. Developmental periods (final stage)		
Vegetative (floral initiation)	T, V, P, G	--
Spikelet and floret initiation (penultimate leaf emergence)	T, P, G	--
Spike growth (anthesis)	T	P, G
Grain filling (loss of green)	T	--
2. Crop growth to give leaf area index at onset of spike growth		
Established plants/m <sup>2</sup>	--	T, W
Duration	T, G	--
Relative growth rate	T, R, W	G
3. Spike growth to give g/m <sup>2</sup> at anthesis		
Leaf area index, prevailing duration	Previous period, W T	T G
Net photosynthetic rate	R	T, D
Partitioning to spike	G	--
4. Processes around anthesis to give grains/m <sup>2</sup> at onset of grain fill		
Spike weight at anthesis	Previous period	
Florets/spike weight	G	W, R
Grains per floret (grain set)	--	T, G, D
5. Individual grain weight determination		
Cell number, duration	T, R	--
Filling duration	T	--
Rate of filling:		
Reserves, kernel number	Previous period	--
Leaf area index prevailing	Previous period, W, T	--
Net photosynthetic rate	R	T, D
6. Grain yield (if no water shortage)		
Grain number	Q during spike growth	--
Individual grain weight	T during grain filling	--
7. Grain protein <sup>o/o</sup>		
Grain nitrogen <sup>o/o</sup>	T	W, G

<sup>a/</sup> T = temperature, V = vernalizing cold, P = photoperiod, R = solar radiation, W = water shortage, D = vapor-pressure deficit, Q = photothermal quotient, G = genotype

Briefly, plant development (the first component in Table 2) proceeds through four phases or periods, delineated by the successive discrete stages of floral initiation, penultimate leaf emergence on the main shoot (approximate guide to the onset of spike growth), anthesis and loss of green in the spike. Control of the duration of each period by the listed environmental factors and by genotype is reasonably well understood. These stages are best considered as representing switches in the allocation of assimilate or dry matter between different organs. First, the crop grows leaves and roots and, in the second period, stems as well. In the third period, commencing some 20 to 30 days before anthesis, spikes and stems become the major sinks for assimilate; in the final period, grains are the dominant sink.

The second component in Table 2 refers to the build-up of the leaf area in periods one and two. Leaf area at the end of period two plays a major role in determining spike growth (component 3), a role best summarized in the percentage of solar radiation intercepted by leaves during the spike growth period which, along with photosynthetic rate and period duration, determine total crop growth in the period. Approximately 25 to 50% (depending on cultivar) of this total dry weight at anthesis is considered pivotal in this analysis, because a given investment in spike tissue (rachis, awns, floral parts, etc.) is necessary to build a competent floret (approximately 10 mg, depending on the cultivar). Therefore, spike dry weight determines potential grain number; some environmental and possibly genotypic factors around anthesis (component 4) can, in turn, affect actual grain number by

reducing grain set (grain per floret) to less than the theoretical maximum of one.

Understanding individual grain-weight determination follows more broadly accepted lines (component 5); conditions soon after anthesis may determine potential grain weight, but often limitations on the duration and/or rate of grain filling affect the realization of this potential, with final grain weight falling below potential, especially if there are many grains to be filled.

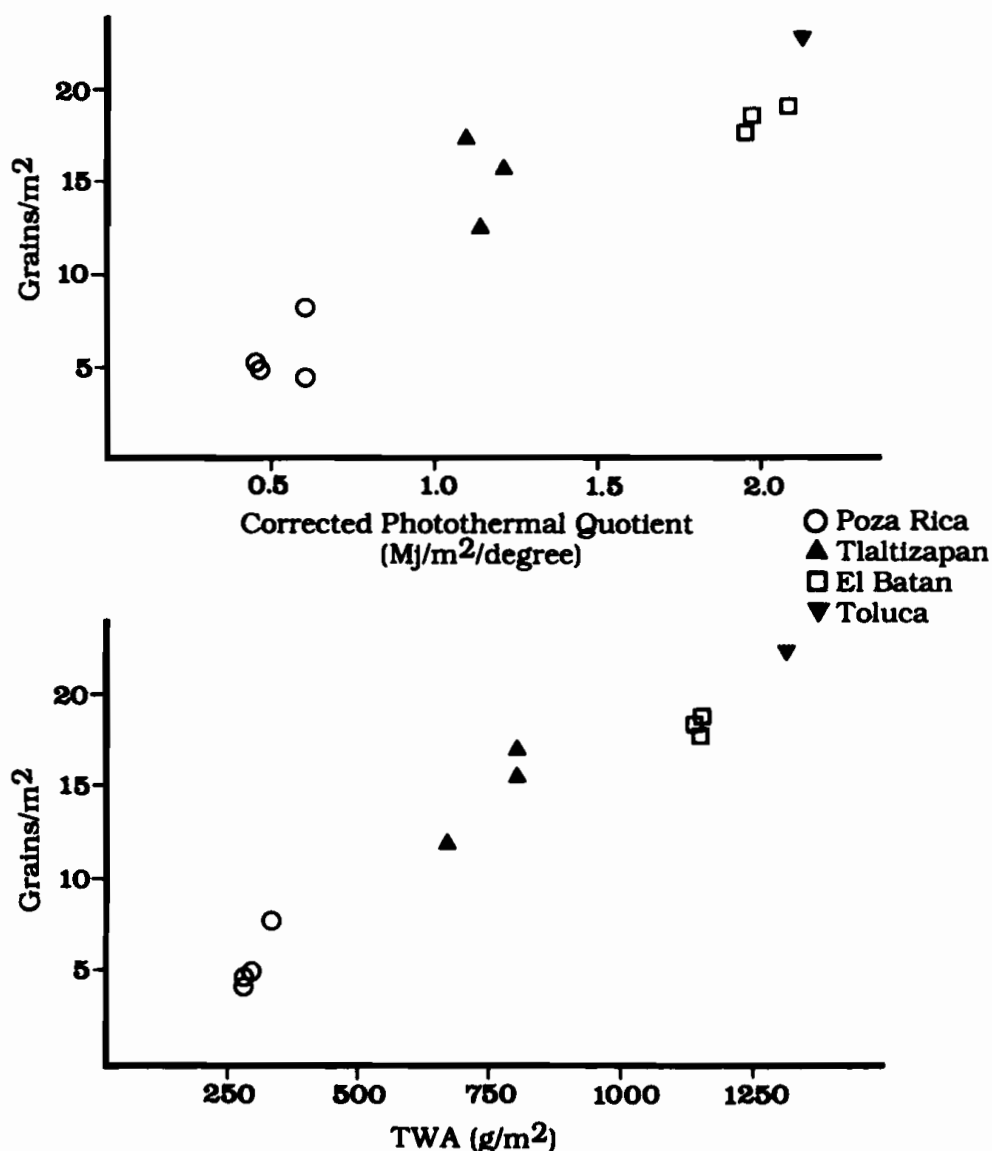
In situations without water limitation, for a given anthesis date, a simple yield index can be derived which integrates the major environmental effects listed in Table 2. This relies on the fact that grain number is reasonably well predicted by the photothermal quotient over the 20 to 30 days preceding anthesis (17,27). Photothermal quotient ( $Q$ ) is defined as mean solar radiation divided by mean temperature less  $4.5^{\circ}\text{C}$  (units of  $\text{MJ}/\text{m}^2/\text{d}/\text{degree}$ ). It specifically integrates the positive and linear effect of radiation on crop growth rate and of mean temperature (less base temperature) on developmental rate (reciprocal of duration). Hence, as defined, it is an index of total crop growth in the approximate spike-growth period. It can be improved by correcting for incomplete radiation interception (thereby reducing  $Q$ ) in situations where leaf-area index is insufficient in this period for full light interception (e.g.,  $>3$ ).

The relationship of grain number to corrected  $Q$  (and to total dry weight at anthesis) for a set of representative cultivars and a range of sowing dates and sites in central Mexico ( $20^{\circ}\text{N}$  latitude) is shown in Figure 2; Poza Rica and Tlaltizapan have hot and humid and hot and dry tropical regimes, respectively. A similar relationship was derived from a wide range of sowing dates and years at the CIANO station in Ciudad Obregon in northwest Mexico (R.A. Fischer,

unpublished). A rule of thumb derived from this work suggests the following simple relationship for good growing conditions and semidwarf cultivars:

$$\text{Grain number/m}^2 = 11,000 \times \text{corrected } Q \text{ (Equation 1)}$$

At the same time, in many studies (i.e., 39), individual grain weight appears to bear a consistent negative linear relationship to grain-filling temperature. This relationship could not be derived in central Mexico because of disease attack during grain filling at several



**Figure 2.** The relationship of grains/m<sup>2</sup> to a) corrected photothermal quotient in the 30 days before anthesis (see text) and b) total dry weight at anthesis. Results are the average of 10 to 19 genotypes sown at four sites in central Mexico (about 20°N lat), Poza Rica (80 m), Tlaltizapan (940 m), El Batan (2249 m) and Toluca (2640 m).

**Source:** Midmore *et al.* (27)

sites, but field work at CIANO (15) and elsewhere suggests the following relationship, as shown for representative cultivars (Figure 3):

$$\text{Grain weight (mg)} = 64 - 1.6 \times T \quad (\text{Equation 2})$$

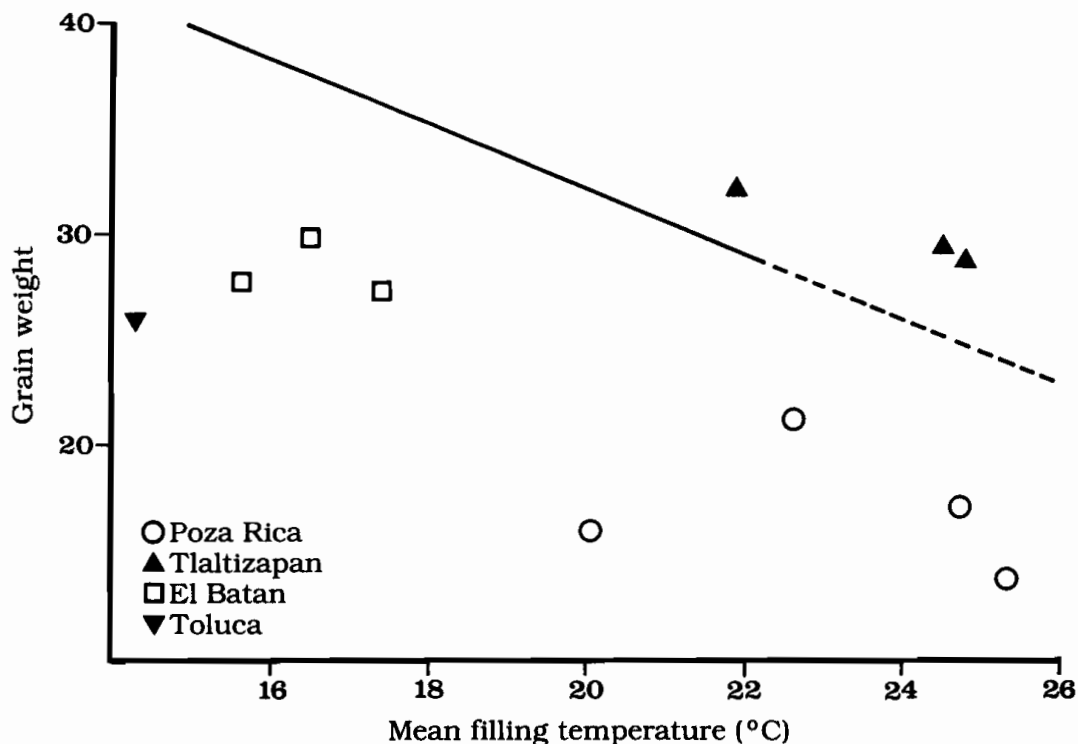
Here T is the mean temperature during grain filling (30 to 40 days following anthesis).

Equations 1 and 2 can be multiplied to give the aforementioned simple index of grain yield:

$$\text{Yield (g/m}^2\text{)} = \text{corrected } Q \times (700 - 17 \times T) \quad (\text{Equation 3})$$

This equation contains the two major negative influences of increased temperature on grain yield, namely that of temperature on duration of the spike growth period and on grain weight. Increased radiation, through Q, has a positive effect on yield.

It is possible to use Equation 3 to estimate grain yield as a function of anthesis date for the locations in Figure 1 (Table 3). Q was calculated for the month prior to anthesis, assuming full light interception, and T for the month after. Q tends to peak in February (August in the southern hemisphere), but the steepness with which T rises before and, especially, after January also influences anthesis date for maximum yield (Figure 5). This is seen to be January at all tropical locations except Los Baños, Philippines, where temperature changes less



**Figure 3.** The relationship of individual grain dry weight to mean grain-filling temperature for the sowings of Figure 2, and the linear relationship derived from disease-free sowings at CIANO, Ciudad Obregon, Mexico.

Source: R.A. Fischer, unpublished

seasonally and cloudiness persists into the early winter (Figure 1). The generally lower yield of hotter and more humid (cloudy) locations is evident in Table 3.

Finally, although yield is reduced because high temperatures hasten development, it should be remembered that, where radiation is high, crops can be quite efficient in terms of yield per day from sowing to harvest. Best genotypes achieved 50 kg/ha/d at Tlaltizapan in central Mexico (27) and 40 kg/ha/d at Kununurra in northwestern Australia (6).

A yield index for water-limited environments might be derived along similar lines to those above,

emphasizing the effect of water on grain number in the critical period around anthesis, as has been done by Woodruff (47). However, a more general, simple index, discussed elsewhere (16,28), relies on the inevitable link between photosynthesis and transpiration:

$$\text{Yield (g/m}^2\text{)} = \text{transpiration} \times \text{WUE} \times \text{HI (Equation 4)}$$

Transpiration (mm) refers to total crop transpiration, WUE to water-use efficiency (g/m<sup>2</sup>/mm); HI is harvest index, or the ratio of grain to total dry matter produced. The major effect of water limitation is the reduction of crop

**Table 3. Estimated grain yield (dry weight) for well-watered wheat crops as estimated by equation 3<sup>a/</sup> using monthly long-term radiation and temperature averages for key locations**

Location	Grain yield (g/m <sup>2</sup> ) according to anthesis date <sup>b/</sup>						
	Nov. 1	Dec. 1	Jan. 1	Feb. 1	Mar. 1	Apr. 1	May 1
Los Baños, Philippines (very hot, humid)	159	163	156	183	226	216	215
Khartoum, Sudan (very hot, dry)	168	234	273	277	249	179	—
Dhaka, Bangladesh (hot, humid)	220	324	361	374	298	218	185
Indore, India (hot, dry)	362	469	492	461	387	238	—
Harare, Zimbabwe <sup>c/</sup> (warm, humid)	685	813	892 <sup>d/</sup>	834 <sup>d/</sup>	726	531	490
CIANO, Cd. Obregon, Mexico (warm, humid, 25-30° lat.)	324	394	472	526	575	542	438

<sup>a/</sup> Yield (g/m<sup>2</sup>) = corrected Q x (700-17 x T)

<sup>b/</sup> Maximum yields are underlined

<sup>c/</sup> Read May 1 to November 1

<sup>d/</sup> Ignores possible frost damage

transpiration which, in any case, might be only 50 to 70% of evapotranspiration (soil evaporation + crop transpiration) during the crop cycle. There may be a reduction in harvest index if the temporal distribution of crop transpiration is unbalanced; for example, post anthesis transpiration falling below 30% of total transpiration. A strength of this approach is that WUE is closely governed by one factor, namely the prevailing leaf-to-air vapor pressure deficit (VPD in Table 1 and Figure 1). The following relationship has been suggested for wheat (34):

$$\text{WUE (g/m}^2\text{/mm)} = 50/\text{VPD(mb)} \\ \text{(Equation 5)}$$

The importance of VPD where water supply is limited is now evident; at high VPD, crop transpiration acquires less CO<sub>2</sub> (dry matter) than at low VPD. The other major effects of high temperature, represented in Equation 3, must also operate under water limitation unless the latter is severe. Their incorporation into Equation 4 is not simple, but is best considered in terms of effects on total transpiration; this may decrease relative to water supply under hotter conditions (crop duration is reduced) and relative to evapotranspiration (soil evaporation increases due to generally lower ground cover). Because most water-limited wheat in the tropics is grown on stored soil water, this situation will be discussed. This discussion will be brief, as possibly the only unique aspect of stored soil waters in the tropics is the probable existence of increasing soil water with depth in the profile, due to the large water input during the wet summer season. Queensland, Australia is an exception in this regard (Woodruff, these proceedings). Many aspects of the difficult task of selection for adaptation to water limitation are discussed elsewhere (16,20).

### **Specific Limitations in the Tropics**

The preceding general discussion, and the simple derived relationships, have indicated major mechanisms by which tropical conditions (higher temperatures, sometimes higher VPDs or lower radiation) can reduce wheat yield; they provide an invaluable framework for further discussion. However, the general approach has not been widely tested or researched under hot conditions. Furthermore, a number of minor mechanisms have been passed over which conjecture or experience, and sometimes solid research, suggest could also be specifically relevant to the tropics. The ensuing discussion will deal with both of these issues, as it proceeds stepwise through the components of Table 2 and searches for possible genotypic adaptations to tropical environments.

### **Acceleration of development by high temperatures**

Notwithstanding some doubts about the actual temperature of the growing point relative to air temperature (it could be hotter when close to the soil surface or cooler when higher and cooled by transpiration), the acceleration of development as air temperature rises is central to yield reduction. The mechanisms are not understood, but are obviously a very fundamental response of plants. Quantitatively, the responses (within upper and lower limits) fit the simple day degree relationship:

$$(T-T_b) \times \text{duration} = \text{constant} \\ \text{(Equation 6)}$$

T is temperature, T<sub>b</sub> is base temperature (for zero rate of development) and duration is the length in days; the constant is the length, in day degrees, of the particular development period under consideration. In wheat, T<sub>b</sub> appears to rise from around 2°C for early

developmental periods, to around 9°C for grain filling (3,36). The relationship implies that duration declines less relatively and absolutely as temperature rises (e.g., if  $T_b = 5$ , the acceleration from 15 to 20°C will be 33%, that from 20 to 25°C, only 25%). Although data for wheat at temperatures above 20°C is scarce, it does show this tendency for duration to be reduced less at temperatures above 20 to 25°C and sometimes but not always (35,39), to approach a minimum value (3,26); this fact is not predicted by Equation 5 and is worthy of further investigation.

Although  $T_b$  and, hence, the sensitivity of duration to temperature, varies between species for given developmental phases (2), there is no evidence of genotypic variation within wheat. In any case, it is not so much the acceleration of development with higher temperature which is critical, but rather the actual duration reached under hot conditions. Three mechanisms exist by which longer duration under hot conditions can come about. The most striking one is vernalization sensitivity, whereby development in the first and, to a limited extent, the second, but not later developmental periods (Table 2), is slowed when the sensitive genotype experiences no vernalizing cold (26,40); the universal effect of higher temperature apparently is overridden (Figure 4). Vernalization in this context appears to operate with minimum temperatures below about 13°C, increasing in intensity down to a minimum of 2 to 8°C (23). In so-called spring wheats, a small number of genes probably control vernalization responsiveness; however, there appears to be a continuous gradient in responsiveness. Pitic 62, Cajeme 71, Gabo, Odzi, Soltane, Oxley and C306 are cultivars with moderate responsiveness.

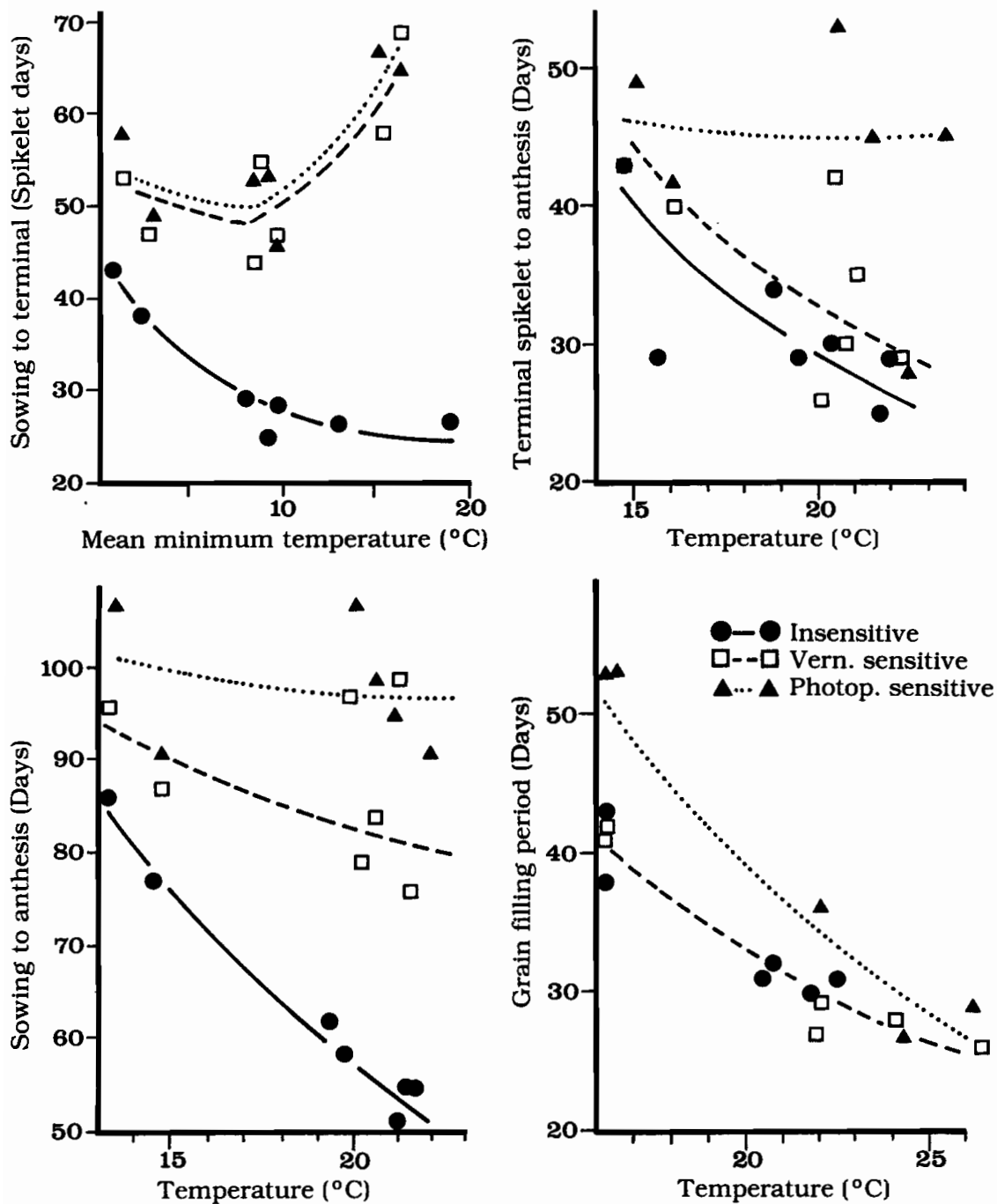
The second mechanism leading to long duration in all periods before anthesis, even under hot tropical conditions, is seen with genotypes such as Manitou

and Era, which are highly sensitive to photoperiod (Figure 4). With moderately sensitive ones (e.g., Kloka and Anza), there is a smaller but still significant effect. Sensitivity to photoperiod is under simple genetic control.

Finally, it can be suggested that significant variation in pre-anthesis duration exists under hot conditions, even in cultivars insensitive to vernalization and minimally sensitive to photoperiod (this might be considered as genotypic variation in the day degree constant of Equation 6). A comparison of Siete Cerros and Hira, both insensitive cultivars, shows that Siete Cerros has a consistently longer sowing-to-anthesis duration (61 days versus 51 days, + 20%) at sowings at hot sites in central Mexico (25). Other workers have also pointed to the relative lateness of Siete Cerros or Kalyansona, which appears to be associated with their tendency to produce an extra leaf on the main stem (25, H.M. Rawson, personal communication).

While differences in vernalization and photoperiod sensitivity do not operate in the grain-filling period (Figure 4), small genotypic differences (20%) in duration under hot conditions do occur and should be likened again to differences in the constant value in Equation 6. Also, larger differences (35%) reported for other cultivars under cooler conditions should persist in a relative sense under hot ones (35).

Accelerated leaf senescence is another aspect of the high temperature-rapid development syndrome. This is not well understood, and may not be a totally negative effect; for example, leaves must senesce if all of their nitrogen is to be mobilized into growing grains. Even so, if a phenomenon such as the genetically controlled delayed leaf senescence in soybeans (29) were to be found in wheat, it might be especially useful under hot grain-filling conditions.



**Figure 4.** The duration of the intervals a) sowing to terminal spikelet for nation versus mean minimum temperature, b) terminal spikelet duration to anthesis, c) sowing to anthesis and d) anthesis to maturity versus mean temperature. Relationships shown for three groups of cultivars (insensitive, vernalization sensitive and photoperiod sensitive) sown at the sites described in Figure 2.

Source: Midmore *et al.* (26)

### **Growth at high temperatures**

*Early stages*—Plant population is the starting point of crop growth. The effects of initial density on crop growth rate quickly diminish with time under good growing conditions, such as high radiation and water availability (13), because of compensatory mechanisms. Midmore's study (25) showed reduced total dry matter at anthesis (55 days after sowing) under hot, low radiation conditions of Poza Rica, Mexico, only if initial plant density fell below 100/m<sup>2</sup>. Such a population may not be easy to achieve in the tropics, because of rapidly receding soil moisture and high soil temperatures. Maximum soil temperatures in the top few centimeters will exceed maximum air temperature by 10 to 15°C if the soil surface is bare and dry and radiation intensity high. Maximum soil temperatures could, under these conditions, exceed 45 to 50°C at many locations, with probably serious effects on seedling emergence. Agronomic management (mulching, deep furrow planting) offers the best solution to this problem, but there could also be useful genotypic variability.

Even when seedlings emerge satisfactorily, brief exposure to extreme soil temperatures may have long-term deleterious effects on growth potential, for example, direct inhibition of crown root or tiller initiation (H.M. Rawson, personal communication). Such possibilities have been inadequately researched and, again, agronomic solutions would seem most relevant. Nevertheless, resistance to metabolically disruptive effects of extreme temperatures (temperature lesions) is a trait for which most species studied show considerable and often simply inherited genetic variation (24).

*Photosynthesis and respiration*—Leaf temperature over the range of 20 to 35°C has remarkably little effect (<10%) on the gross rate of photosynthesis by wheat leaves (39); this has also been demonstrated for

wheat leaves grown at different temperatures (5,12). The point at which photosynthesis of acclimated wheat leaves is seriously disrupted by high temperature is probably above 40°C. Remembering that leaf temperature is usually several degrees below air temperature if water supply is adequate, it is therefore unlikely that tropical temperatures *per se* inhibit wheat photosynthesis. With water stress, photosynthesis may well be inhibited, but the major cause will be the lack of water and not temperature; the key question is whether water-use efficiency rather than photosynthetic rate changes (which is unlikely).

Recent research suggests that, quite independently of leaf water status or temperature, stomatal conductance in many species is linearly and negatively related to VPD. In the case of wheat at least, leaf photosynthesis appears unaffected with VPD up to 25 mb conductance (30). Considerably higher VPD levels would be reached at midday in dry tropical locations; the effect on photosynthesis is not known.

In contrast to gross photosynthesis, respiration increases markedly as temperature rises. Theory suggests that the growth component of respiration (respiratory cost of synthesizing new plant constituents) is unaffected, whereas the maintenance component responds to temperature. Daily maintenance respiration is conveniently expressed as a fraction (*m*) of total biomass. While measurements involving short-term temperature changes suggest that *m* has a  $Q_{10}$  of around 2 (i.e., it doubles for each 10°C rise), the responsiveness of wheat *m* to longer-term changes is probably less (39). Also, *m* probably declines steadily from the early vegetative stage to maturity, as the proportion of structural and dead biomass increases (21). Unfortunately, there is no reliable measure of *m* at anthesis under hot

conditions, but theory suggests about 0.02 g/g/d at 25°C. This means that 2% of the crop biomass is respired in maintenance daily or, with 500 g/m<sup>2</sup> biomass, 10 g/m<sup>2</sup>/d is lost. In this context, it is intriguing that genotypic variation in maintenance respiration has been found in ryegrass and exploited in a selection program, to produce a low-respiring, high growth-rate cultivar (46). A project to look for such variation in wheat, specifically under hot conditions, has been commenced by H.M. Rawson in Australia.

*Leaf area production*—The investment of photosynthate into new leaves or the leaf-area ratio (cm<sup>2</sup> per g plant dry weight) is a key factor determining early crop growth rate, especially when leaf-area index is low and new leaves do not shade existing ones. One component of this, the leaf-weight ratio or proportion of dry weight in leaves relative to total dry weight, does not appear to be greatly affected by mean temperatures from 10 to 25 or 30°C and may even increase, other things remaining equal. The second component of this investment, namely leaf area per unit leaf weight, actually increases with higher temperatures up to 25°C, and is greater with lower radiation (12,18,27). It appears, therefore, that green leaf-area production as a proportion of daily dry matter gain is, if anything, improved by growth under tropical conditions, and is unlikely to limit performance. One proviso is that temperatures not be high enough to inhibit chlorophyll production, a phenomenon seen in certain genotypes (18) and readily selected against. Also a more complete and longer-term analysis of leaf-area dynamics must include the acceleration of leaf senescence under hot conditions as mentioned earlier.

*Overall crop growth*—Relative growth rate (daily dry matter increase per unit total dry weight) integrates effects of

environment on photosynthesis, respiration and leaf area ratio. It is a useful index of early crop growth rate, before mutual shading and ontogenetic changes begin to dominate relative growth rate. Evans and Bush (10), working under field radiation levels in the Canberra, Australia, phytotron, recently found early relative growth rate of wheat to peak at 20 to 25°C, with only small declines down to 12°C and up to 33°C. This represents quite remarkable thermal stability. Limited results (18) suggest that early growth at a given mean temperature is somewhat greater with a narrower diurnal temperature range, a response which would favor the humid tropical locations. Genotypic differences in the various components of relative growth rate may exist, but they would seem of limited relevance to performance in the tropics, since relative growth rate does not suffer markedly under such conditions, and because of the possibility of compensating for limitations in early growth by increasing plant population.

Crop growth rate, once leaf-area index is high enough for substantial mutual shading (i.e., >1.0), is best considered in terms of total radiation intercepted by green leaves. Under a wide range of conditions, notwithstanding possible effects on photosynthetic efficiency and on maintenance respiration, the ratio of dry matter accumulation to radiation input is relatively constant for wheat at around 3 g/MJ of photosynthetically active radiation absorbed by green leaves (17,39).

This implies growth at 1.2 g/MJ incident total solar radiation with full ground cover (100% interception), e.g., if daily solar radiation is 20 MJ/m<sup>2</sup>/d, light-limited growth rate should be 24 g/m<sup>2</sup>/d. This relationship has not been tested at temperatures above 20°C or at high radiation intensities typical of the tropics; however, unless maintenance respiration estimates are seriously in error, it should apply reasonably well.

Certainly crop growth rates in excess of  $20 \text{ g/m}^2/\text{d}$  have been recorded at hot tropical sites, such as Tlaltizapan, Mexico (27), and the low veldt of Zimbabwe (8). Peak rates were lower at Poza Rica, Mexico ( $10 \text{ g/m}^2/\text{d}$ ), probably due to the lower radiation and leaf area indices (27). There, and at Tlaltizapan, greater leaf area indices and dry matter at anthesis were achieved with later vernalization and photoperiod-sensitive genotypes. Although their crop growth rates were somewhat lower than earlier genotypes, lateness seems to be a clear way of increasing total growth at anthesis (45) and growth rate during the pre-anthesis spike-growth period under hot conditions where leaf area indices in earlier types fail to reach full light interception.

#### **Reduction in grain number**

It was proposed in the general discussion of yield determination that grain number is reduced under hot conditions, essentially because crop growth and, hence, spike growth during the spike-growth period is limited by the shortened duration of the period. Possibly leaf-area indices are also insufficient to intercept all radiation, essentially a consequence of reductions in duration of earlier periods. This appeared to be the case in a study of crop heating at CIANO, Ciudad Obregon, Mexico (14); grain number reductions were closely related to reductions in spike dry weight at higher temperatures and in tropical locations. Additional mechanisms by which grain number is reduced at higher temperatures and in tropical locations are alluded to in Table 2.

*Partitioning of dry weight to the spike*—At Tlaltizapan and, especially, at Poza Rica in Midmore's study in Mexico (27), late cultivars sensitive to vernalization or photoperiod produced few grains/ $\text{m}^2$  relative to dry weight at anthesis; these were precisely the cultivars which produced most growth at anthesis. The problem was due to low investment in spike tissue and a

high percentage at anthesis of green tillers which failed to bear spikes (often the spike died in the boot), and with small, abnormal spikes for daylength-sensitive cultivars (26,27). In earlier, relatively insensitive cultivars, the proportion of dry weight invested in spikes was unaffected at either tropical site, as was the case at high temperatures in a controlled environment (31). If the connection, under hot conditions, between lateness and high total dry matter at anthesis, on the one hand, and poor partitioning to (and fertility of) spikes, on the other, could be broken, grain numbers would be increased substantially.

*Grain set*—Grain number per unit of spike weight (Table 2) is largely influenced by grain set. There are several controlled environment studies indicating that high temperature reduces grain set, i.e., increases the proportion of large and superficially normal florets which are sterile and do not bear grain (23,32,43). Curiously, early high temperature may increase grain set (1). In Gabo wheat, usually grown at  $20^\circ\text{C}$ , grain set was reduced 60 and 30%, respectively, on exposure to a continuous temperature of  $30^\circ\text{C}$ , or  $30^\circ\text{C}$  by day and  $20^\circ\text{C}$  at night, for three days at meiosis (about flag-leaf emergence) (32). Plant water status was unaffected; but abnormalities in both ovary and pollen development were recorded (33). Another study, while not finding an effect from a  $30/25^\circ\text{C}$  temperature regime with Gabo, found effects with other cultivars (42). Other controlled environment studies have shown that final grain set is weakly sensitive to elevated temperatures at and soon after anthesis (35,41), but is insensitive after seven to ten days have elapsed (39). Evidence accumulated in the Division of Plant Industry laboratory and elsewhere (9) shows that continuous high humidity (70%) around meiosis can also reduce grain set in certain cultivars. The mechanisms involved are not known.

Unfortunately, the significance of these controlled-environment findings to field conditions, where little attention has been paid to grain set *per se*, is not clear. Soil water deficit-induced male sterility can be very striking in the greenhouse, but is less evident, although important, in the field; the same may apply to high temperature and humidity-induced sterility. In any case, the subject needs attention and the approach outlined here of measuring spike (or chaff) weight and grains per unit weight (or grain set) is recommended. Should grain set problems be evident in tropical conditions, genotypic variation in this response is likely, and careful visual selection against the problem is feasible.

#### **Reduced individual grain weight**

Over the range of 12 to 26°C, increased temperature during grain filling reduces grain weight from 4 to 8% per degree (10,12,39,41,42,43,44); underlying causal mechanisms were alluded to in Table 2. Potential grain weight (unlimited assimilate) appears to be reduced by higher temperatures (a range of 15 to 21°C), according to field studies at CIANO (15). Potential kernel weight may be determined by the number of endosperm cells formed in the early cell-division stage (17,39,41); however, increasing temperature to 24°C did not affect final cell number in one study (41). Actual grain weight is usually below potential, because either filling duration and/or filling rate are inadequate. The depressing effect of higher temperature on duration has been discussed. It should be noted that the termination of grain filling and onset of spike senescence may occur independently of leaf senescence, as demonstrated by spike warming (7) and, therefore, is under different controlling mechanisms. The rate of grain filling becomes greater with higher temperature, but is unable to

fully compensate for the reduction in duration of filling and, in any case, does not increase much above 20°C (35,39).

The supply of assimilate for grain filling comprises pre-anthesis reserves plus current net assimilation (17). Under hotter conditions, increased respiration may contribute to reduced supply, but it cannot fully explain grain weight reductions (10,35). Increased leaf senescence is probably more important and can precede grain maturity, whereas, under cooler conditions, it often follows it. It has been suggested (39) that hastened leaf senescence arises because the protein (nitrogen) demand of grains increases more rapidly with temperature than their carbohydrate demands; this is satisfied by a correspondingly faster withdrawal of nitrogen from the leaves. The increase in grain-nitrogen percentage with higher temperatures is well established (10,36). Finally, photosynthetic rate is unlikely to be affected by higher temperatures, as already discussed, but would be reduced by low radiation during grain filling in parts of the humid tropics.

It would seem that higher temperature shifts the balance towards grain weight limitation through reduced assimilate supply (15,39); thus, leaf-area maintenance (e.g., avoiding premature leaf firing) is probably more critical. This makes more difficult the study or screening of genotypes for resistance to reduced grain weight under controlled-environment conditions, and the few studies available have not found convincing genotypic differences in this temperature response, or that of the components involved. It is conceivable (39) that genotypes with inherently low grain-nitrogen percentages would show lower thermal sensitivity. It is also possible that waxy genotypes would be better, since their leaf and, especially, spike temperatures are lower, (R.A. Richards, personal communication). It is worth noting that grain weight in

rice, another C3 crop plant, is little affected by grain-filling temperature, dropping less than 1% per degree over the range 18° to 33°C (10).

Selection solely for high individual kernel weight, at high or any other temperature, is unlikely to advance yield, as many studies show compensatory declines in other yield components. It may be worthwhile asking whether, for a given grain weight, long duration and slow filling may be a better high temperature strategy than short duration and rapid filling. Although correlated positively in one wheat study (35), work with other crops suggests some independent genetic variation in these two components.

Damage from hot spells during grain filling, when associated with hot dry winds, can lead to grain shriveling; this is mentioned as a problem in parts of the dry tropics. This problem has been investigated (37) and found to be related to air temperature (>40°C appears critical) and associated with reduced plant water status and elevated plant temperature. It is greatly aggravated by soil drought, followed immediately by green-area loss, and is generally unrelated to the exact stage of grain filling. Genotypic adaptations to reduce damage have been claimed (4).

### **Selection for Adaptation to the Tropics**

With regard to yield selection, there would seem to be agreement that, once obvious disorders and unadapted height and maturity types have been eliminated from breeding populations, early-generation visual selection for yield potential is ineffective; yield progress comes from empirical, but effective, yield testing. Spring wheats for temperate regions reached this point some time ago and progress has slowed, stimulating interest in less empirical and perhaps more efficient strategies. In fact, certain physiological

criteria are now being used regularly in some successful breeding programs (e.g., harvest-index selection in the University of Sydney, Australia, program). Drought-resistance criteria (e.g., osmotic adaptation, rooting characteristics) are of special interest (16,20) because testing for yield under dry conditions is very inefficient.

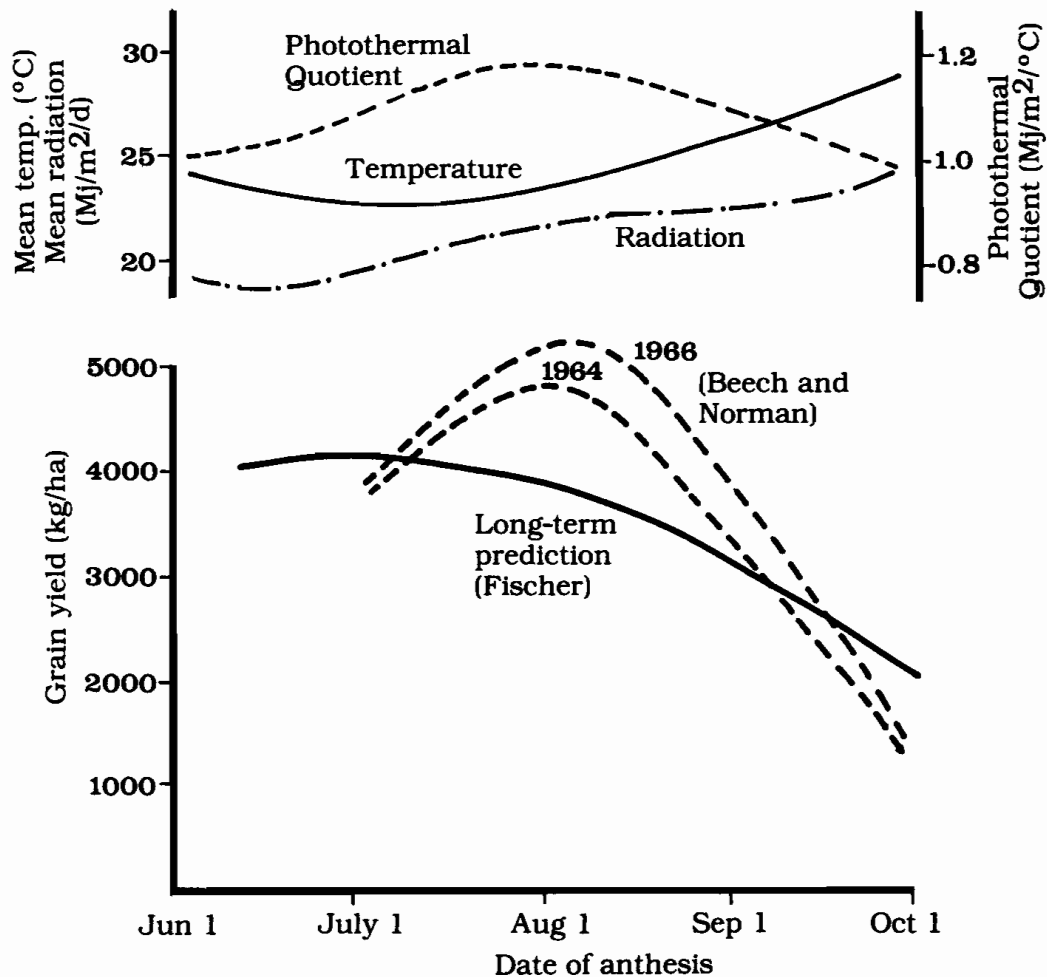
Where then do we stand in regard to wheat in the tropics, and what is the practical relevance of this lengthy and, at times, uncertain discussion of physiology under such conditions? It is probable that there are still high-temperature disorders which can be eliminated by early-generation visual selection, e.g., floret sterility, chlorophyll inadequacies, premature leaf firing and grain shriveling, as distinct from small-sized grains. Yield testing in appropriate tropical environments is also likely to be a more efficient tool for progress than it now is under temperate conditions. Can physiological considerations improve on these traditional and empirical strategies?

Probably the most important issue in any new environment is that of deciding when the wheat crop should reach anthesis, given the ruling climatic constraints. Next follows the question of how many days before optimal anthesis date the crop should be sown (i.e., the best maturity class) and how agronomic management can guarantee this sowing date, assuming that there are no timing constraints from diseases or from preceding or following crops in multiple-cropping situations. Table 3 suggests January anthesis for maximum yield of well-watered wheat at most tropical locations; planting date studies tend to confirm this (6,19,22,38), although they also tend to show a sharper optimum than these predictions suggest (Figure 5). The reason for this is probably that the prediction assumes full light

interception for the month before anthesis. Herein lies the answer to the question about maturity class; the cultivar needs to have enough time (hence, sowing be early enough) to reach adequate light interception (i.e.,  $LAI > 3.0$ ) no later than one month before the optimum anthesis date. Sixty days sowing-to-anthesis is just adequate

if radiation is high and management good; a longer time may be needed otherwise.

The excellent work of De *et al.* (11), although at New Delhi just outside the tropics, illustrates this point. Sown on October 15, October 30 and November 15, Kayansona (with other improved cultivars) was earlier than the older cultivar C306 by 31, 24 and 4 days, respectively. Its yield was 46, 98 and



**Figure 5. Long-term climatic averages, predicted grain yield from these averages and Equation 3, and actual yields for the best cultivars and management in two seasons at Kununurra, northwestern Australia (16°S lat.).**

**Source: Beech and Norman (6)**

105% that of C306 for the three sowings, respectively; the yield of C306 was unaffected by sowing date. Clearly, Kalysansona developed too rapidly to anthesis with the October 15 sowing, and a cultivar like C306, with a small vernalization response, was better adapted to the early date.

Early sowing, as described in this New Delhi study, is often desirable for wheat sown on receding monsoon moisture, although improved agronomic management (better tillage, deep-furrow drills) can permit later seeding. Under such non-irrigated conditions, one of two key issues is the importance of having maximum crop growth coincide with the period of lowest VPD, December to February (Figure 1), in order to maximize WUE. Fortunately, this does not disagree with optimum anthesis date considerations when water is not limiting. The other issue with growth on ample stored water is the importance of maximizing water available for crop transpiration (Equation 4) by having deep rooting. Deep rooting is probably related to having a long sowing-to-anthesis duration, and may be another reason why C306 performs well in the early sowing when WUE may be prejudiced. Certainly, in a dry season, its yield advantage over Kayansona was especially evident (11). The juggling of sowing date and cultivar-maturity class is both complex and profitable in dryland Queensland, Australia (Woodruff, these proceedings). In conclusion, it should be emphasized that there are genetic mechanisms for extending the duration up to anthesis, even under hot conditions. Yield potential will be approximately proportional to duration up to some limit (i.e., 60 to 100 days, depending on the crop growth environment), provided that the longer duration is accompanied by earlier planting and that poor partitioning to the spike and abnormal

spike growth can be avoided. Also, water supply must be adequate to support the extra growth. Breeding for the new tropical environments should be more efficient when optimum anthesis dates and durations are better defined.

Of the other possible adaptations to hot conditions, none has reached the status of recommended selection criteria; however, there are many possibilities worthy of investigation in pilot breeding projects. They are, along with some other relevant physiological questions:

- Vernalization sensitivity versus photoperiod sensitivity to extend duration;
- Spikes cooled by increased waxiness;
- Long sowing-to-anthesis period, for deep rooting and full exploitation of stored water;
- Genetic variability in maintenance respiration;
- Long filling duration versus rapid filling, and low grain-nitrogen content to stabilize grain weight;
- Grain set, as affected by temperature, humidity and other effects;
- The role of the Norin 10 dwarfing genes in the tropics, where stature is reduced in any case, and
- The likely magnitude of heterosis in the tropics.

To this list of worthwhile research topics should be added the analysis and interpretation of international yield trials in the tropics, something which could contribute significantly to the understanding of genetic adaptation, provided enough trials were conducted in a standard manner and with good agronomic management.

Whether or not these specific suggestions on issues are followed, there is no doubt that researchers, both within and outside the international network, will continue to look inquisitively at the physiology of wheat in the tropics. This is good, since so little is known. However, efforts for advancing general understanding would be more useful if a minimum set of information were collected and reported in future field experiments. At the least, this should include sowing date, established plant population, anthesis date, yield, harvest index and individual grain weight. Prevailing temperatures are essential information, and reliable radiation data are important. If the crop is rainfed and water limited, data on soil moisture at sowing and maturity, rainfall and pan evaporation are essential. Everyone should agree on these data. A serious consideration is urged of measurements of ground cover or light interception, total and spike dry matter at anthesis and counting of florets and grains to determine grain set. Growth and yield sampling should be on an area basis, rather than per plant, and edge effects must be avoided. Finally, those tempted or obliged to work in controlled environments should continually examine results for their relevance to field research programs.

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## Soil Management as an Alternative for Minimizing Environmental Constraints for Wheat Production in the Semitropical Areas of Brazil

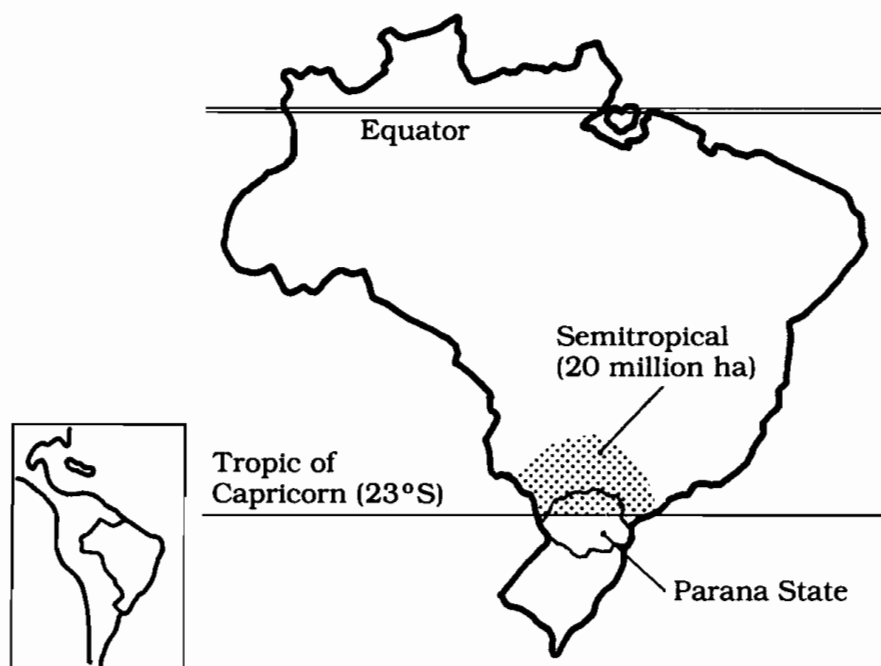
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### Abstract

*In the semitropical areas of Brazil, the increase and stabilization of wheat production are restricted by such environmental factors as irregular rainfall, frost, soil acidity, low fertility and disease, associated with improper soil management. Some progress has been obtained by Brazilian research efforts for finding alternatives to minimize these environmental constraints. Alternatives include cropping practices and the use of varieties tolerant to soil acidity, combined with soil tillage methods and appropriate use of fertilizers.*

Under Brazilian semitropical conditions (Figure 1), the increase and stabilization of wheat production is mainly affected by climatic conditions and diseases. Other factors are improper soil management, which promotes erosion and obstructs root development, and natural soil constraints such as acidity and low fertility.

The breeding programs in Brazil have achieved great genetic progress in obtaining varieties better adapted to its environmental conditions. Some of the major accomplishments are soil-acidity tolerance, disease resistance, heat tolerance (better adaptation to the



**Figure 1. The Brazilian semitropical area (inset of South America showing Brazil)**

relatively warm autumn-winter season) and nonsensitivity to photoperiod. This technical progress has allowed the expansion of the wheat production boundaries toward more tropical conditions, such as the Cerrados region in central Brazil (2). Because of this, environmental constraints can no longer be considered an impediment to wheat production in semitropical areas. Nevertheless, a challenge remains for agricultural scientists in the development of alternative cropping practices more appropriate to tropical and semitropical conditions. Such alternatives and their association with advances in plant breeding can help to increase and stabilize wheat production under these conditions.

The aim of this paper is to report some of the progress, obtained through Brazilian agricultural research efforts, in finding alternatives to minimize environmental constraints for wheat production in the semitropical areas, particularly those obtained by the Agronomy Institute of Parana (IAPAR) for the prevailing conditions of the northern part of the state of Parana.

### Alternatives to Minimize Climatic Constraints

Among climatic factors, irregular rainfall during the season is the most important constraint affecting wheat production in the Brazilian semitropical

area (Table 1). Sporadic frost occurrence (once or twice in each five-year period) is also a constraint when it coincides with wheat heading. However, frost occurrence cannot be predicted and farmers accept that risk.

In northern Parana, rainfall affects wheat production, mainly through unreliable distribution rather than by amount during the cropping period. According to data shown in Table 2, despite low rainfall in 1968, wheat yields were reasonable (900 kg/ha) in comparison to the state average (1000 kg/ha). On the other hand, the excess of rainfall during the heading-maturing stages in 1972 led to very low yields (245 kg/ha) and also affected grain quality. In 1974, rainfall distribution was adequate to supply crop needs during the growing period, resulting in better yield levels (1547 kg/ha) (3).

Yield instability due to such climatic conditions may be minimized within certain limits by adopting the stagger sowing practice. This consists of planting varieties of different maturities at different times, within the recommended wheat-sowing calendar. Associated with this practice, the adoption of soil tillage methods for improving water storage in the arable layer is desirable as an alternative to minimize the negative effects of the lack of rainfall during the winter season. Figure 2 shows the increasing

**Table 1. Occurrence of climatic factors affecting wheat production, northern Parana state, Brazil, 1974 to 1978**

Climatic factor	Occurrence <sup>a/</sup>					Average
	1974	1975	1976	1977	1978	
Frost	0	xxx	0	0	0	x
Excessive rainfall	0	0	xx	0	0	x
Lack of rainfall	x	xx	0	xxx	xxx	xx

<sup>a/</sup> 0 = did not occur; x = light occurrence; xx = medium occurrence; xxx = heavy occurrence

Source: Y.R. Mehta (personal communication)

water content in the surface arable layer of an oxisol soil (red latosol) when the zero tillage system is adopted (7). This practice in the soybean-wheat rotation leaves the soil surface covered by the crop residues. This cover or mulch reduces water evaporation and stabilizes the temperature in the arable layer. By reducing soil disturbance through no-tillage, the soil structure is improved, soil compaction is minimized

and roots can penetrate more deeply, resulting in better growth. As a consequence of more uniform and vigorous growth, the wheat crop can better tolerate inadequate rainfall, and grain yields can be increased (Table 3). However, there were negative effects of frost in the 1979 season under no-tillage; damage was more pronounced due to the lower temperature caused by the mulching effect on the soil surface.

**Table 2. Rainfall during the various wheat growth stages as related to grain yields under northern Parana semitropical conditions, Brazil, 1968 to 1978**

Growth stage	Rainfall (mm)			Average 1968-78
	1968	1972	1974	
Sowing-shooting (March/April)	93	157	197	60
Shooting-heading (May/June)	68	156	313	108
Heading-maturity (July/August)	88	415	80	167
Total rainfall	249	728	590	875
Wheat yields (kg/ha)	(899)	(245)	(1547)	

Source: Godoy and Bernardes (3)

**Table 3. Comparison of wheat yields under inadequate and normal rainfall conditions related to tillage systems, northern Parana, Brazil, 1977 to 1980**

Rainfall/year	Wheat yields (kg/ha) according to tillage system	
	Conventional	No-tillage
Inadequate		
1977	609	967
1978	507	2036
Normal		
1979	1854	1281 <sup>a/</sup>
1980	1867	1799
4-year average (1977-1980)	1209	1521

<sup>a/</sup> Frost damage

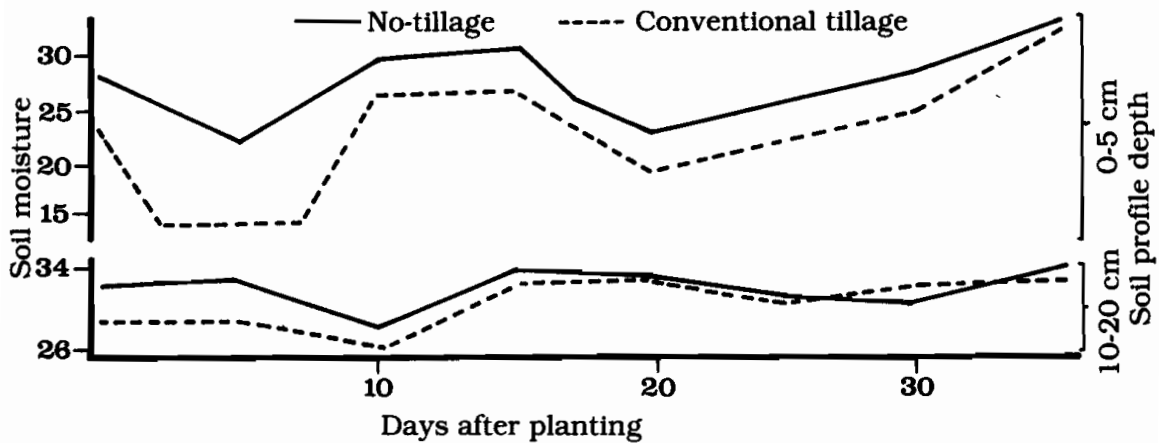
Source: Vieira (7)

**Alternatives to Minimize Soil Constraints**

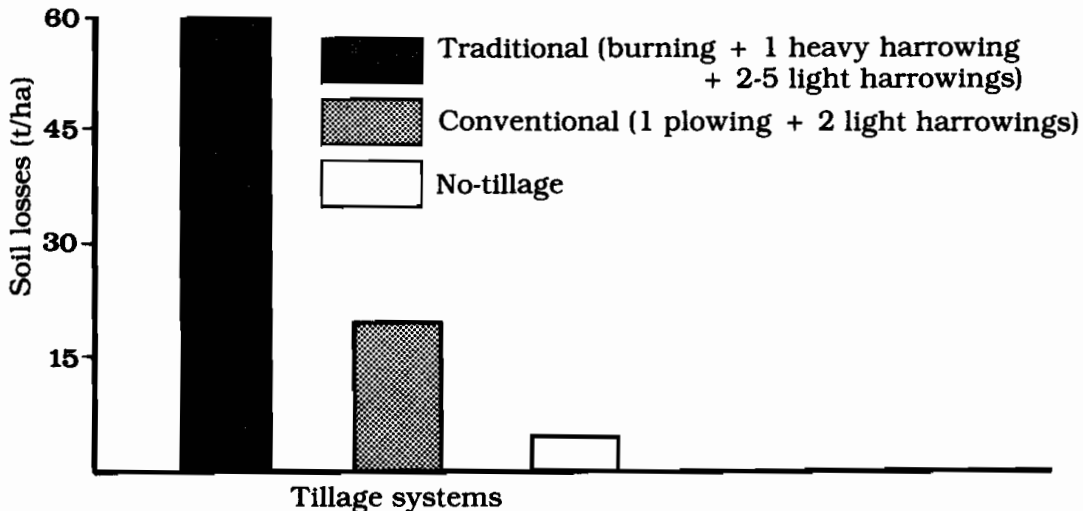
**Soil conservation and water retention**

Soil tillage practices utilized in the soybean-wheat rotation are leading to severe soil erosion in the Brazilian semitropical area. Burning wheat straw after harvest, followed by land preparation using heavy disc harrows, are common practices. These operations result in an intensive disturbance of the arable surface layer

(0 to 10 cm), destroy organic matter, decrease water infiltration and build up a compacted layer (hard-pan) between the 10 and 15-cm depth, causing strong run-off and inadequate conditions for root penetration and development. Soil erosion losses can be reduced 70 to 90% by adopting a more appropriate conventional tillage method (plowing plus two light harrowings) or a no-tillage system (Figure 3). No-tillage enhances surface mulching by leaving crop residues and helps to increase water retention and water availability for the wheat crop (Figure 2).



**Figure 2. Soil-water availability under conventional and zero tillage systems in an oxisol soil, northern Parana, Brazil**



**Figure 3. Soil losses by erosion as related to tillage systems in an oxisol (red latosol) soil, northern Parana, Brazil**

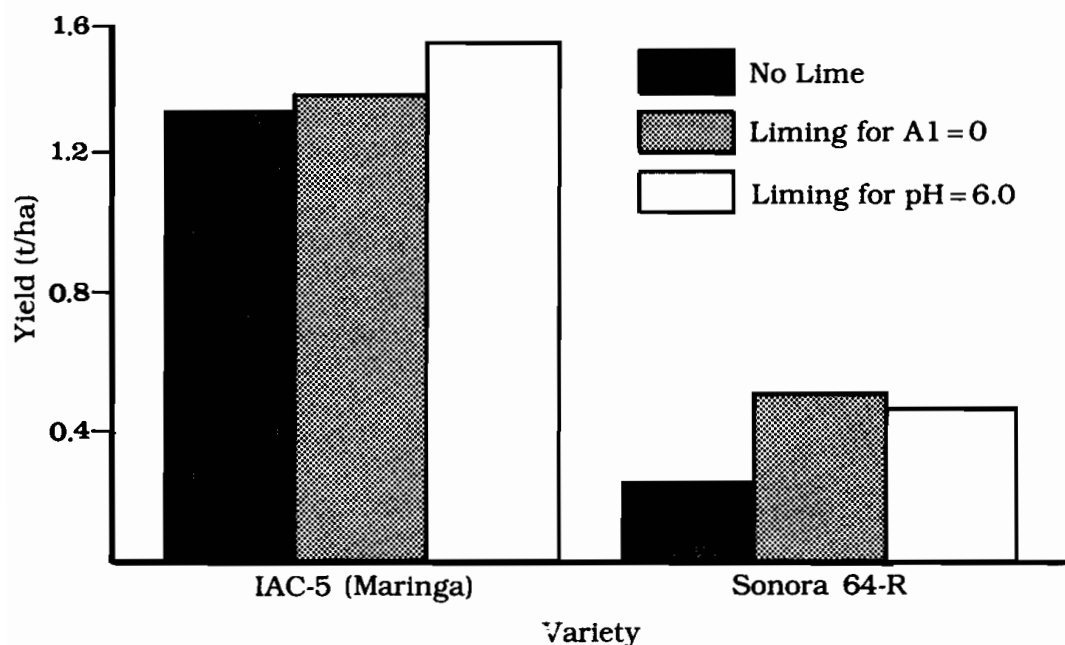
### Tolerance to soil acidity

Soil acidity is one of the major constraints for agricultural production in tropical and subtropical soils in Brazil, and effects of excess aluminum on the wheat crop are well known. Advances in plant breeding, initiated by Iwar Beckmann in southern Brazil in 1920, have led to the development of aluminum-tolerant varieties which give reasonable yields under acid soil conditions, even when lime is not applied; sensitive varieties give lower yields even when lime is applied (Figure 4). To arrive at appropriate recommendations for farmers, the

variety tolerance level to soil acidity must be considered, since soils are variable in acidity levels and varieties give different performance on acid soils, even with liming. Under field conditions, a study was carried out in order to characterize limit-values for % of soil-aluminum saturation:

$$(\% \text{ Al} = \frac{\text{Al}}{\text{Al} + \text{Ca} + \text{Mg} + \text{K}} \times 100)$$

This formula can be used as a parameter to quantify the tolerance of wheat varieties to soil acidity. Table 4



**Figure 4. Effects of liming on yield of two wheat varieties in an oxisol (red latosol) soil, northern Parana, Brazil**

**Table 4. Criteria used to classify aluminum tolerance of wheat varieties, Parana, Brazil**

Tolerance level of variety	Critical value of soil-Al saturation (80 cm profile depth)
Highly susceptible	Less than 5 %
Susceptible	Less than 20 %
Medium tolerant	Less than 35 %
Tolerant	Less than 45 %
Highly tolerant	More than 45 %

shows the classification of wheat varieties according to their aluminum resistance (4). Since 1979, the recommendation of varieties for the acid soils of Parana have been based on this criteria.

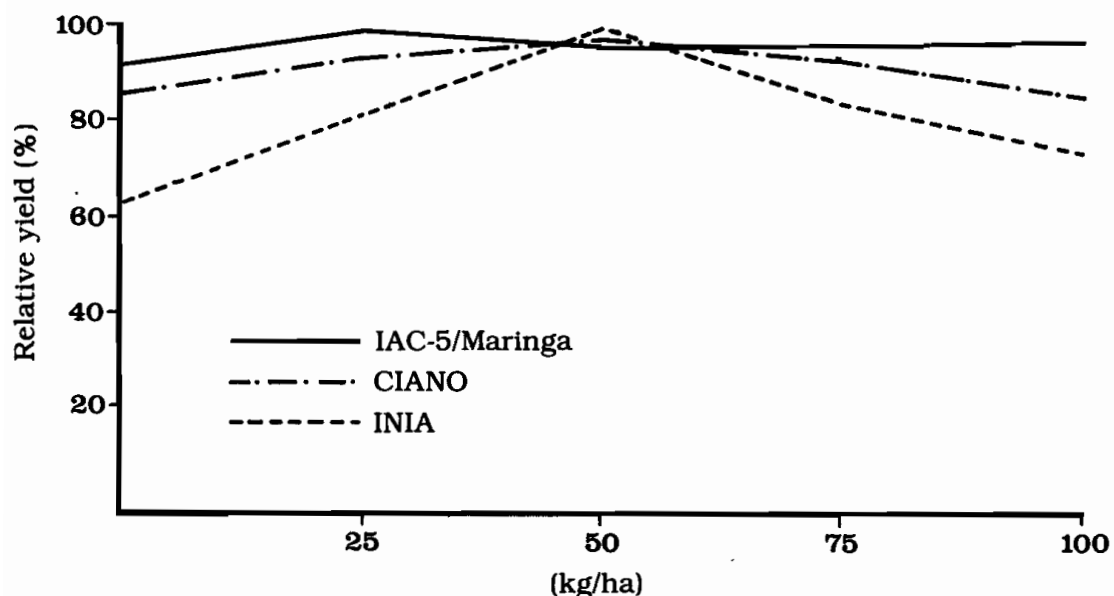
#### Nitrogen fertilization

With Brazilian wheat varieties, the use of high nitrogen levels frequently promotes negative effects, such as lodging, increased disease susceptibility and delayed maturity due to an extension of the vegetative growth period. Usually the Brazilian varieties do not respond to levels higher than 30 kg N/ha and, under Brazilian cropping conditions, even the Mexican varieties do not respond to levels higher than 60 kg N/ha (Figure 5). The low N response may be due to the benefits of the soybean-wheat double cropping system. Soybeans supply that nutrient to the soil, not only through symbiotic N fixation, but also because remaining crop residues (6 to 8 t/ha) increase the N availability in the arable layer after the organic material is decomposed. Therefore, a large part of the N needed

by the following wheat crop is supplied (5). Varietal response to nitrogen differs from one region to another and from one year to another in the same region. This variation is mainly due to climatic factors, particularly rainfall occurrence.

#### Phosphorus fertilization

Tropical soils are, in general, poor in available phosphorus, and the majority of annual crops show a strong reaction to phosphorus application. The relevant effects of phosphorus, in areas where wheat has recently been cultivated, have induced the use of relatively high amounts of this nutrient. The widespread adoption of this practice in the soybean-wheat rotation has promoted a gradual increase in soil-phosphorus availability after several years, and an equilibrium is being achieved between crop needs and P availability in the soil. As a consequence, the response to phosphorus application has tended to decrease, a fact supported by experimental data (Figure 6). Once this condition is achieved, it is possible to reduce the amount of phosphorus



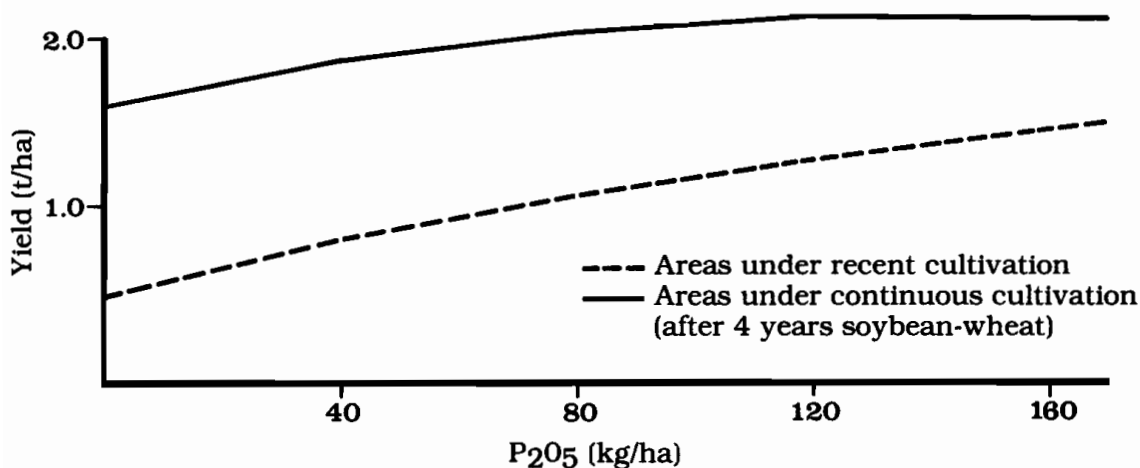
**Figure 5. Responses of three wheat varieties to nitrogen fertilization, northern Parana, Brazil**

applied without increasing the risk of yield reductions (Figure 7). Thus, production costs can be lowered (5).

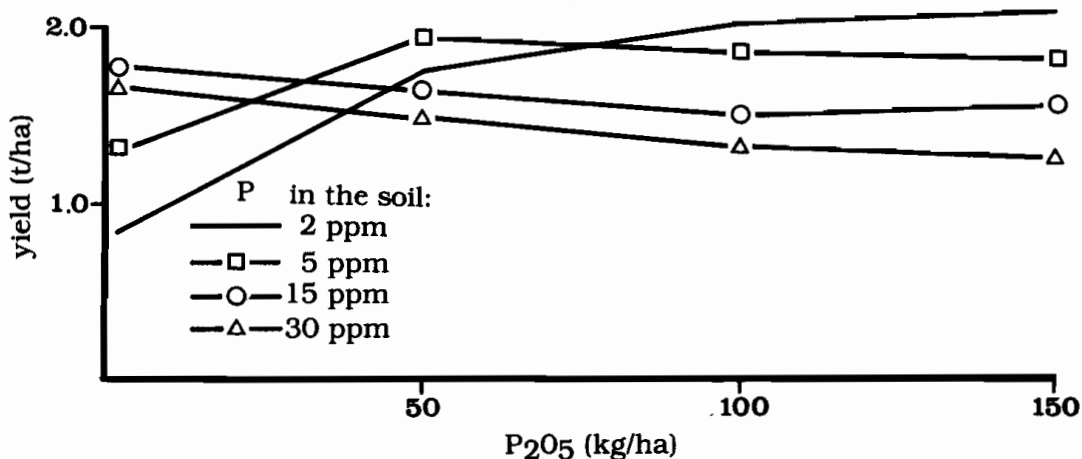
Adverse environmental factors associated with improper soil management and diseases are constraints affecting wheat production in the Brazilian semitropical areas. Considering the high cost of production and the high value of land in these areas, appropriate technologies must be generated and adopted, especially in terms of land use and soil management, in order to minimize environmental

constraints, increase wheat production and lower production costs.

Agricultural scientists are challenged to develop efficient alternative soil management and cropping practices, appropriate to the environment and to farmers' conditions. Also, the Extension Service must devote more effort to advising farmers about the relevance of these practices as options for reducing risks and increasing benefits, thus making possible the success of wheat production in the semitropical areas.



**Figure 6. Wheat response to phosphorus application in areas under recent wheat cultivation and after four years of soybean-wheat rotation, Parana, Brazil**



**Figure 7. Wheat response to phosphorus application in an oxisol (red latosol) soil as related to P availability in the soil, Parana, Brazil**

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## The Cerrados: Future Wheat Production Prospects and Limitations

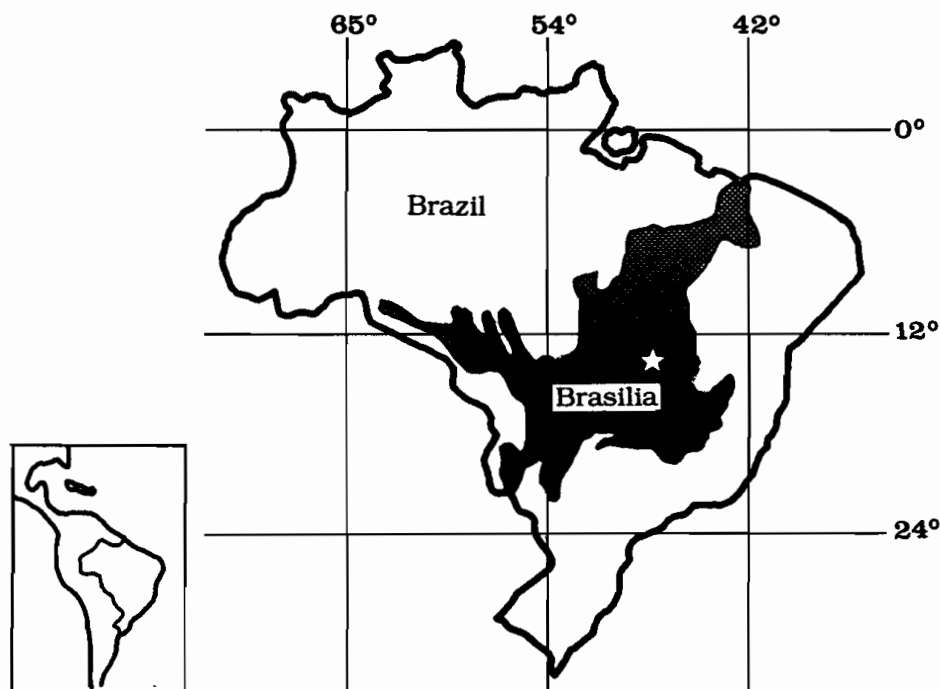
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### Abstract

*Over the past twenty years, a lot of interest has been shown in developing the agricultural potential of what is known as the Campos Cerrados. The Campos Cerrados is a semitropical savannah composed of a woodland-shrub-grassland complex which is thought to be an edaphic climax. This means that the soil is the major factor in the development of the vegetation. The soil is based on a very old geological surface and has been highly weathered and leached, leaving very few nutrients and a subsequent breakdown of clays; the underlying rock is mostly shale. Similar areas are found in Africa.*

The increased interest in the Cerrados is due to the following factors:

- It covers a very large area suitable for crop production; of an estimated 50 million hectares, only 3% is at present under cultivation (Figure 1);
- It has suitable temperatures for most crops, and sufficient summer rainfall (Figure 2);
- It has a well-developed and still developing infrastructure (i.e., transport), and
- Its virgin land prices are still low (5).



**Figure 1. Distribution of Cerrados (shaded area) in Brazil (inset of South America showing Brazil)**

**Source: Goedert (5)**

### Soil Fertility Problems

The soils most suited for cropping in the Cerrados are the red-yellow latosols and the dark red latosols. A survey carried out by Lopes and Cox (8) shows that these soils are extremely low in fertility in every aspect except organic matter (Table 1). Virgin soils normally have a reasonable level of organic matter, but this is decreased by cropping, and nitrogen needs to be added to obtain high yields of nonleguminous crops. The two main soil problems are 1) low pH with its accompanying high exchangeable aluminum saturation and 2) low soil phosphorus levels. These two problems must be resolved, and their solution will be costly.

### Low pH

The problem of low pH and high exchangeable aluminum saturation can be solved by liming. Two formulas are normally used for making liming recommendations:

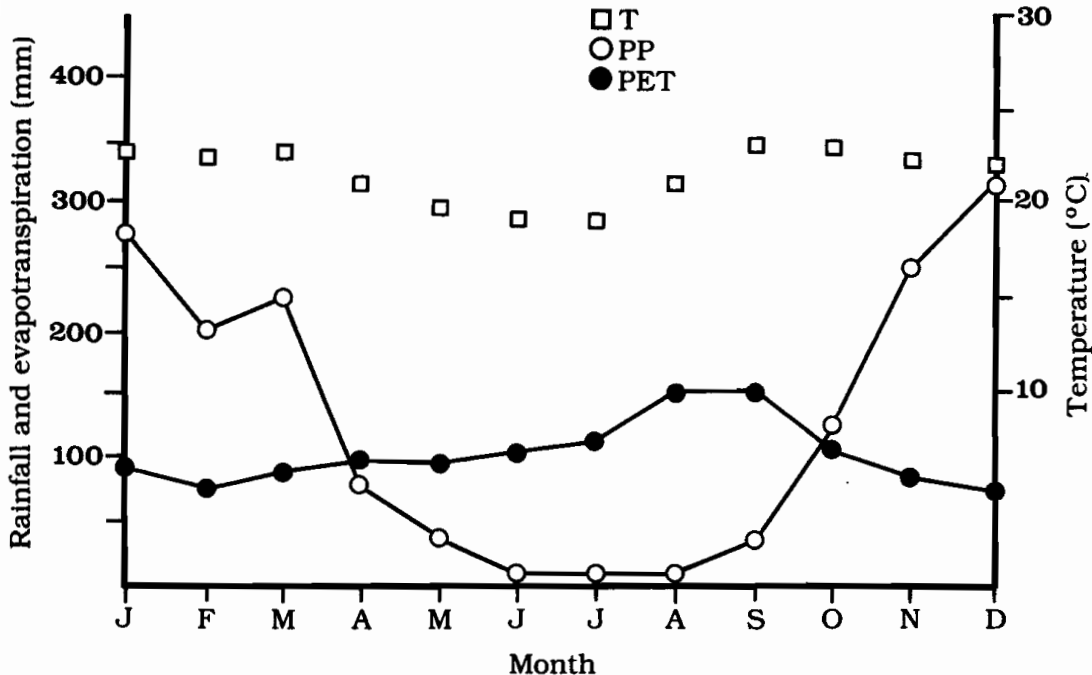
$$\text{CaCO}_3(\text{t/ha}) = 2 \times \text{meq exch Al}/100 \text{ g}$$

or

$$\text{CaCO}_3(\text{t/ha}) = (2 \times \text{meq exch Al}/100 \text{ g}) + [2 - \text{meq exch (Ca + Mg)}/100\text{g}]$$

As a result of these formulas, recommendations usually range from 2 to 4 tons of lime per ha; this results in good crop response.

The lime is usually incorporated to a depth of 30 cm, which corrects the problem only to this level; in other words, with the application of lime, there is an effective rooting depth of only 30 cm. Under Cerrados conditions,

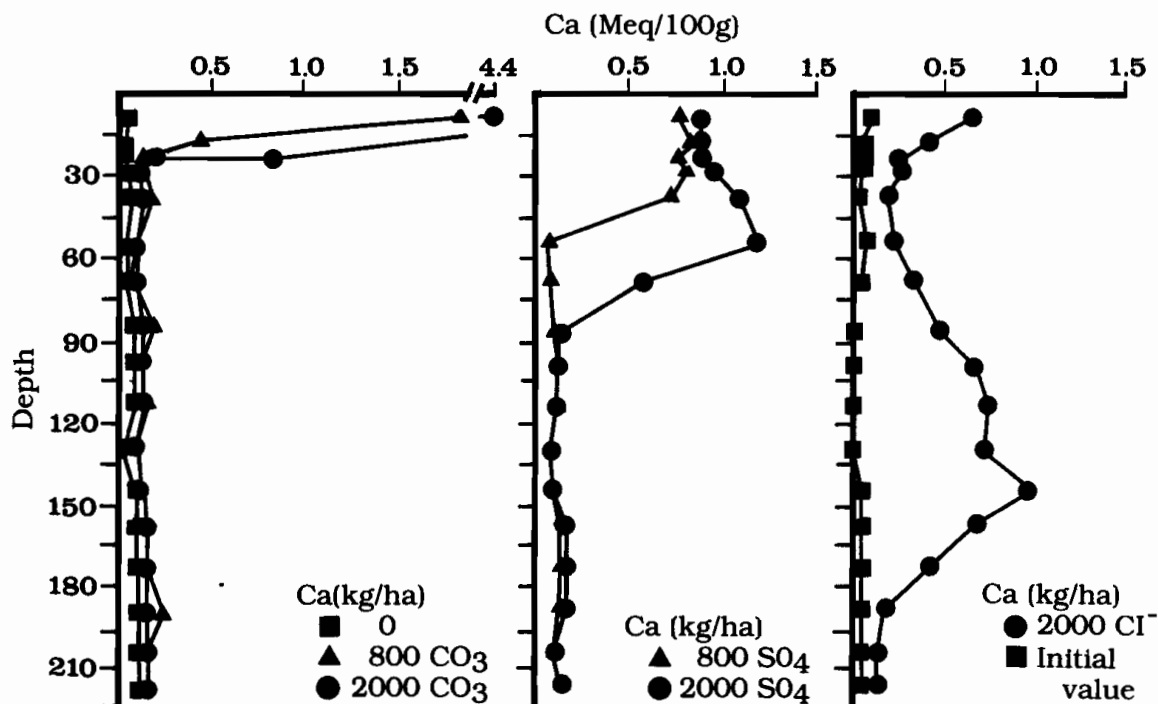


**Figure 2. Climatic conditions of Brasilia, D.F., Brazil (average monthly temperature (T) 21 °C, annual rainfall (PP) 1570 mm and annual potential evapotranspiration (PET) 1280mm)**

**Source: EMBRAPA-CPAC(2)**

there is utilizable water storage for only five to six days ( $ET = 5-6$  mm/day). Therefore, it would be very desirable to increase rooting depth by moving the calcium down the profile. This problem has been the subject of research for a

number of years, and very promising results have been achieved. As shown in Figure 3, wheat root growth responds very dramatically to small concentrations of calcium; therefore,



**Figure 3. Wheat root growth as a function of calcium application in samples taken from the subsoil layer of a red-yellow latosol, Brazil (vertical lines represent 1 SD)**

Source: EMBRAPA-CPAC(4)

**Table 1. Fertility status of a range of soils from the Cerrados area of Brazil**

Parameter	Range	Median	Sufficient level (SL)	Percent of SL
pH	4.30-6.7	5.0	5.0	48 <sup>o</sup> /o below
Extractable phosphorus	0.10-16.5 ppm	0.4 ppm	10 ppm	92 <sup>o</sup> /o below
Extractable potassium	0.02-0.6 meq/100 ml	0.08 meq/100 ml	0.15 meq/100 ml	85 <sup>o</sup> /o below
Exchangeable calcium	0.04-6.81 meq/100 ml	0.25 meq/100 ml	1.5 meq/100 ml	96 <sup>o</sup> /o below
Extractable zinc	0.20-2.2 $\mu$ g/ml	0.6 $\mu$ g/ml	0.8 $\mu$ g/ml	81 <sup>o</sup> /o below
Extractable copper	0-9.7 $\mu$ g/ml	0.65 $\mu$ g/ml	1.0 $\mu$ g/ml	70 <sup>o</sup> /o below
Aluminum saturation	1.10-84.9 <sup>o</sup> /o	59 <sup>o</sup> /o	20 <sup>o</sup> /o	91 <sup>o</sup> /o above
Organic matter	0.70-6.0 <sup>o</sup> /o	2.2 <sup>o</sup> /o	--	60 <sup>o</sup> /o between 1.5 and 3.0 <sup>o</sup> /o
Cation exchange capacity (CEC)	0.35-8.1 meq/100 g	1.1 meq/100 g	--	--

Source: Lopes *et al.* (8)

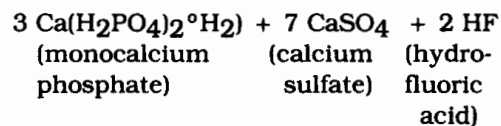
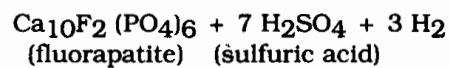
the movement of small amounts of calcium down the profile should increase effective rooting depth. The work of Ritchey *et al.* (10) presents various ways of solving this problem. As can be seen from Figure 4, the rate and amount of movement of calcium down the profile is an electrically neutral phenomenon. Every  $\text{Ca}^{++}$  ion must be accompanied by two monovalent anions, such as  $\text{Cl}^-$ , or one divalent anion, such as  $\text{SO}_4^{--}$ . The accompanying anion, therefore, plays a very important role.

Calcium carbonate ( $\text{CaCO}_3$ ) is neutralized by hydrogen ions at the soil surface; therefore, there is no anion to accompany the calcium down the profile. This results in very little calcium movement from this level.  $\text{CaCl}_2$  is very soluble in water and, since it is monovalent, it reacts very little with the soil colloids. This source of calcium shows the fastest movement down the profile and, possibly, even out

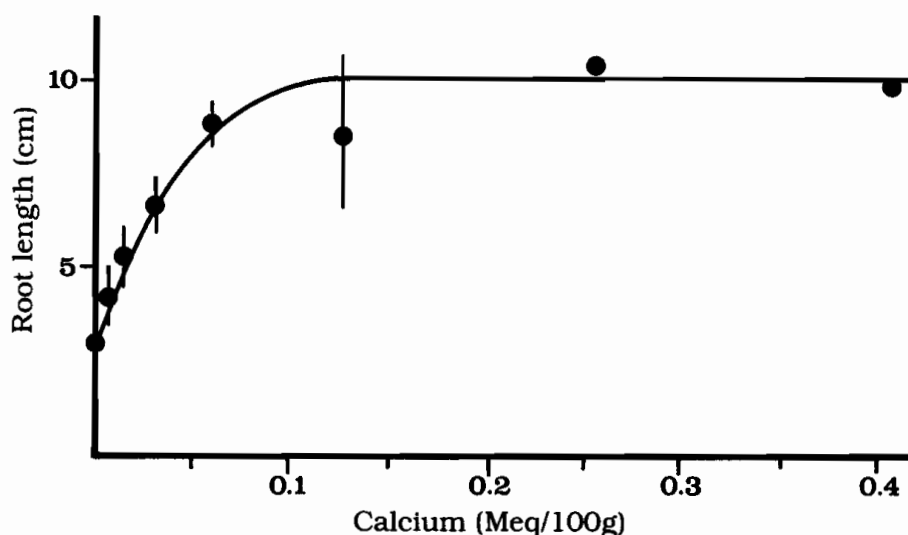
of the rooting zone.  $\text{CaSO}_4$  or gypsum is less soluble and the  $\text{SO}_4^{--}$  ion reacts more strongly with the soil, leading to a more desirable distribution of calcium throughout the profile.

The practical way of achieving good distribution of calcium in the soil is to apply one of the following:

- $\text{CaSO}_4$  (gypsum)
- Single superphosphate (SSP), which contains calcium sulfate. The reaction for producing SSP is:



The effect of varying rates of SSP on calcium and magnesium movement down the profile are shown in Figure 5.



**Figure 4. The effect of various anions on the distributions of calcium in a dark red latosol after leaching, with the equivalent of 1200 mm of rainfall, Brazil**

**Source: Ritchey *et al.* (10)**

- Ammonium sulfate  $[(\text{NH}_4)_2\text{SO}_4]$  as a nitrogenous fertilizer

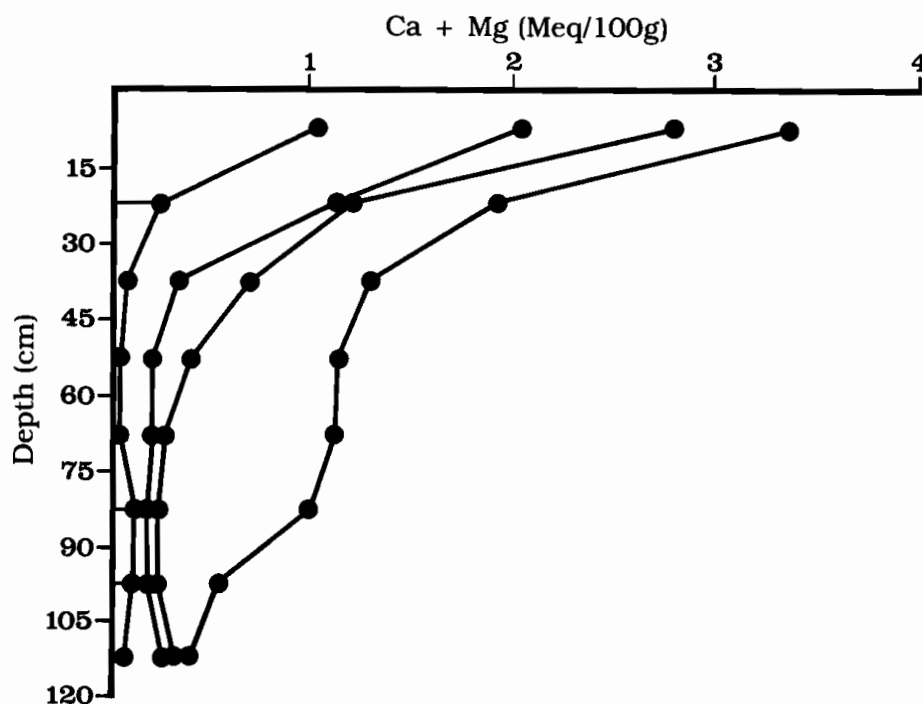
### Low phosphorus levels

Phosphorus is highly and universally deficient in the Cerrados area. Therefore, correction of this deficiency is imperative for the production of crops in these soils. Crop responses to phosphorus fertilization, as shown in Figure 6, include quite high yields, but the amount of phosphorus necessary is also high, with economic levels being in the range of 250 to 500 kg  $\text{P}_2\text{O}_5/\text{ha}$ . Much work has been carried out on different management strategies for the use of phosphorus, such as broadcast versus banded applications and a large single application versus smaller repeated applications. This work is summarized in Table 2.

These results show that, in the long term, yields are determined by the total amount of  $\text{P}_2\text{O}_5$  applied; different methods of application give similar results. However, it was observed that broadcast applications outyielded banded applications for the first crop; the opposite was found after the third crop. An initial broadcast application seems to give better root development and, therefore, better water extraction.

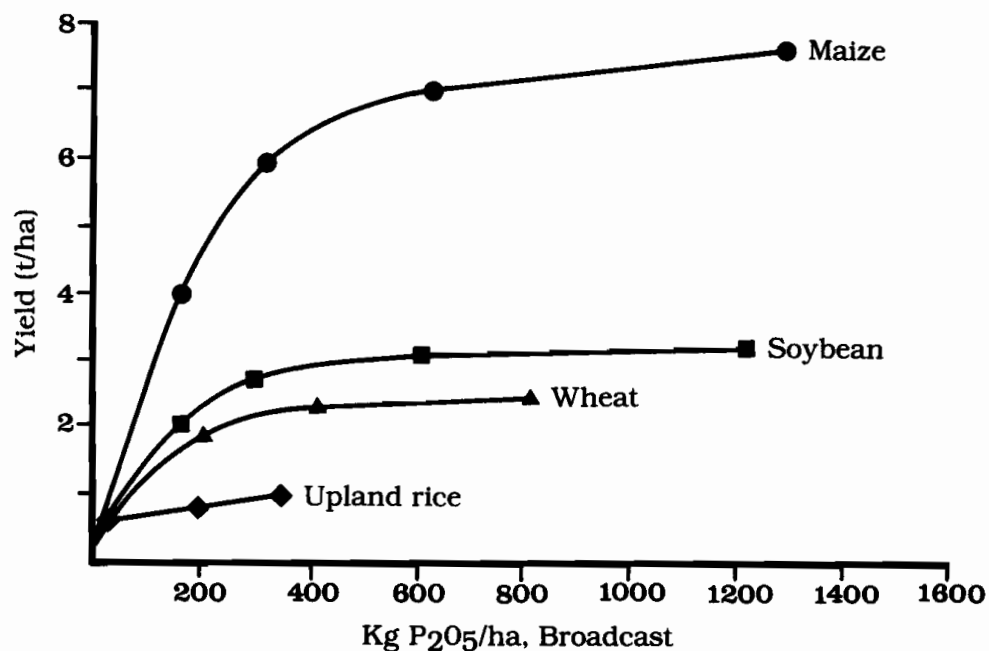
### Low levels of other nutrients

Insufficient zinc and potassium very often limit yields on these soils and their deficiencies need to be corrected. Nitrogen and sulphur usually become deficient after several years of cropping.



**Figure 5. Effect of varying rates of phosphorus (kg/ha) as SSP on the distribution of calcium + magnesium in the soil profile of a dark red latosol, Brazil**

**Source: Ritchey *et al.* (10)**



**Figure 6. Crop responses to phosphate fertilizer, Brasilia, D.F., Brazil**

**Source: Lobato (7)**

**Table 2. The influence of rate and placement of phosphorus fertilizer on the yield of ten consecutive crops of maize on a dark red latosol, Brasilia, D.F., Brazil**

Phosphorus application (kg P <sub>2</sub> O <sub>5</sub> /ha)			Maize yield (10th crop)		Maize yield (total of 10 crops)	
Broadcast	Banded	Total	T/ha	% of best treatment	T/ha	% of best treatment
160	0	160	0.35	6	17.06	28
320	0	320	0.55	10	27.85	45
640	0	640	1.47	27	42.67	69
1280	0	1280	3.98	74	60.83	99
1960	0	1960	5.38	100	61.64	100
0	80(4) <sup>a/</sup>	320	0.88	16	30.09	49
0	160(4)	640	1.90	35	44.05	71
0	320(4)	1280	4.09	76	61.51	100
320	80(4)	640	1.35	25	43.89	71
80	80(10)	880	4.81	89	49.77	81

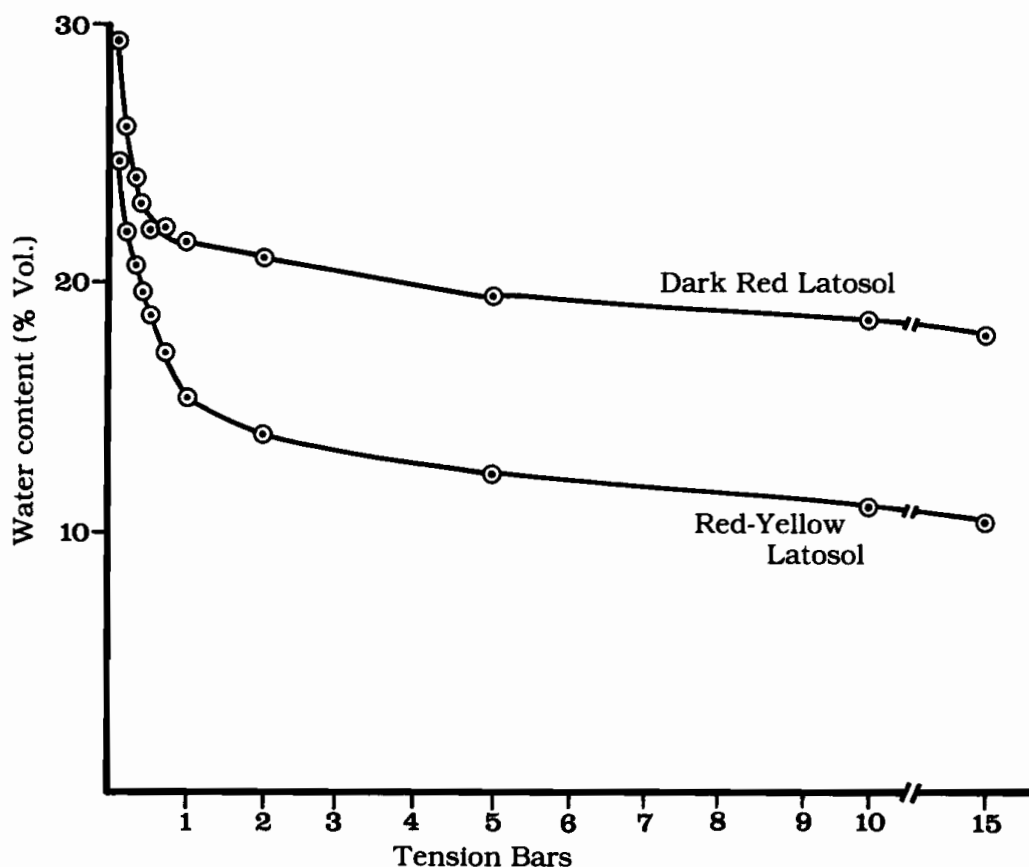
<sup>a/</sup> Numbers in brackets = number of applications

Source: Lobato (7)

### Physical Soil Problems

The soils under the Cerrados are generally deep and drain well; they are easily worked over a wide range of moisture conditions. The moisture release curves of a dark red latosol and a red-yellow latosol are shown in Figure 7. As can be seen from this figure, the water retention characteristics are similar to those of sandy soils. There is very little available water above one bar tension. The total amount of available water is only 33.9 mm in the top 30 cm of a dark red latosol, and 42.3 mm in the top 30 cm of a red-yellow latosol. If

evapotranspiration is 5 to 6 mm per day, drought stress occurs very rapidly if rooting is limited. Therefore, in these soils, it is of utmost importance to increase effective rooting depth. As mentioned earlier, this can be done mechanically, by deep incorporation of lime (although, due to high energy requirements, this seldom exceeds 30 cm), chemically, by applying sulphate salts, or genetically, by selecting materials resistant to aluminum. Breeding resistant materials alone is not sufficient, as there is probably no



**Figure 7. Moisture tension curves for a dark red latosol (DRL) and a red-yellow latosol (RYL)**

**Percent available water (0.1-15 bar) DRL = 11.3, RYL = 14.1**

**Available water (mm) (0-30 cm) DRL = 33.9, RYL = 42.3**

germplasm resistant to the levels of aluminum found in these soils. The use of a combination of the above methods will increase effective rooting depth, which is now the greatest limitation to water use.

### **Future Wheat Production in the Cerrados**

While research has been carried out on wheat in the Cerrados for the past ten years, it has not been with the same intensity as on other crops. This is especially true in terms of agronomic management; the data that exist for other crops are nonexistent for wheat. This is due to the fact that other crops, such as maize and soybeans, are more important to the region economically, and have greater agronomic possibilities because they are sown during the rainy summer season. However, a breeding program based at CPAC, Brasilia, has released a number of wheat varieties in the past few years which have performed well under Cerrados conditions. At the moment, both summer and winter wheat is grown.

#### **Summer wheat**

The summer wheat crop is found above 800 m altitude; it is sown in February, after early-crop soybeans. Because of low yields, this crop has little possibility of continuing. The principal limiting factor for this rainy-season wheat crop is disease, mainly helminthosporium.

#### **Winter wheat**

The wheat crop sown in May, at the beginning of the dry season, and harvested in September has the greatest economic potential. It is grown under irrigation, and is recommended for altitudes above 600 m. Until 1978, this crop was recommended only for areas above 800 m; below that level, spikes showed increasing sterility. However, this problem has been solved through applications of boron.

Varieties exist that can be cultivated under these conditions, based on experimental data generated by CPAC, EPAMIG, ENGOPA and other research institutions in the area. These varieties are recommended by the Commisao Norte Brasileira de Pesquisa de Trigo. In 1982, varieties were recommended for cultivation under irrigation (1) for the area (13°30' to 24°S and 42 to 54°W), according to two classifications:

- For recently cleared soils, above 600 m, which still contain some exchangeable aluminum, recommended varieties were IAC5 (Maringa) and CNT7
- For areas above 600 m, with soils with good fertility and no exchangeable aluminum, recommended varieties were Alondra 4546, Moncho "S", Anahuac, Nambu, Confianca and Jupateco F73

The yielding ability of some of these varieties can be judged from the data in Table 3.

### **Diseases and Pests**

The main wheat diseases are leaf rust (*Puccinia recondita*) and stem rust (*Puccinia graminis*); some powdery mildew (*Erysiphe graminis*) has also been recorded. Genetic resistance to these diseases is easily incorporated and, with a good wheat breeding

**Table 3. Wheat yields of four varieties from the 1978 CIMMYT International Spring Wheat Yield Nursery (ISWYN), CPAC, Planaltina, D.F., Brazil**

Variety	Yield (kg/ha)
Alondra S-46	3455
Jupateco 73	3435
Confianca	2785
Moncho "S"	2510

Source: EMBRAPA-CPAC (3)

program, these diseases will not be a barrier to wheat production in the future. The severity of the rusts will increase with increasing area under wheat production. The life span of any variety under these conditions probably will be four to five years, which further emphasizes the need for a dynamic research program. There is no disease data for sprinkler-irrigated conditions; the general observations of the scientists involved are that sprinkler conditions will not change the disease spectrum. Since the complete cropping sequence made possible by sprinkler irrigation has not been tested, diseases peculiar to such a sequence, if they exist, are not yet known.

Insect problems have not been observed, and weeds, although a

problem with summer crops, do not constitute a problem in the winter season.

### Economic Considerations

The main barriers to increased wheat production in the Cerrados area of Brazil will be economic rather than agronomic. This is especially true if irrigation is incorporated into the system. The cost of reclaiming one hectare of land, as of June, 1984, is shown in Table 4. As can be seen from this table, the irrigation cost per hectare is US\$ 750 or 61% of total cost.

Without irrigation, the cost of reclamation is only US\$ 477.50, and this would also permit the growing of summer crops, such as soybeans, rice and maize.

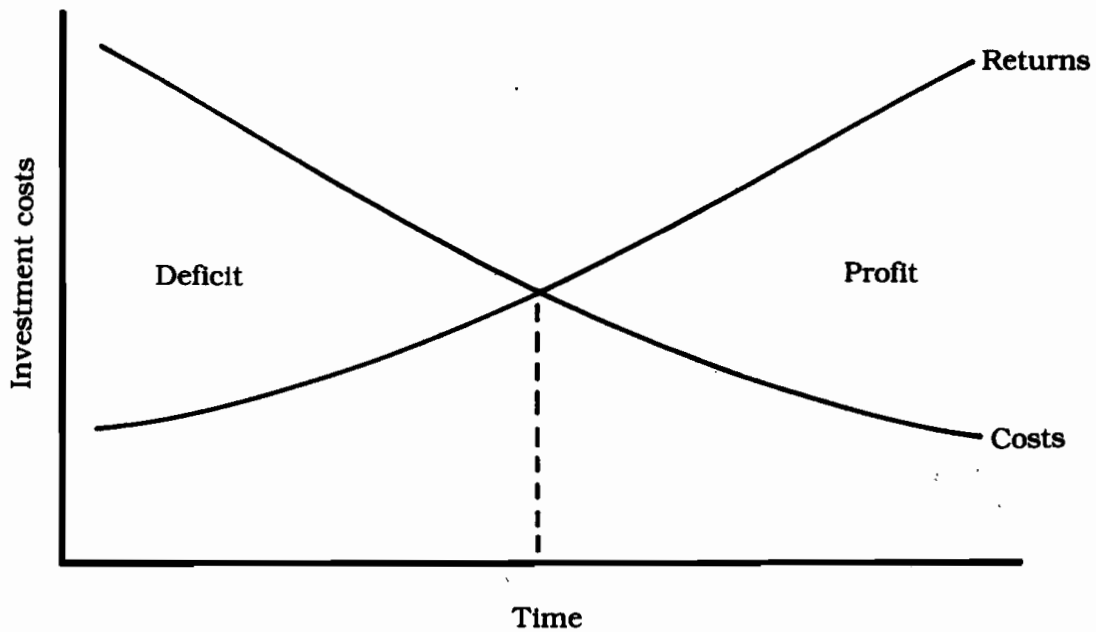
**Table 4. Average cost to reclaim one hectare of Cerrados land, with and without irrigation, Brazil, June 1984**

Reclamation needs	Cost (US\$)	Percent of total cost	
		Dryland	Irrigation
<b>Fertilizer</b>			
Lime	60	13	5
Phosphorus	125	26	10
Potassium	50	10	4
Micronutrients	35	8	4
Subtotal	270	57	23
<b>Land preparation</b>			
Clearing	67.5	14	5
Liming	17.5	4	1
Terracing	15.0	3	1
Other	7.5	1	1
Subtotal	107.5	22	8
Price of virgin Cerrado	100	23	8
Total cost, dryland	477.5	100	--
Cost of irrigation system	750	--	61
Total cost with irrigation	1227.5	--	100

Source: Goedert *et al.* (6)

The other economic consideration is that the large initial investment has a low initial return, caused by low yields in the beginning; this concept is shown

graphically in Figure 8. The break-even point is considered to be four to five years, and very few farmers can carry such costs for that long. These factors may be the greatest barriers to wheat production in the Brazilian Cerrados.



**Figure 8. Hypothetical evolution of costs and returns on a reclaimed Cerrados soil**

**Source: Goedert *et al.* (6)**

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## Alleviating the Constraints of Acid Soils on Rainfed Wheat in Zambia

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### Abstract

*Rainfed wheat cultivation in Zambia is still in the early stages of development. The major problems of production are diseases and acid soils. However, a combination of disease-resistant and aluminum-tolerant varieties, with liming and optimum seeding date, are now giving yields of over 2 t/ha in trial plots and in a few commercial fields. Areas where aluminum toxicity is not a problem are being identified, and the size of the land area available for wheat production is being quantified.*

Very little rainfed wheat is grown in Zambia at present. Attempts to grow wheat between 1975 and 1982 were largely unsuccessful, with yields below 1 t/ha, due mainly to high disease pressure (particularly *Helminthosporium sativum*), aluminum toxicity and the lack of varieties with adequate resistance and tolerance (10). The situation is improving with the recent introduction of PF7748 from Brazil, the use of lime on acid soils and the identification of soils with lower aluminum content.

### Soils

The areas of Zambia with reliable rainfall and reasonable rainfall distribution are mainly in the north of the country, with an annual precipitation of more than 1,000 mm. Most of the soils in this area are reddish brown in color, highly leached and chemically poor, with a pH (CaCl<sub>2</sub>) of about 4.0, CEC of 6 to 13 me/100 g clay and BSP of usually less than 25%; aluminum saturation may exceed 60% in the subsoil. The soil texture is a sandy clay loam, the clay fraction being mainly kaolinite (1,3,4,6). The soils are classified as typic haplustox or xanthic, orthic or rhodic ferralsols (1,3). Their high aluminum content makes them particularly problematic for wheat production.

There are smaller areas of soil developed from basic parent materials which are red in color; the precise location and size of these is not accurately known. They have a higher CEC, approximately 12.20 me/100 g clay, a BSP of 25 to 50%, an average pH of about 5.0 (2) and an aluminum content that is variable, but often quite low. The iron content in the B horizon is very high (average 19%), which probably accounts for the good micro-aggregation of these soils (4); they are classified as ferralic or cambic arenosols (3).

### Aluminum toxicity

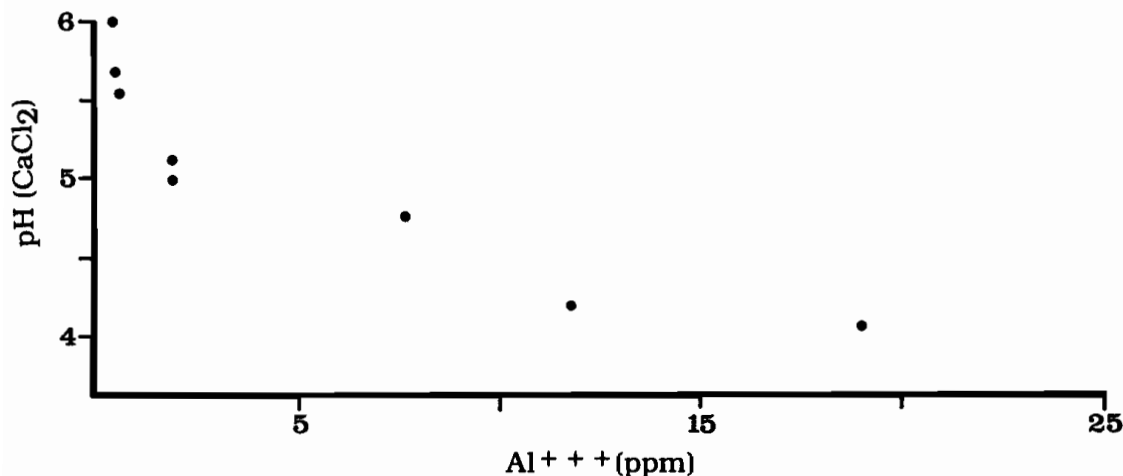
Symptoms of aluminum toxicity are commonly expressed as a swelling and thickening and/or darkening of the root tips and lateral growth of the roots, resulting in shallow rooting. This, in turn, usually results in short, weak plants that are very susceptible to drought, since the shallow rooting allows limited access to nutrients and moisture below. The pH of the soil at the Zambia-Canada Wheat Project farm at Katito, Mbala, is about 4.0, with approximately 20 ppm aluminum (extracted in 0.20 M CaCl<sub>2</sub>), which is highly toxic to wheat.

The relationships between pH and aluminum and between aluminum and wheat yield were studied on a field that had been limed at 2 t/ha and planted with the nontolerant wheat variety Jupateco 73. The distribution of the lime

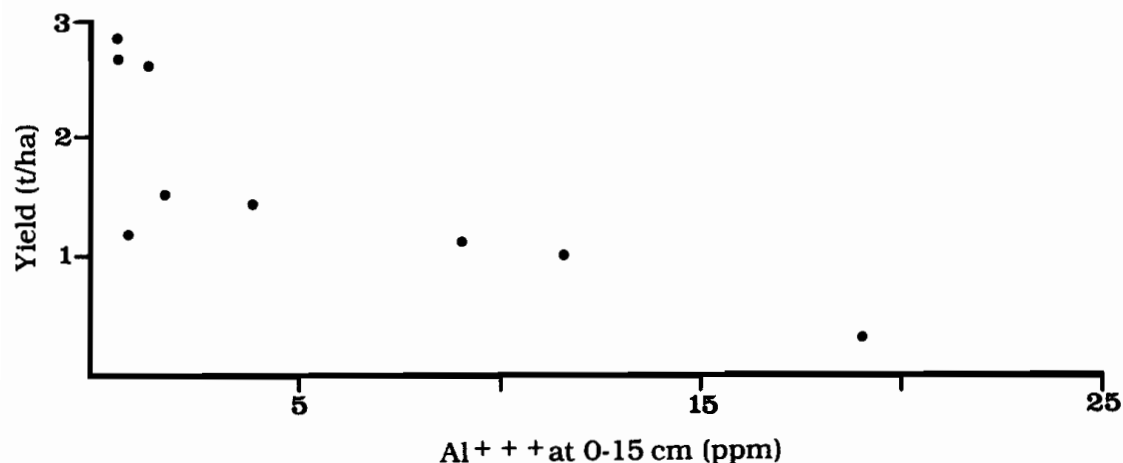
was rather poor and the crop vigor ranged from very poor to good. Soil samples were taken from nine areas with differing crop vigor and analyzed for pH and aluminum. Figure 1 shows a very close correlation between pH and aluminum ( $r = -0.83$ ). Wheat yields were assessed from the same nine areas by taking samples of three  $0.25 \text{ m}^2$  plots in each area. Considering the small plot size, there is a very close correlation between yield and aluminum content ( $r = -0.78$ ) (Figure 2).

#### Alleviating the effects of aluminum toxicity

*Liming*—Rates of lime ranging from 0 to 8 t/ha, in single and split applications to the top 15 cm of soil, have been investigated at Mbala since 1979. Until 1983, the nontolerant variety Jupateco 73 was used, since tolerant varieties (7,8,9,10,11,12). Virtually zero yield was obtained without lime. Four years of trials showed increased wheat yields



**Figure 1. Relationship between soil pH and aluminum presence, Zambia**



**Figure 2. Relationship between wheat yield and presence of aluminum at 0 to 15 cm soil depth, Zambia**

from the application of 1 to 8 t/ha of lime (Table 1); however, only 2 t/ha can be considered economic, and that only marginally so.

A long-term trial investigated the effect on yield of single and split applications of lime over several years. The treatments included single applications of 2 and 4 t/ha in 1979. In Table 2 the yield of the 2 t/ha treatment in 1981 is compared with the 1 t/ha treatment in 1979, plus 0.5 t/ha in 1980 and 1981. Similarly, the yield in 1983 of the 4 t/ha

treatment is compared with that of 2 t/ha in 1979, plus 0.5 t/ha in each of 1980, 1981, 1982 and 1983. There were no significant differences in yield.

Heavy applications of lime (6 and 8 t/ha) to the top 15 cm of soil have caused a downward movement of calcium through the soil profile over time; the lower rates had the same reaction, as evidenced by the amount of soluble aluminum present (Table 3). However, this precipitation of the aluminum in the lower layers has not resulted in any further increase in yield.

Trials investigating deeper incorporation of lime have been carried out for three seasons since 1982 (10,11,12). Depths of 0 to 15, 0 to 30 and 0 to 45 cm have been investigated, with 3 t/ha of lime being applied for each 15 cm of soil. Wheat yields have increased with increasing depth of incorporation, but there has been no benefit of incorporation to 45 cm as compared with 30 cm (Table 4). The practicality and economics of incorporation to these depths on a commercial scale are, of course, questionable.

**Table 1. Effect of lime application at different rates on wheat yield, Zambia, 1979 to 1982**

Lime (t/ha)	Yield (kg/ha) <sup>a/</sup>
0	278
1	586
2	868
4	931
6	981
8	1051

<sup>a/</sup> Mean 1979 to 1982

**Table 2. Comparison of single and split applications of lime on yields of wheat, Zambia, 1981 and 1983**

Treatment	Lime (t/ha)	Yield (t/ha)
<b>1981</b>		
Single application	2	738
Split application <sup>a/</sup>	1 + (0.5 x 2)	685
<b>1983</b>		
Single application	4	950
Split application <sup>b/</sup>	2 + (0.5 x 4)	969

<sup>a/</sup> 1 ton in 1979 and .5 t in 1980 and 1981

<sup>b/</sup> 1 ton in 1979 and .5 t in 1980, 1981, 1982 and 1983

*Tolerant varieties*—The yield of varieties with a wide range of aluminum tolerance was also determined in the trial with deep lime applications; Table 4 includes yield data for the aluminum-tolerant PF7748. It also responded to deeper liming up to 30 cm, but its yields were increased by a factor of less than two; yields of Jupateco 73 were increased by a factor of seven. In these trials, the increase in yield as a result of the use of the tolerant variety in the absence of lime was approximately 800 kg/ha; when lime was used, the difference was only about 260 kg/ha.

**Table 3. Presence of aluminum four years after application of lime to the top 15 cm of soil, Zambia, 1983**

Lime application (t/ha)	Aluminum (ppm) at soil depth	
	15-30 cm	30-45 cm
0	20	18
1	13	15
2	9	19
4	10	19
6	5	17
8	1	1

Considerable effort is being placed on the selection of aluminum-tolerant varieties in Zambia. So far, screening has been done in the field on unlimed land at Mbala. Lines are entered in a nursery consisting of plots of 2 x 2 meter rows spaced 20 cm apart in a randomized block design in three replications. Three rows of each of two control varieties, one tolerant (PF7748) and one nontolerant (Jupateco 73), are seeded along the paths between the replications at right angles to the direction of the nursery rows. The same control varieties are also included in the nursery. Individual plots are scored for aluminum tolerance on a 1 to 9 scale, based on plant vigor at the soft dough stage, relative to the controls seeded in the pathways (PF7748 set at 3 on the scale and Jupateco at 8). This enables adjustments in scoring which take into account the variability in pH and aluminum that occurs in the field. The same check varieties entered in the nursery itself give an added check.

**Table 4. Effect of depth of incorporation of lime on yields of two wheat cultivars, Zambia, 1983 and 1984<sup>a/</sup>**

Lime application (t/ha)	Jupateco 73		PF 7748		Mean	
	Yield (kg/ha)	% of 0 application	Yield (kg/ha)	% of 0 application	Yield (kg/ha)	% of 0 application
0	222	100	1014	100	618	100
3 t in top 15 cm	1269	572	1529	151	1399	226
6 t in top 30 cm	1580	712	1855	183	1718	278
9 t in top 45 cm	1566	705	1767	174	1667	270

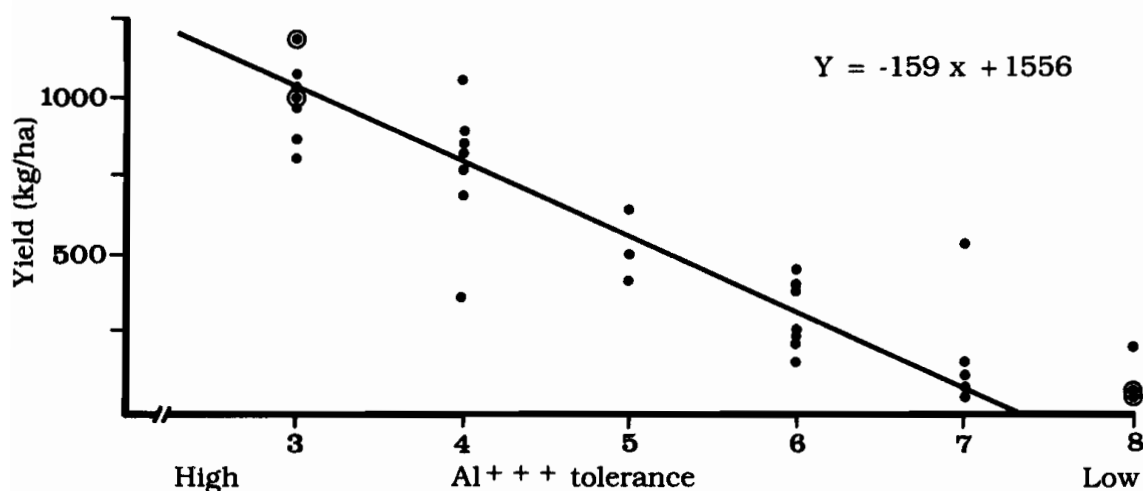
<sup>a/</sup> Mean of 1983 and 1984

In 1983-84, the yields of entries in the aluminum tolerance nursery were determined. Figure 3 shows the correlation between the mean aluminum tolerance score and the mean yield over the three replications ( $r = -0.88^{**}$ ).

These same entries were also included in yield trials at Mbala on limed land (a total of 3.5 t/ha of lime applied to the top 15 cm over four years), and yields from these trials (mean of four replications from net plot sizes of 0.6 x 6 m) have also been correlated with the aluminum-tolerance scores (Figure 4). The correlation coefficient is again very large, negative and highly significant ( $r = -0.88^{**}$ ). This indicates that subsoil acidity is playing a significant role in the determination of yield on limed soils. Liming increases yield but those varieties having poor

aluminum tolerance are affected by subsoil acidity. Therefore, the value of aluminum-tolerant varieties is again evident.

*Early planting*—Aluminum toxicity causes sensitive, shallow rooted plants to be highly susceptible to drought, since they require frequent precipitation to obtain sufficient moisture from the surface layers of the soil. If the rains finish early, the crop can suffer quickly and severely from drought; early planting allows the grain-filling stages of the crop to occur before the rains normally finish. However, this benefit may be off-set by increased disease pressure, due to the enhancement of disease development by the wetter conditions. Currently, the optimum planting date is a compromise for minimizing disease pressure and drought stress. Varieties with more aluminum tolerance and disease resistance will extend this period and reduce risks.



**Figure 3. Relationship of wheat yields on unlimed soil and aluminum-tolerance rating of the cultivar, Zambia, 1983-84**

*Alternative locations*—An evaluation of more suitable areas, those with less acid soils, is being undertaken for growing rainfed wheat in Zambia. Twenty sites from Magoye in the south and Mbala and Nakonde in the north have been planted at two seeding dates and with the best available varieties. The preliminary results indicate promising areas near Nakonde and Mpika and also between Serenje and Mpika. These areas are now being further surveyed to determine the extent of the potential areas.

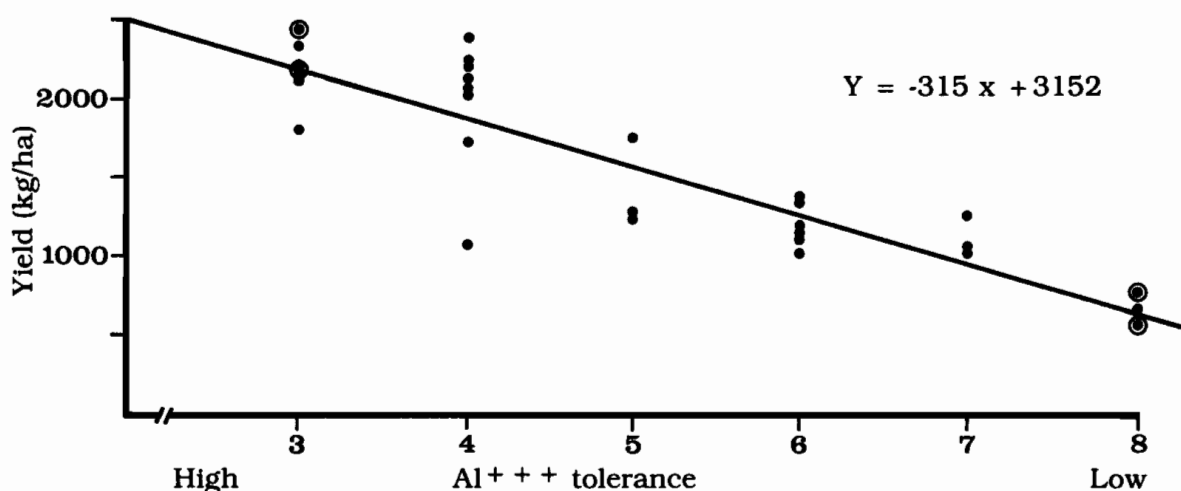
### Conclusions

Yields of about 2.5 t/ha are now being obtained in rainfed wheat trials in Zambia. These have been achieved by combining the use of varieties tolerant to aluminum and resistant to diseases with liming (at about 2 t/ha on acid soils) or growing on soils with a pH (CaCl<sub>2</sub>) of about 5.0, where aluminum toxicity is very much reduced or

absent. Currently recommended fertilizer rates are approximately 20 kg N/ha (basal), 100 kg N/ha (top dressing), 54 kg/ha phosphorus, 36 kg/ha potassium, 30 kg/ha sulphur and 0.3 kg/ha boron.

### Acknowledgements

The use of data of colleagues of the Zambia-Canada Wheat Research Project, B. Aulakh, J. Brandle, L. Hodgins, G. Musa and D. Penney, is gratefully acknowledged. The author also thanks J.R. Boyer, M. Hangala, S.K. Hartley, M.M. Mwanamwenge and M. Ngwele for their technical assistance, as well as Mrs. S. Wateridge for typing and J. Little for preparation of the figures.



**Figure 4. Relationship of wheat yields on limed soil and aluminum-tolerance rating of the cultivar, Zambia, 1983-84**

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## Wheat Production Constraints and Management in Bangladesh

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### Abstract

*The average temperature is quite similar in all of the wheat-growing areas of Bangladesh. The amount and distribution of the monsoon rains and the differences in soil texture and elevation affect the flood situation, which in turn affects the selection of cropping systems by the farmers; the cropping system has a great effect on wheat yields. The main management problems of wheat farmers are the fitting of wheat into the system, land preparation, time of seeding and fertilization.*

A study of the climatic conditions of the different wheat-growing areas of Bangladesh would reveal no great differences in average daily temperature, but significant differences in the amount of average annual rainfall and its distribution. Table 1 shows total annual rainfall and that of the wheat-growing season.

Although the annual rainfall is very high in all locations, ranging from about 1600 mm in the west to 2300 mm in the east, only a small portion of this amount falls during the wheat season. However, the amount and the distribution of rainfall in the monsoon season in different locations affects the time of planting and harvesting of the preceding rice crop; this, in turn, affects the seeding time of wheat.

Another important ecological factor for wheat growth is soil texture. In Bangladesh, wheat is grown in almost all soils except the very heavy-textured soils. Textural differences in soils cause differences in soil moisture, which in turn affects the timing and intensity of tillage operations, as well as the wheat yield level.

Ten percent of the wheat-growing area of Bangladesh is classified as upland, with rice being grown without wetland preparation or transplanting and with complete dependence on rainfall for moisture (2). In these areas, the favorable wheat-seeding date ranges between mid-November and early December; because of the cropping system chosen by the farmers, which

**Table 1. Rainfall in six locations, Bangladesh**

Location	Average rainfall (mm)	
	Annual	Wheat season (Nov-March)
Dinajpur (northwest)	1778	53
Bogra (west)	1756	76
Ishurdi (west)	1585	75
Jessore (southwest)	1652	104
Jamalpur (north)	2241	115
Comilla (east)	2298	151

Source: Manalo (1)

enables an earlier harvest of the preceding rice crop and earlier drying of the soil, it is possible to seed wheat at a favorable date. The remaining 90% of the wheat-growing areas are broadly classified as lowland. There are large variations in these lowland areas, depending on the amount and distribution of rainfall and the texture of the soil.

In Bangladesh, three crops a year are possible, depending on the above-mentioned conditions and irrigation facilities. The most popular rotation systems including wheat are wheat-rice-rice and wheat-fallow-rice.

Different cropping systems are employed in different areas of Bangladesh, according to the occurrence of flood or drought during the monsoon season and because of differences in elevation, soil texture and distribution of rainfall. All of these factors have profound effects on wheat production in terms of management practices. The main management problems may be classified as:

- The addition of wheat to the prevailing cropping system as the second or third crop;
- Land preparation methods;
- Selection of varieties;
- Optimum seeding rate and method, and
- Rate of fertilization and method of application.

### **Research Approaches in Bangladesh**

#### **Fertilization**

Since wheat is a relatively new crop in the country, many farmers still have reservations concerning its value. A belief shared by many farmers is that wheat reduces the yield of the following rice crop. This problem is being studied in a series of fertility experiments, conducted in ten locations on farmers'

fields. It was assumed that the nutrient uptake of wheat resulted in lower yields of the following rice crop because of insufficient application of necessary nutrients to wheat. A split-plot design was used in these experiments, in which applications of nitrogen, phosphorus, potassium and sulphur to wheat were main plots, and the application of the same nutrients to the following rice crop were subplots. The experiments will be evaluated after the harvest of the rice crop.

#### **Tillage**

Since 75% of the wheat in Bangladesh is still grown under non-irrigated conditions, most of the crop is dependent upon residual moisture in the soil. In order to determine which land preparation method will make the best use of residual moisture in the earliest and most economical manner, on-station and on-farm experiments comparing minimum tillage with traditional practices are being conducted. Results thus far indicate that, in light and medium-textured soils, there is no significant yield difference between minimum tillage (seeds sown in rows opened by a country plow and covered with the foot) and traditional tillage (plowing four to five times with a bullock-drawn country plow and smoothing the soil surface after each plowing); in heavier textured soils, higher wheat yields have been obtained from minimum tillage.

#### **Planting date**

The time of seeding depends upon the harvest of the preceding crop and/or the water status of the soil. The time of seeding is one of the most important factors affecting yield. An experiment was conducted in two locations to evaluate the performance of several wheat varieties at different dates of seeding. For each variety, a linear regression of individual variety yield on the mean yield of all varieties was computed. The mean yields of all varieties at different dates provided a

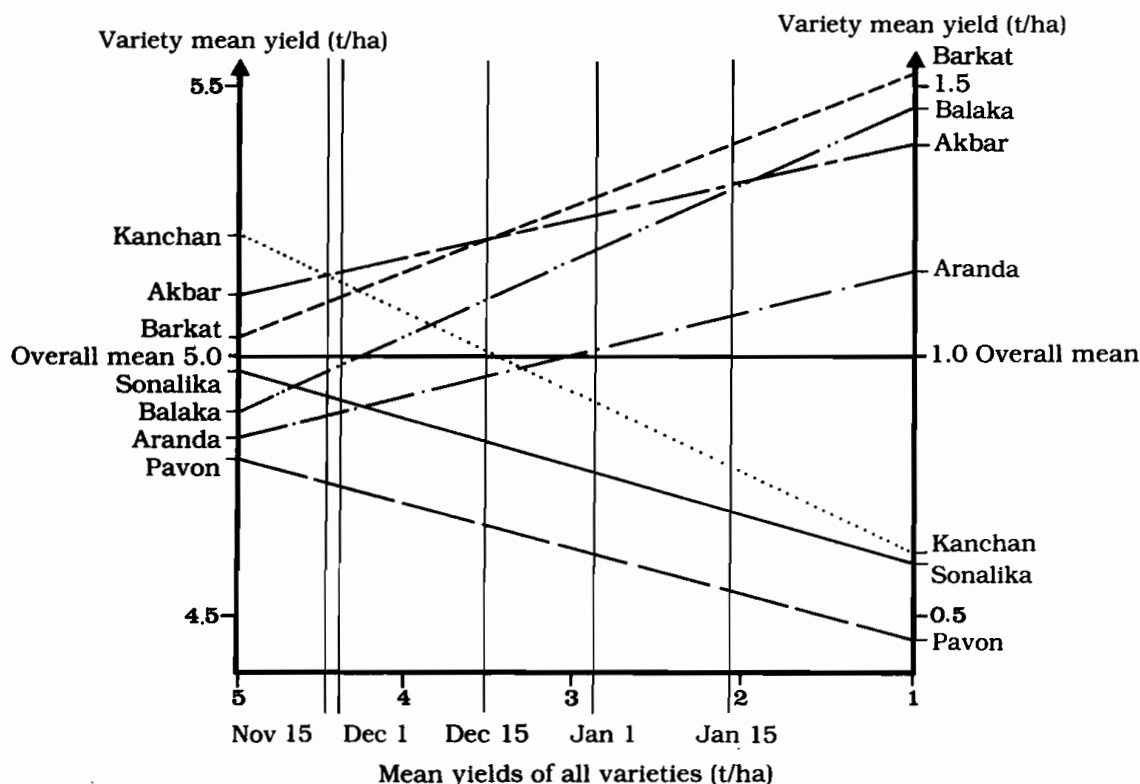
numerical grading which showed the yield potential for each date. Then, the individual variety yields were plotted against the mean of all variety yields, according to the regression equations obtained. Although the yield differences among the varieties were within a range of 0.5 t/ha when the mean of all varieties was 4.5 t/ha at the optimum date of seeding, this range was close to 1 t/ha at later dates of seeding when the mean yield was approximately 2 t/ha. These results demonstrated the great importance of selecting appropriate varieties for later seeding dates (Figure 1). Most of the newly released varieties performed better than Sonalika, which currently occupies more than 75% of the wheat area. The varieties Kanchan, Akbar and Barkat yielded better than the mean of all varieties at optimum dates of seeding, while Barkat, Balaka and Akbar performed better when sown at later dates.

### Other research areas

Research on seeding rate, nutrient rate and seeding and fertilizer application methods has been conducted with competence and success throughout the country since 1974. Some recommendations for farmers are available as a result of this research.

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**Figure 1. Yields of seven wheat varieties according to planting date, Bangladesh**

## **Agronomic Management Issues for Wheat Production in More Tropical Environments of Southeast Asia**

**D.A. Saunders, Wheat Program, CIMMYT, Bangkok, Thailand**

### **Abstract**

*Wheat is not intended as a competitor to established crops in Southeast Asia; rather, due to its relative water efficiency, it is expected to produce crops where none are presently grown. Where some irrigation is available, management must be directed towards avoidance of waterlogging, particularly during establishment. Under rainfed conditions, the correct timing of sowing and the conservation of soil moisture are key factors. Strategies can involve reduced cultivation depth, reduced or zero tillage and straw mulching. Weed populations are high in both irrigated and rainfed areas, necessitating excessive labor inputs for control by hand weeding; chemicals to control major weed species have been identified. Response to nitrogen fertilizer is normally obtained, but responses to phosphorus have not been consistent.*

Wheat has been cultivated on restricted areas, mainly at high altitudes, in Southeast Asia for many years; it is now proposed that it might be grown at lower elevations where a larger land potential exists. This interest has been stimulated by the increasing consumption of wheat products (approximately 12% per annum) throughout the region.

There are basically two situations where wheat may be fitted into existing farming systems without competing with other well-adapted crops. The first is in areas where dry-season irrigation is not available, and the crop would be grown on residual moisture plus any rainfall during the crop cycle. This encompasses rainfed paddy, after rice, and upland areas, usually following maize. The other situation is in lowland soils, following rice, where the quantity or availability of irrigation water cannot sustain another rice crop. Present management aims to maximize the yield of relatively unadapted varieties within the climatic and cropping-systems restraints.

### **Soil and Water Management**

Preliminary estimates of crop-water use suggest that a successful rainfed crop may be grown on about 350 mm of water in northern Thailand, and that the greatest chance of success is where the upper 1.5 meters of soil has an available water content (AWC) of approximately 250 mm (14). This recommendation would be affected by the expectation of rainfall during the crop cycle and the influence of a shallow water table (22).

The objective in the rainfed situation is to commence the crop in a full soil profile, while avoiding periods of prolonged waterlogging. On upland soils this presents few difficulties; the farmer has sufficient time to prepare the seedbed (due to early harvest of the prior crop in the rotation) and merely seeds into a full profile when the probability of continuous, heavy rainfall has decreased.

On rainfed paddy, wheat seeding would often be delayed beyond the optimal time (in relation to rainfall probabilities), due to the utilization of long growing season rice varieties (8); crop establishment systems should be

directed towards minimum loss of soil moisture. In these heavy soils, the practice of rather deep tillage creates large clods which are difficult and time-consuming to break down and, therefore, during this time, soil moisture is lost (16). The more intensive the tillage, the greater the moisture loss (21). There should be a reduction of tillage depth, preferably not deeper than 5 cm, to reduce moisture loss from the lower soil layers (22). In many areas where hand tractors are becoming widespread (e.g., Philippines, Sumatra, Indonesia and northern Thailand), this would be possible through the use of rototillers for creating a fine mulch of soil and straw-residue.

Alternatively, rice straw can be utilized as mulch. Impressive yield increases have been reported in the Philippines for a number of upland crops following rice, soybeans and mungbean (11), maize (21) and wheat (S.P. Liboon, personal communication). Among the benefits of mulching are reduced evaporation and increased infiltration (10), lower soil temperature (4) and improved fertilizer availability (21). Of course, the availability of straw, the economics of the operation and the effects on plant diseases must be considered.

Another strategy could be to use zero or minimum tillage methods, after burning the rice stubble or in the standing straw; the latter reduces moisture loss (21). Direct seeding by various methods, and seeding following conventional tillage have resulted in comparable yields in the Philippines (S.P. Liboon, personal communication). In the extreme, wheat has been relay cropped in rice in Taiwan (6). However, weed populations are usually greater with reduced tillage systems (13,20), and ratoon growth of rice could cause problems. Surface-applied fertilizers, particularly phosphorus, may also be poorly utilized (9), and some disease problems such as *Sclerotium rolfsii* may be increased (12).

In lowland situations where limited irrigation is possible, water will normally be available, at least for crop establishment. The most consistent management problem on paddy land is that of the waterlogging of the crop, particularly in the establishment phase, either through too much water being applied or through insufficient drainage after irrigation. It is recommended that pre-irrigation following seedbed preparation be practiced, and the seed sown into drained soil. Where inundation from rainfall or uncontrolled water is a possibility, a bed or ridge and furrow system of culture should be followed. Small differences in micro-relief have resulted in large effects on crop survival and development. Alternatively, drainage canals at regular intervals could be provided (20). Present indications are that well-controlled irrigations at any crop growth stage between early tillering and milk stage increase yield. The largest effect from a single irrigation is at the early booting stage of crop development (S.P. Liboon and B. Rerkasem, personal communication).

### Weed Control

The predominant grass weeds in wheat are various species of *Digitaria*, *Eragrostis*, *Eleusine* and *Echinochloa*; broadleaf weeds include *Amaranthus* spp., *Trianthema portulacastrum* and *Portulaca oleracea*. Volunteer rice can also create a serious problem.

The low yields of wheat currently attained under rainfed conditions precludes intensive weed control. Where some supplementary irrigation is available, the increased yield potential should encourage more thorough weed control. Data suggest that the critical period during which weeds must be controlled is the first five weeks after sowing (5).

In pilot sowings in the Philippines, the average labor expenditure for hand weeding has been about 25 man days per hectare (12), although some farmers' fields have required double this amount. Mechanical aids to weeding (rotary hand weeders, hinged hand hoes, bullock-drawn shallow plows and harrow weeders) are being promoted. However, a cheaper and more satisfactory solution in the future might be chemical weed control.

Some commercially available herbicides (e.g., Butachlor, Alachlor, Oxadiazon and Isoproturon) have been tested experimentally with acceptable results (5,18,19). However, in practice, there have been phytotoxicity problems with their use, related to the level of soil moisture following application and to seeding depth. Recently, a wider range of chemicals have been tested in Thailand and in the Philippines. These experiments have consistently demonstrated that a Diclofop-methyl and Chlorsulfuron mixture adequately controls weeds, including volunteer rice.

### **Fertilizer Technology**

Yield responses to nitrogen have been obtained from applications of up to 40 kg of nitrogen per ha in rainfed upland (14) and lowland conditions (S.P. Liboon, personal communication), and 80 to 120 kg/ha with irrigation (15, S.P. Liboon, personal communication). In no experiment has split nitrogen application demonstrated a clear yield advantage over totally basal application (5, S.P. Liboon and O. Werasopon, personal communication). Phosphorus levels measured in many soils in the region are low (often less than 5 ppm, using the Bray II method). It is surprising, then, that virtually no

response to phosphate fertilizers has been obtained, even at rates up to 300 kg of P<sub>2</sub>O<sub>5</sub> per ha.

There have been no responses to potassium, and little experimentation on other elements. However, the generally low yields obtained with adequate moisture, nitrogen, phosphorus and potassium, the response to organic manure in northern Thailand (17) and a study of micronutrient deficiencies/toxicities in Asian paddy soils (7) indicate this to be a potentially productive area of study.

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## Wheat in Rice-Based Cropping Systems in Thailand

**K. Rerkasem and B. Rerkasem, Multiple Cropping Project, Chiang Mai University, Chiang Mai, Thailand**

### Abstract

*Rice-based multiple cropping in Thailand is currently restricted by the low temperatures of the season after rice harvest; this limits the growing of tropical and subtropical crop species, such as rice or soybeans. The shortage of irrigation water after December is also a restriction. A rice-wheat system, with wheat's adaptability to a cool season and its relative tolerance to water stress, offers a more efficient use of limited resources. The requirement for early rice harvest can easily be met by choosing from a wide range of early rice varieties, traditional ones as well as the new IRRI types. In terms of management, land preparation may be a major problem as well as micro-nutrient deficiencies. Seasonal and spatial distribution of irrigation water must be considered in determining the potential area of rice-wheat cropping in northern Thailand.*

### The Potential of Wheat in Rice-Based Cropping Systems

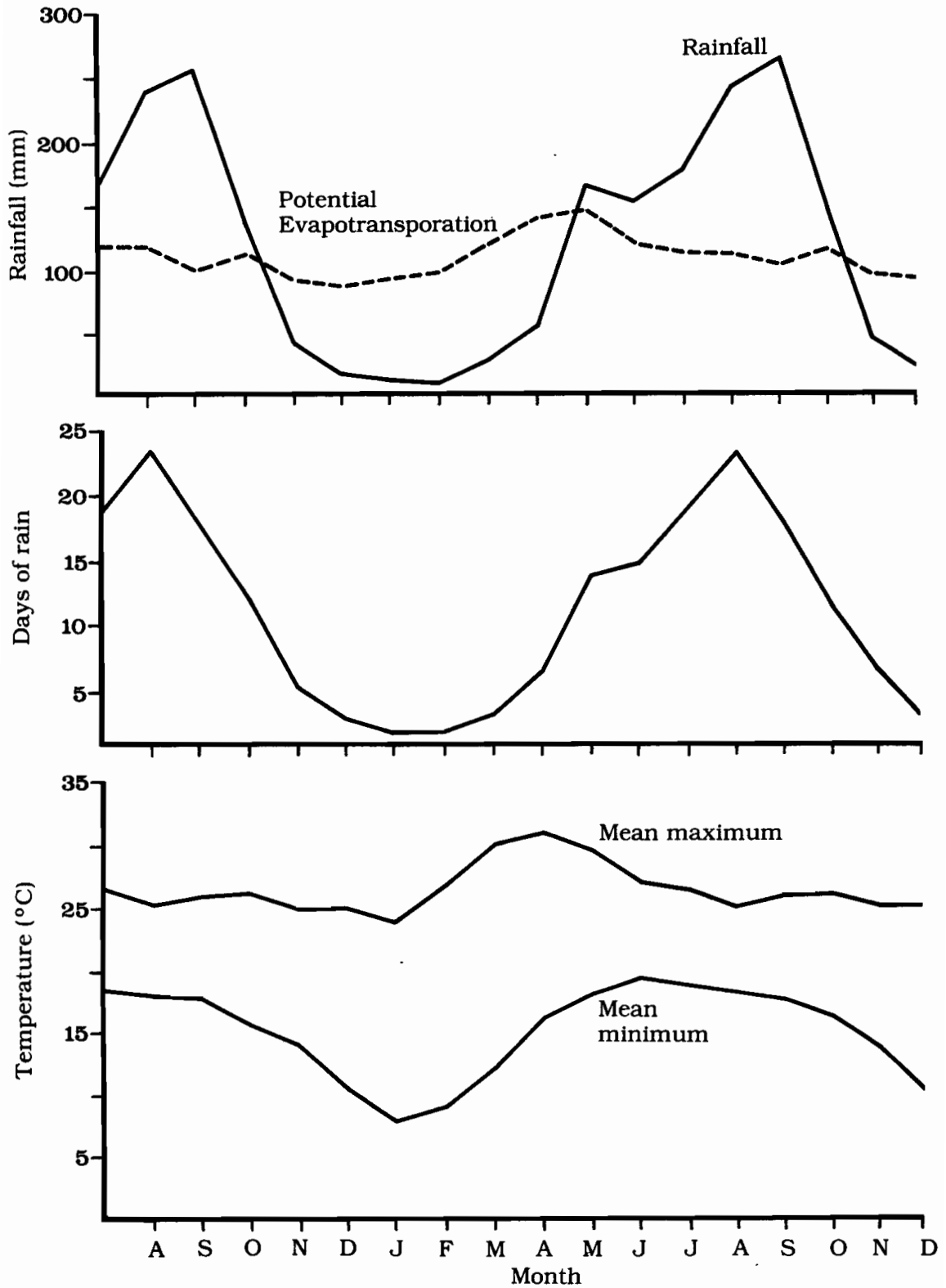
In northern Thailand, where wheat appears to have some potential, there are about 0.5 million hectares of irrigated rice land; this is the possible area for a rice-wheat cropping system. A typical regime of rainfall and temperature for northern Thailand is shown in Figure 1. The rains end quite suddenly in October, so that any dry-season cropping after rice must rely on irrigation. The period from November to February has sufficiently low temperature for temperate crops such as wheat to be grown, but the low night temperatures may limit tropical crops. The planting of soybeans, the major crop grown after rice, must wait until the end of December, because of low night temperatures; there is an even longer delay for dry-season rice. Because of this, the current growing season for a rice-based cropping system must extend to April or even later. Wheat, on the other hand, has been successfully planted in October and November, with an average experimental yield of 3.6 t/ha and a best yield of 5 t/ha with INIA 66. The lower evaporative demand from November to February also can lead to

much better water-use efficiency. Other crops which currently utilize the cool season are garlic, vegetables and tobacco. Their total area is relatively limited, due to restricted demand. Rice-wheat offers an improvement in land and water-use efficiency, with its shorter growing season and better adaptation to cool weather (Figure 2). However, there are several agronomic considerations that may have implications on large-scale adoption of the rice-wheat system in northern Thailand.

### Management Problems of Wheat after Rice

#### Planting date

The growing season for wheat in northern Thailand is relatively short (Figure 1). It is essential that the crop be planted as early as possible, before temperatures begin to rise again. Results from planting-date studies vary considerably from year to year, possibly due to slight variations in the length of the cool season. The latest date that the currently available varieties, such as INIA 66 and CMU26, can be planted without drastic yield reduction ranges from the end of November to mid-December (2).



**Figure 1. Rainfall and temperature, Chiang Mai, northern Thailand (20-year average)**

### Rice varieties

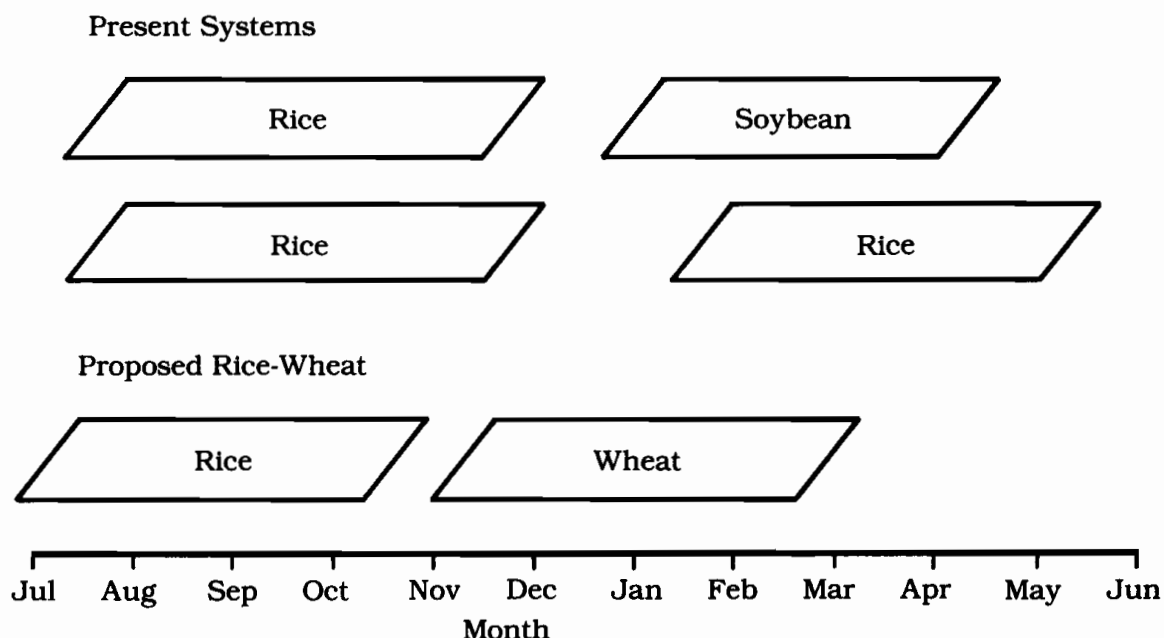
As mentioned above, early planting of wheat is essential; it follows that the preceding rice crop must be harvested early. The range of maturity that exists in rice germplasm now available in northern Thailand is considerable (1). There are traditional, photosensitive varieties which seem to respond to photoperiod changes while the days are still much longer than required to induce flowering in full-season varieties. These early varieties, which can begin to be harvested in early October, have long been used in rice-based cropping systems which require early rice harvest, such as rice-shallot, rice-garlic and rice-tobacco. New IRRI-type RD varieties which are not sensitive to photoperiod, e.g., RD1, RD7 and RD10, offer more alternatives for earliness in rice. Although all of these early rices are somewhat inferior to full-season varieties, experience from the village program of the Multiple Cropping Project has shown that farmers are willing to sustain this loss in the rice crop if it can later be compensated for by the following crop.

### Soil

Rice-based multiple cropping involving upland crops is somewhat of an anomaly. During the rice season, the main objective in soil management is to keep the water in the field. This is achieved with puddling, which effectively destroys any structure that the soil may have; the original structure may be regenerated only in certain soil types. For other soils, management of tillage, water and organic manure is crucial in the modification of soil structure, especially during the early establishment of the crop.

Unfortunately, the majority of rice soils in northern Thailand belong to this group, and the management of tillage and water are extremely critical to wheat yield. Organic manure is now extensively used for high-value crops, but will not be the solution for wheat.

Satisfactory germination and establishment have been achieved by sowing into moist soil and flood irrigating in subsequent applications. A successful practice is that of sowing



**Figure 2. The growing season of a rice-wheat cropping system compared with the existing rice-soybean and rice-rice systems, northern Thailand**

directly into the rice stubble, as is commonly done with soybeans. Preliminary studies have shown that the growth of wheat in rice stubble is better than in tilled soil (Table 1). The method of sowing wheat into stubble deserves further attention. The population density of wheat needs to be

16 to 20 hills per square meter, higher than the original spacing of the old rice crowns.

#### Yield decline

In the last twenty years, there has been a remarkably rapid expansion of multiple cropping in northern Thailand.

**Table 1. A comparison of wheat yields from stubble-sown and conventional tillage, Thailand**

Density effects	Stubble-sown (50 plants/m <sup>2</sup> )	Conventional tillage (plants/m <sup>2</sup> )		
		150	45	112
Yield (t/ha)				
Grain	1.84	2.18	0.30	1.00
Straw	1.83	2.20	0.70	0.80
Total dry matter	3.67	4.38	1.00	1.80
Yield (g/plant)				
Grain	3.68	1.45	0.67	0.89
Straw	3.66	1.47	1.56	0.71
Total dry matter	7.34	2.92	2.22	1.60

Source: Jongkaewwatana, S., and K. Rerkasem, 1982. A study of yield-density relationship on wheat in a rice-wheat system (in Thai). *In* Proceedings of the Third National Winter Grain Workshop, Northern Agricultural Development Centre, Bangkok, Thailand.

**Table 2. Responses to boron application on upland crops grown in rice-based systems, Chiang Mai, Thailand**

Borax application (kg/ha)	Grain yield (g/m <sup>2</sup> )			
	Sunflower <sup>a/</sup>	Soybeans	Peanut	Wheat
0	74.68	197.98	144.66	219.29
6.7	298.47	207.48	157.37	219.12
6.7 + Zn	277.31	207.45	130.90	215.81
10	428.90	160.26	141.86	189.56

<sup>a/</sup> Grown in sunflower-mungbean-rice system

<sup>b/</sup> Dry matter yield

A problem of declining yields has been identified in a long-term study of wheat within intensive rice-based cropping systems; similar symptoms have been observed in farmers' fields in intensively multiple-cropped areas in Chiang Mai (1,3). Micro-nutrient depletion is one likely cause. Wheat has responded markedly to a mixture of boron, copper, zinc and magnesium, but the response to animal manure is even stronger (5). Responses to boron have been observed in sunflower, mungbean and blackgram, but not in wheat, soybeans or peanuts (Table 2). This soil deficiency problem may be a major factor limiting yield potential of wheat in this environment.

#### Water stress

As the dry season progresses, water shortage becomes the most critical problem faced by farmers. From November 1983 to March 1984, an

experiment was carried out at the Multiple Cropping Project at Chiang Mai to evaluate the effects of water stress on wheat yield (Table 3). Wheat appears to be tolerant to water stress in this environment. Receiving only three irrigations in the first four weeks, the crop still yielded 75% of the maximum yield obtained with full irrigation. Omitting one irrigation at boot reduced yield slightly; there was a more marked reduction when an irrigation was missed at anthesis. Yield was unaffected by the omission of one irrigation at crown root initiation, tillering or grain filling.

#### Wheat in the Agricultural System of Northern Thailand

In addition to agronomic feasibility, the main questions related to the introduction of the rice-wheat system

**Table 3. Effects of water stress on grain yield of the wheat cultivar INIA66, Chiang Mai, Thailand, 1983-84**

Treatment	Grain yield <sup>a/</sup> (kg/ha)
Full irrigation <sup>b/</sup>	3226 a
One irrigation omitted at:	
Crown root initiation	3329 a
Tillering	3301 a
Boot	3041 ab
Anthesis	2815 b
Grain filling	3230 a
Two irrigations omitted at anthesis and grain filling	2805 b
Three irrigations omitted at boot, anthesis and grain filling	2398 c

<sup>a/</sup> Numbers followed by same letter not significantly different at P = 0.5

<sup>b/</sup> Full irrigation consisted of six irrigations of approximately 50 mm each at days from sowing -7 (pre-sowing), 9 (crown root initiation), 28 (tillering), 48 (boot), 63 (anthesis) and 77 (grain filling)

are where and how much will be planted; how it will be used is a subject to be covered by other delegates at this meeting. The feasibility of the rice-wheat system in northern Thailand is closely related to availability of irrigation water and its seasonal and spatial distribution.

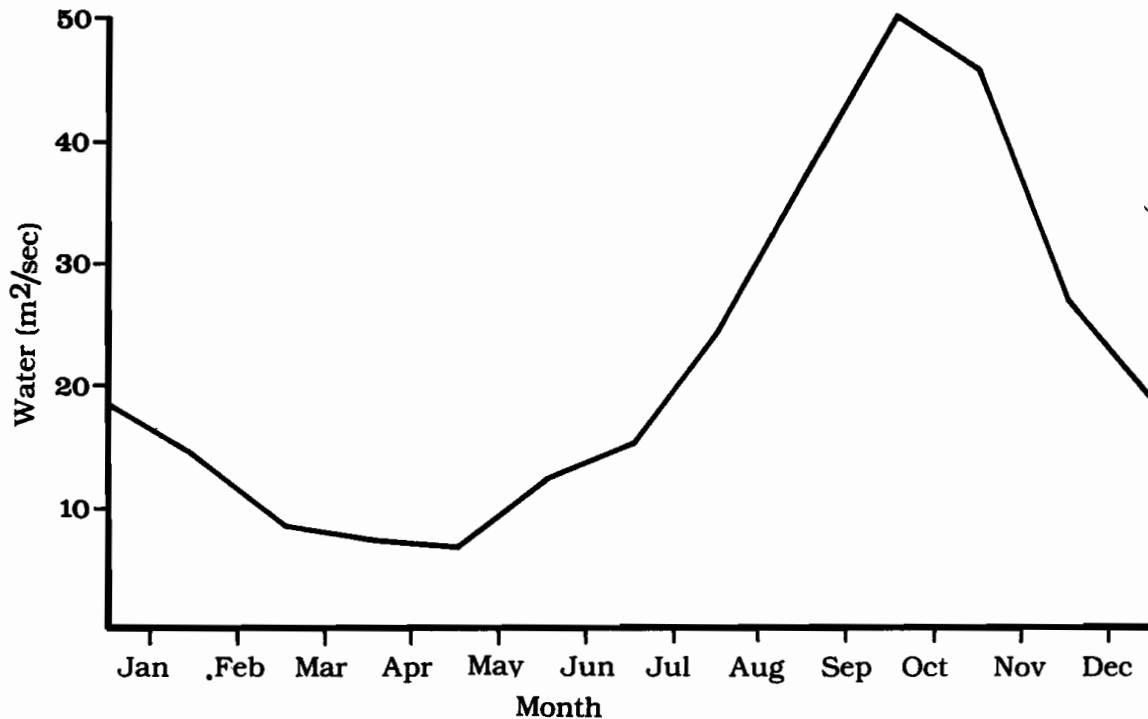
#### **Seasonal distribution of irrigation water**

With the rains ending in October, the level of water in the rivers and streams that is available for irrigation is still quite high until early January. An example from Mae Taeng, the largest irrigation project in the Chiang Mai Valley, is shown in Figure 3. This project covers an area of 24,000 ha of irrigated wetland rice. Currently, there is enough water for only 10,000

hectares of dry-season cropping, mainly soybeans; the area planted to crops after rice under dry-season cropping is limited, mainly by the amount of water available after the end of January. With a system incorporating a shorter growing season, such as rice-wheat, this area could be greatly expanded.

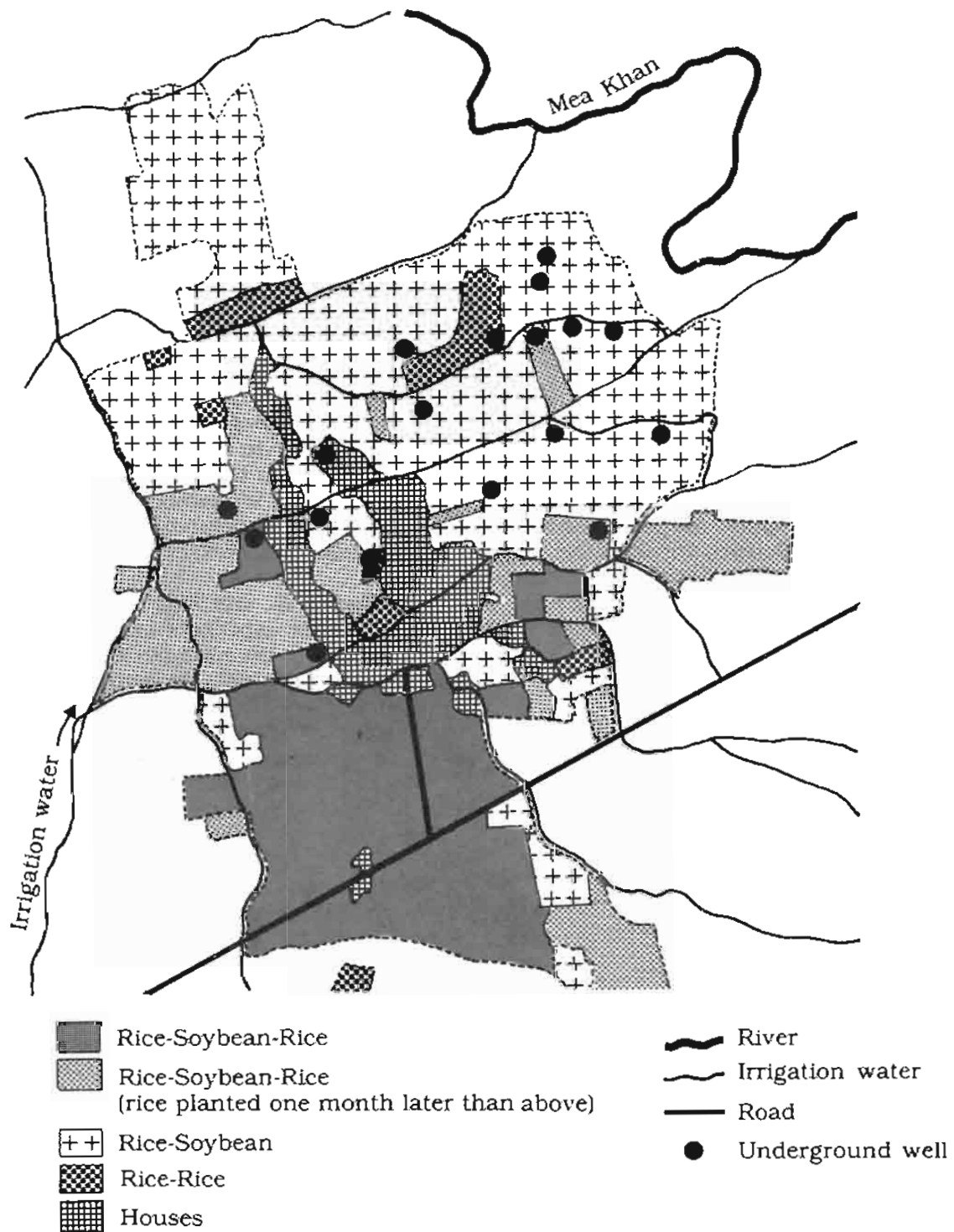
#### **Spatial distribution of irrigation water**

Irrigated rice agriculture in northern Thailand is characterized by its variability over relatively small areas. This is particularly true with respect to the availability of irrigation water in the dry season. For example, a close study of a village south of Chiang Mai showed that, in an area covering 130 hectares of rice land, four distinct cropping systems could be identified as a result of four levels of water availability (Figure 4). This example comes from a village with an extremely good water



**Figure 3. Water available at the wier, Mae Taeng Irrigation Project, Chiang Mai, Thailand (average 1975 to 1982)**

**Source: Royal Irrigation Department, Thailand**



**Figure 4. Distribution of rice-based cropping systems as related to spatial variation in availability of irrigation water, San Pong, Chiang Mai, Thailand**

**Source: Anan Ganjanapan**

supply; in most cases, the range is likely to be at the scarce end of the scale, with underground water not always available. The most common cropping systems, therefore, would be a double-crop system, with a shortage of water at the end of the season; this would mean that there could be only a single rice crop. A shorter duration cropping system, such as rice-wheat, should have a good chance of fitting in where available water is too limited for rice-soybeans. In certain areas, the rice-wheat system might be limited by slow drainage after the rice season.

Further projections for the Chiang Mai Valley and the rest of northern Thailand will require more data, but the characteristics of the Mae Taeng project should apply. An improvement in water-use efficiency through the introduction of wheat, or any other crop with similar adaptability, into the rice-based cropping systems of northern Thailand seems highly promising.

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## **Agronomic Practices and Problems for Wheat Following Cotton and Rice in Pakistan**

**P.R. Hobbs, Wheat Program, CIMMYT, Islamabad, Pakistan**

### **Abstract**

*Three million hectares of wheat follow cotton or rice in Pakistan. To date, little research has been done on the agronomy for wheat following these two major cash crops on a cropping-pattern basis. Both of these crops delay wheat planting significantly, and results suggest that, from 3 million hectares, 120,000 tons of wheat are lost for every one-day delay in planting past November 10. Current recommendations for land preparation, fertilizer use, weed control and varieties are based on wheat following fallow. Scientists must begin working in teams, rather than according to commodities or disciplines, to develop more useful recommendations for cotton-wheat and rice-wheat cropping patterns.*

Cotton and rice in Pakistan are grown on 2.25 million and 1.8 million hectares, respectively, in the kharif (summer) season. Following harvest, it is estimated that 70% of the cotton and 80% of the rice is followed by wheat. This is equivalent to 3 million hectares of wheat or 30% of the wheat area in Pakistan.

Unfortunately, most of the agronomic research on wheat has been done with wheat as the sole crop (i.e., following fallow), and very little information is available on what happens to wheat in the double cropping patterns that include cotton and rice. This commentary will, therefore, identify issues for research in these important cropping patterns rather than give specific agronomic recommendations.

### **Planting Date**

Seeding of wheat is delayed by both cotton and rice harvest in Pakistan. The exact timing in cotton-wheat areas is influenced by the cotton variety (maturity), farmer decision as to whether to have an extra cotton picking and the gathering of the cotton sticks, which can be a valuable bonus for the farmers.

In rice, variety is also an important factor in the delay of wheat planting. Only two rice varieties are commonly

grown in Pakistan, mainly because 40 to 50% of the rice is exported; therefore, the government restricts the release of varieties. The two varieties are IR6, a high-yielding, nonphotosensitive type, and Basmati, a traditional, high-quality photosensitive type. With IR6, fields are harvested by late October to mid-November, and wheat can be planted in November; with Basmati, harvest is often delayed to the end of November or even into December. In addition, farmers cut, dry and thresh the rice in the same fields before turning to land preparation for wheat. This extra 10 to 20-day delay often pushes wheat planting into late December or even January.

Figure 1 shows the effect of wheat planting date on the yield of three wheat varieties. The optimal date for wheat planting is November 10 and, on average, 40 kg/ha (120,000 tons for 3 million hectares) of grain is lost for every one-day delay in planting after this date. Earlier plantings have lower yields because of frost damage during flowering. Obviously, delayed planting because of cotton and rice substantially reduces yield potential, especially with wheat planted after Basmati rice. This situation can be improved by using earlier-maturing cotton and rice varieties, speeding up turn-around time and using wheat varieties that yield better when planted late.

Interestingly, Blue Silver (or Sonalika), which is considered as short-maturing and is recommended for December planting, does not do as well as Pakistan 81 (Veery 5) or Punjab 81 when planted late. Although its yield declines less with late planting, its potential yield is much lower than that of the other two varieties; this reduces its yield to below that of Punjab 81 and Pakistan 81, even in late-planted fields. More screening is needed of wheat germplasm to follow rice or cotton with late planting, especially to identify varieties like Punjab 81 for these situations.

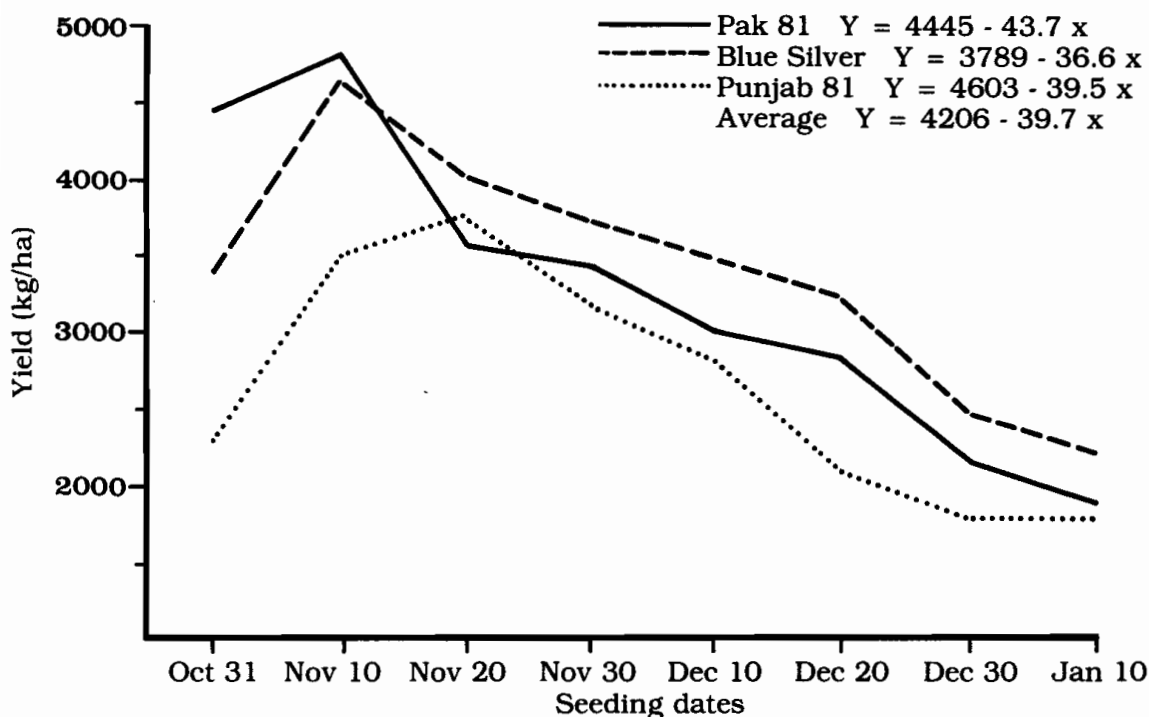
### Land and Seedbed Preparation

In cotton-wheat areas, seedbed preparation is relatively easy, following the removal of the cotton sticks; the soil

is relatively friable and can be prepared for wheat quickly. Because of the use of shallow-tillage implements over many centuries in Pakistan, there might be some benefits from deep tillage in these areas; some experiments should be initiated to test this hypothesis.

In the rice areas, the situation is different. About one-half of the rice in Pakistan is grown on puddled clay and clay-loam soils. Therefore, the farmer is faced with a hard, structureless mass of soil to be prepared for wheat. This takes time and, where soils are heavy in texture, final seedbed preparation may be very poor. Luckily, the other half of the rice soils in Pakistan are medium textured.

Associated with these unfavorable soils for wheat are the plow pans, developed by puddling and needed to restrict



**Figure 1. Effect of planting date on yield of late (Pakistan 81), medium (Punjab 81) and early (Blue Silver) wheat varieties, Pakistan**

**Source: AARI, Faisalabad, Pakistan, 1982 to 1984**

water percolation in rice. For wheat, these pans may limit rooting and subsequent moisture and nutrient availability. They also increase waterlogging in wheat and increase the problem of seedbed preparation. If the plow pan is broken, wheat yields may increase, but more water will be needed for rice and the soils may not be able to physically support the animals or tillage implements needed to puddle the soil for rice. As with cotton, there is also the problem of crop residues facing the farmer when he prepares the land for wheat.

Little information is available on these issues. More studies are needed to identify the best implements for land preparation. They must be evaluated as to cost, time needed and ability to handle residues. It would also be interesting to study the effect of deep tillage on total annual productivity.

### **Seeding Rates and Methods**

Most farmers broadcast wheat, following cotton and rice, at the rate of 100 kg of seed per hectare. More studies are needed on using higher seed rates and comparing broadcasting versus machine drilling when wheat is planted late. Poor plant stands are common in the rice-wheat areas, largely because of poor land preparation; a higher seed rate may compensate for this problem. Studies should also be initiated on no-till planting of wheat into rice as a means to reduce turn-around time.

### **Fertilizer Use**

As with the previous agronomic practices, fertilizer studies in Pakistan have been on wheat following fallow, but rarely following cotton or rice. Response surfaces for nitrogen and phosphorus must be determined for cotton-wheat and rice-wheat cropping

patterns for different soils over time. There are also reports of response to potash and micronutrients in wheat following rice, but more studies are needed in this area on a cropping-pattern basis.

### **Weed Control**

Weeds are greatly influenced by the previous crop and the cropping pattern. Common weeds in the cotton-wheat pattern include *Chenopodium album*, *Chenopodium murale* and *Convolvulus arvensis*. In rice-wheat, *Phalaris minor* and *Avena fatua*, along with *Chenopodium album*, are the major weeds causing economic losses in wheat.

Herbicides could be used to control these weeds. Any of the phenoxyacetic acid family will control the broadleaf weeds, although *Convolvulus arvensis* would regrow after a time; the use of Dicamba + MCPP (Banvil-P) does a better job on this weed. The substituted ureas, Tribunil, Dicuran, Dosanex or Isoproturon can be used for the *Phalaris* or *Avena*, although Suffix, Mataven or Difenzoquat may be better for *Avena*. These grassy-weed herbicides are more costly than the broadleaf herbicides.

In Pakistan, herbicide use is in its infancy and few scientists, much less farmers, have expertise in applying them properly. Other methods are needed. Many farmers rotate land when weeds become a problem. Berseem (*Trifolium alexandrinum*) is used in place of wheat as a winter fodder when weeds are a problem; however, this is not a viable option except in areas where berseem is a cash crop. Two-thirds of the farmers' fields in a recent study had been planted to wheat continuously for three or more years.

Pre-irrigation is another way of reducing weed populations; the weeds are plowed under just before planting. The major problem here is the delay in planting associated with irrigation, and so this is obviously not a solution with Basmati rice. Many farmers irrigate their rice fields before harvest to germinate weeds and not delay land preparation for wheat. The major wheat variety in the Punjab is Yecora, a triple dwarf, which accentuates the problem caused by weeds, especially *Phalaris*

and *Avena*. More research is needed on quantifying losses caused by weeds and economically evaluating alternative strategies.

A team approach is needed to bring the present commodity and discipline-oriented scientists together to work on problems on a cropping-pattern basis. At present, Pakistani scientists tend to work in isolation and do not look at the problems and issues associated with wheat grown in a multiple cropping pattern.

## Rice-Wheat Cropping Systems in South and Southeast Asia

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### Abstract

*Rice-wheat rotation is practiced in South Asia in India, Pakistan, Nepal, Bhutan, Bangladesh, Burma and China. In Southeast Asia, wheat is not yet a commercial crop, but national programs are intensifying their research because of increasing demand and heavy importation. IRRI and CIMMYT are collaborating with 13 countries involved in the Asian Rice Farming Systems Network to identify suitable varietal combinations for rice-wheat cropping systems and to evaluate performance of rice-wheat systems in different rice environments in Asia. In South Asia, rice-wheat is the most predominant cropping pattern; in some countries, it is rice-wheat-upland crop. Most cropping-pattern evaluations indicate that three-crop systems give higher production and net returns than do two crops. The Philippines, Indonesia, Thailand, Burma and Sri Lanka are especially interested in increasing wheat production. Variety trials in northern Thailand and high elevation areas have given yields of up to 3.5 t/ha. The first International Rice-Wheat Integrated Trials in the Philippines, Burma and Thailand showed low yield levels; agronomic management studies at IRRI reported only up to 2.5 t/ha. There is a need to develop better varieties for the tropics and better agronomic management in rice fields.*

Rice and wheat are the most important cereal crops in the world. About 90% of the world's rice is grown in Asia, with India and China accounting for about 60%. Rice is grown in temperate, subtropical and tropical countries, under both rainfed conditions (upland, lowland and deepwater) and irrigation (including partial irrigation). Wheat is mainly cultivated in the subtropical and temperate countries in Asia, usually with irrigation under lowland conditions. In some rainfed lowland and deepwater areas, wheat is also grown, especially in areas with good moisture lasting into the dry season.

Rice-wheat rotation is practiced in temperate and subtropical Asia. In the last 15 years, the rice-wheat rotation has rapidly expanded to nontraditional rice-wheat areas, mainly due to the development of photo-insensitive, early-maturing, nonlodging, high-yielding, disease and pest-resistant varieties of rice and wheat, but also to the development of better agronomic

practices and the expansion of irrigation. In irrigated areas, rice-wheat, rice-rice-wheat, rice-wheat-upland crop and rice-upland crop-wheat are the common cropping patterns. Rice-wheat rotations are mainly practiced in India and Pakistan, and have recently become important rotations in Nepal, Bhutan and Bangladesh.

In tropical countries where wheat is not a commercial crop, attention is now being given by national programs to the production of wheat because of heavy importation for local consumption. Research is now in progress in the Philippines, Indonesia, Thailand, Burma and Sri Lanka to develop appropriate wheat production technology. With the development of early-maturing rice varieties (100 to 120 days), wheat can now be grown under irrigation and partial irrigation on light to medium-textured soils during the dry season, usually the cooler months of the year. It can also be

grown in rainfed upland or lowland rice areas where there is enough rainfall during the cooler season.

### **Rice-Wheat Cropping Systems**

Major collaborative research in the Asian Rice Farming Systems Network is in rice-wheat cropping; IRRI and CIMMYT are collaborating with 13 countries in Asia, Nepal, Bangladesh, Thailand, Philippines, Sri Lanka, Bhutan, Pakistan, Malaysia, Indonesia, China, Taiwan, Burma and Korea. The objectives of the collaboration are to:

- Identify rice-wheat cropping systems technology that is suitable for small-scale farmers;
- Identify better combinations of rice and wheat varieties;
- Encourage rice and wheat scientists to work together and identify component technologies that will increase the production of rice-wheat systems, and
- Promote collaborative research in the network on other problems common to the region.

The first two projects in this collaboration are cropping-pattern testing in six countries, Nepal, China, Taiwan, Bangladesh, Korea and Sri Lanka, and the International Rice-Wheat Integrated Trials (IRWIT) in all 13 countries.

Cropping-pattern trials are conducted on farmers' fields to compare rice-wheat systems with other cropping systems. IRWIT, on the other hand, is a varietal evaluation trial of rice (from IRRI) and wheat (from CIMMYT) at the time the crop is grown within the system. IRRI provides six varieties of rice, and the national programs are requested to include six varieties from their breeding programs. For the wheat trials, CIMMYT provides five entries and national programs five entries. There are two sets of trials for each crop for rice, a set of early-maturing rice for temperate and subtropical countries and a set of early

and medium-maturing rice varieties for tropical countries. For wheat, there is a set of early-maturing wheat varieties for optimum planting time (November 15  $\pm$  10 days) and a set of early-maturing varieties for late planting (December 15  $\pm$  10 days).

### **Rice-Wheat in South Asia**

#### **Nepal**

Rice-wheat rotation takes place on approximately 480,000 hectares, and there is potential for doubling the area, especially in the Tarai. Wheat is rotated with rice in both irrigated and rainfed areas. In the hills, rice-wheat and rice-wheat-corn are the common cropping patterns while, in the Tarai rice-wheat and rice-rice-wheat are common. In some areas, mixed cropping of wheat and mustard after rice is practiced.

There are seven cropping systems sites in Nepal. Of these, three are involved in the network collaboration on cropping-pattern testing, Pundi Bhumdi in the hills, Ratna Nagar in the inner Tarai and Bhairawa Tubewell in the Tarai. In Ratna Nagar, several cropping patterns have been tested on both irrigated and rainfed lowlands. Rice-wheat-mungbean and rice-wheat-maize have given higher production and net returns as compared to the farmers' practice of rice-wheat (Table 1). The wheat varieties Lumbini and UP262 have yielded 65 to 91% more than the farmers' RR21; rice yield from varieties Laxmi and Malaka Janaki was up to 63% higher than the farmers' Masuli variety. On rainfed lowlands, rice-maize, with improved management, and rice-wheat patterns showed higher production and net returns as compared with the local farmers' rice-maize practice.

In the Bhairawa Tubewell, 17 cropping patterns were tested. Rice-maize-maize showed higher production and net returns than did rice-wheat-rice (Table 2). The farmers' practice of rice-rice-wheat is comparable to the

**Table 1. Yield and economic returns of different cropping patterns tested at Ratna Nagar, Nepal, 1982-83**

Cropping pattern	Yield (t/ha)			Net returns (US\$/ha) <sup>a/</sup>
	Crop 1	Crop 2	Crop 3	
Irrigated, lowland				
(F) Rice (Masuli)—wheat (RR21)—fallow	3.18	2.10	—	232
(FA) Rice (Laxmi)—wheat (Lumbini)—mungbean (Pusa Baisakhi)	5.19	4.01	0.54	860
Rice (Bindeshwari)—wheat (Lumbini)—maize (Arun)	4.27	3.80	2.48	951
Rice (Malika)—mustard (local)—maize (Rampur Comp)	3.78 <sup>b/</sup>	0.53	3.64	580
Rice (Janaki)—wheat (UP262)—dhaincha (local)	4.25	3.48	GM <sup>c/</sup>	562
Rice (Janaki)—wheat (UP262)—fallow	3.19	3.48	—	523
Rainfed, lowland				
(F) Rice (Masuli)—fallow—maize (Rampur Comp)	2.82	—	2.40	306
(FA) Rice (Masuli)—fallow—maize (Rampur Comp)	3.25 <sup>b/</sup>	—	4.15	503
Rice (Janaki)—mustard (local)—fallow	4.93	0.52	—	354
Rice (Janaki)—wheat (UP262)—fallow	4.25	2.28	—	400
Rice (Masuli)/lentil—fallow	2.85 <sup>b/</sup>	— <sup>b/</sup>	—	—
Rice (Masuli)—fallow—dhaincha (local)	2.72	—	GM <sup>c/</sup>	(-16)
Rice (Masuli)—fallow—fallow	2.93	—	—	87

F = farmers' cropping pattern, FA = alternative cropping patterns

<sup>a/</sup> US\$ 1 = 16.30 Rs

<sup>b/</sup> Most plants suffered from severe lodging

<sup>c/</sup> Green manure crop (plowed under)

Source: Cropping systems staff, 1984

**Table 2. Yield and economic returns of different cropping patterns tested at Bhairawa Tubewell, Nepal, 1982-83**

Cropping pattern	Yield (t/ha)			Net returns (US\$/ha) <sup>a/</sup>
	Crop 1	Crop 2	Crop 3	
(F) Rice (Masuli)—wheat (improved)—rice (local and improved)	1.79	3.04	4.20	1079
(FA) Rice (Janaki)—mustard (local)—maize (Rampur Comp)	4.78	0.82	3.07	1030
Rice (Laxmi)—maize (Rampur Y)—maize (Arun)	4.79	6.41	2.31	1419
Rice (Bindeshwari)—maize (Rampur Y)—mungbean (PS-7)	4.10	4.35	0.95	1009
Rice (Malika)—wheat (UP262)—mungbean (PS-7)	3.55	3.15	0.89	879
Rice (Janaki)—wheat (Lumbini)—dhaincha (local)	4.93	3.22	GM <sup>b/</sup>	971
Rice (Janaki)—wheat (Lumbini)—fallow	4.08	3.22	—	894
Rice (Masuli)—wheat (Lumbini)—rice (Malika)	1.76	2.94	4.86	1096

F = farmers' cropping pattern, FA = alternative cropping pattern

<sup>a/</sup> US\$ 1 = 16.30 Rs

<sup>b/</sup> Green manure crop (plowed under)

Source: Cropping systems staff, 1984

improved rice-rice-wheat because, in the past three years, the use of improved varieties and better agronomic practices has steadily increased. The other improved patterns have lower production and net returns.

There are two land categories in Pundri Bhumdi. The rainfed lowlands have a high production potential where the cropping pattern is rice-wheat-maize, and a medium production potential where the cropping pattern is rice-maize. Several years of testing have resulted in the identification of a variety of rice adapted to the hills. K39 is an early-maturing variety with satisfactory grain type, high grain yield, acceptable straw characteristics; it is less damaged by hail. It fits into both the areas of high and medium production-potential. Its yield ranges from 4.0 to 4.4 t/ha in the rice-wheat-maize pattern and from 3.6 to 4.4 t/ha in the rice-wheat pattern in the areas of high production potential. The maize variety Arun has now been adopted by farmers in both high and medium production potential areas, with yields up to 3.57 t/ha. Yield levels of wheat (RR21) are low (1.9 t/ha) in both patterns. Hence, better varieties of wheat are needed to further increase production and income.

The rice-wheat-maize pattern under good agronomic management was tested in 1982-83 in the high production potential areas. The annual production was 12.8% higher than the farmers' rice-wheat-maize pattern, but the net returns did not differ. The results of several tests led to farmer adoption of improved agronomic practices and high-yielding varieties. In the medium production potential areas, four cropping patterns were tested, rice-wheat, rice-maize, rice-broad beans-maize and rice-oats. The highest net return was obtained from the rice-maize pattern (US\$ 899); it was 25% higher than the rice-wheat pattern.

### **Bangladesh**

Wheat is a nontraditional crop in Bangladesh. In the 1970s, a ten-fold increase in wheat production was achieved. It increased from a total of 89,000 tons in 1973 to 1.1 million tons in 1981. Approximately 500,000 hectares are now under rice-wheat cropping systems. There is the potential to expand to about 2 million hectares, if better varieties are identified and irrigation provided. Wheat is generally grown after transplanted Aman rice in rainfed and irrigated rice areas. The most common cropping patterns involving wheat are rice-wheat and rice-rice-wheat.

On-farm cropping systems research in Bangladesh is conducted on 16 sites by seven institutions under the coordination of the Bangladesh Agricultural Research Council. In several sites, the rice-wheat system is one of the patterns being studied. As in Nepal, the farmers' existing cropping pattern is compared with alternative or improved cropping patterns. Results involving wheat from three sites are presented in Table 3.

The farmers in Hathanzari traditionally grow only two rice crops, and leave the field fallow for 180 days after harvest. The team has introduced wheat as a third crop, coupled with an improved variety of rice. The total yield of the two rice crops under improved management was 7.5 t/ha, 32% better than the farmers' practice (6). The net returns of rice-rice-wheat was 59% better than the farmers' rice-rice cropping pattern (Table 3).

In the rainfed areas of Trishal Thana, the Bangladesh Agricultural University tested rice-rice-wheat and jute-rice-wheat. The predominant or existing cropping patterns are rice-rice and jute-rice, using local varieties; wheat was introduced as a new crop. The yields of improved rice and jute were much higher than the local varieties, and the wheat crop was excellent. Net return

was higher with the introduction of wheat in both the rice-rice pattern (318-510% better) and in jute-rice (383% better).

The predominant cropping pattern in Thakurgaen is local rice-wheat. In some areas, rice-rice-wheat is grown. The Water Development Board tested several cropping patterns, using improved varieties and medium levels of fertilizer in the Aman season. The yields and net returns of alternative cropping patterns were higher than the farmers' rice-rice-wheat rotation (Table 3). Inclusion of mungbean and millet proved to be good alternatives in improving the existing system; the highest net returns were observed in the rice-wheat pattern. The use of Jupateco, Balaka and, especially, Pavon increased production and net returns.

### India

Under irrigated conditions, the rice-wheat cropping system is an important practice in the states of Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, Orissa, parts of Madhya Pradesh and Rajasthan. The area has expanded in the last 20 years with the development of photo-insensitive, high-yielding and early-maturing varieties of both rice and wheat and the development of irrigation systems. Recently, the area has also expanded to rainfed rice areas, especially when there is available moisture. The three-crop systems are becoming popular in irrigated areas in northeastern India. Cropping patterns such as rice-wheat-rice and rice-wheat-mungbean are fast becoming popular among farmers.

**Table 3. Yield and economic returns of cropping patterns tested at three sites in Bangladesh, 1982-83**

Location and cropping pattern	Yield (t/ha)			Net returns (US\$/ha) <sup>a/</sup>
	Crop 1	Crop 2	Crop 3	
<b>Hathazari (partially irrigated, highland)</b>				
(F) Rice (Purbachi)—rice (Nizershail)	3.16	2.46	—	552
(FA) Rice (Purbachi)—rice (BR11)—wheat (Sonalika)	3.70	3.75	1.62	879
<b>Trishal Thana (rainfed, lowland)</b>				
(F) Rice (Aus L)—rice (T. amon L)—fallow	1.31	1.87	—	273
(FA) Rice (BR10)—rice (BR11)—wheat (INIA66)	3.86	4.84	3.57	1142
(FA) Rice (BR10)—rice (BR11)—wheat (INIA66)	4.91	5.40	4.17	1665
(F) Jute (L)—rice (T. amon L)—fallow	1.34	1.87	—	243
(FA) Jute (I)—rice (T. amon HYV)—wheat	2.43	5.38	3.99	975
<b>Thakurgaon (irrigated, highland)</b>				
(F) Rice (Sani)—rice (Kalam)—wheat (Sonalika)	1.91	1.57	1.30	576
(FA) Rice (Dharial)—rice (BR11)—wheat (Jupateco)	1.68	4.19	2.33	1181
(FA) Mungbean—rice (BR10)—wheat (Balaka)	0.70	3.73	2.65	1066
(FA) Millet—rice (Pajam)—wheat (Pavon)	1.12	4.13	3.43	1171
(FA) Fallow-rice (BR4)—wheat (Pavon)	—	4.53	3.73	1200

F = farmers' cropping pattern, FA = alternative cropping pattern

<sup>a/</sup> US\$ 1 = 25 TK

Source: Rahman and Manzano (6)

Data on the production potential of three-crop systems involving wheat, reported from various centers of the All-India Coordinated Agronomic Research Projects (AICARP), showed high total production and net incomes (5). The most promising sequence with rice and wheat in each state is shown in Table 4. At Kalyani, the rice-wheat-maize pattern gave a total yield of 10.3 t/ha, with a net income of US\$ 812. Rice-wheat-cowpea + maize in Pantnagar showed a net income of US\$ 959. Highest yield and net income were reported on rice-potato + wheat + wheat-mungbean (US\$ 1,861) from Faizabad in Uttar Pradesh. Rice-wheat-mungbean was the best at Karjat in the Konkan region. Most of the latest data indicate that the rice-wheat-pulse (mungbean) crop pattern appears to be the most promising in terms of production, income and nutrition. Rice and wheat provide carbohydrates and pulses provide protein.

### Sri Lanka

Wheat is not grown commercially in Sri Lanka. However, there is potential to grow wheat after rice, especially in the high-elevation areas. In 1980, the Director of Agriculture introduced wheat (Trigo 1 from the Philippines) in Bandarawela. Performance was very promising.

The cropping-systems team in Bandarawela tested wheat in a three-crop system. The dominant cropping patterns in lowland rice areas were rice-potato and rice-vegetables. The research team was able to identify an early-maturing variety of rice which has now been adopted by farmers; with this new variety, the three-crop system has been stabilized. In their multilocation testing, wheat is one of the crops in the patterns. The first crop is rice in February, followed in June by potato, beans, cabbage, carrots, garlic or tomato; the third crop in November is wheat, soybeans, carrots or radish. Wheat has

**Table 4. Yield and economic returns of three crop patterns involving rice and wheat, India, 1979-80 to 1981-82**

Location and cropping pattern	Yield (t/ha)			Net returns (US\$/ha) <sup>a/</sup>
	Crop 1	Crop 2	Crop 3	
Pantnagar (F) Rice-wheat-cowpea + maize	3.82	4.29	29.30	959
Kalyani Rice-wheat-maize	4.07	3.48	2.75	812
Faizabad Rice-potato † wheat-green gram	4.39	12.73	0.63	1861
Varanasi Rice-wheat-green gram	4.75	3.43	1.06	937
Karjat Rice-wheat-green gram	3.42	2.01	0.54	553

F = farmers' cropping pattern

<sup>a/</sup> US\$ 1 = 11.30 Indian rupees

Source: Pillai (5)

to compete with other high-income crops, and present yield levels are quite low.

In a yield trial of five wheat varieties (Sonalika, INIA66, 213, Zambezi and Trigo 1) in Bandarawela during the 1982-83 Maha season, the highest yield was from Trigo 1, and that was only 1.07 t/ha (4). Better varieties of wheat are needed in order to compete with other crops that can be grown during the season.

### Pakistan

The common cropping patterns in the Punjab are rice-wheat and rice-clover and, in Sind, rice-wheat and rice-peas; approximately 700,000 hectares in the two provinces are grown to rice-wheat. The most popular variety of rice is IR6 which matures in 135 to 140 days, and so fits into the rice-wheat system very well. It is transplanted in June and harvested in October. IR6 is grown on 77% of the rice area in Sind and 24% of the area in the Punjab. The other popular variety of rice is Basmati (scented rice), which is generally transplanted in July and harvested in December. Wheat planted after Basmati has lower yields than wheat planted after IR6. However, farmers plant Basmati because of its high price (twice the price of IR6). About 80% of the rice farmers planted Basmati in the Punjab

in 1983 and 24% in Sind. KS282, a new variety, was recently released in the Punjab. It is high yielding, early maturing and has resistance to bacterial leaf blight; it can be planted in June and harvested in mid-September. With the early harvest, new cropping patterns were tested in Kala Shah Kaku, including rice-wheat, rice-clover, rice-mustard-mungbean and rice-mustard-sunflower (3). Yield of rice in the trial was 3.7 t/ha; wheat yielded 3.2 t/ha. Total net return of rice-clover was 29% better than the rice-wheat rotation, rice-mustard-mungbean was 33% better and rice-mustard-sunflower, 19% better (Table 5). These are alternative cropping patterns that can be used instead of rice-wheat in some areas.

Wheat is grown under both irrigated and non-irrigated conditions in Sind. Wheat yields under irrigation are generally higher than those without irrigation. In the last few years, chickpea is being replaced by wheat, because of the adoption of IR6 which matures later than local varieties. Chickpea is planted later and its yield is lower. Several cropping patterns were tested at the Dokri Rice Research Institute (1), with the winter crops not irrigated and not fertilized. Wheat yield was only 0.95

**Table 5. Yield and economic returns of four cropping patterns tested at the Rice Research Institute, Kala Shan Kaku, Punjab, Pakistan**

Cropping pattern	Yield (t/ha)			Net returns (US\$/ha)
	Crop 1	Crop 2	Crop 3	
Rice-wheat	3.7	3.2	--	345
Rice-clover	3.7	82.1	--	444
Rice-mustard-mungbean	3.7	1.1	0.6	459
Rice-mustard-sunflower	3.7	1.1	1.0	409

Source: Majid Chaudhary (3)

t/ha. Highest net income was obtained in the rice-chickpea rotation (US\$ 893), 22% better than rice-wheat (Table 6).

### Rice-Wheat in Southeast Asia

Wheat is not commercially grown in most Southeast Asian countries, except in Burma. However, the consumption of wheat in these countries is increasing at a rapid rate. The Philippines, for example, imported about 1.2 million tons in 1983; likewise, Indonesia, Sri Lanka and Thailand are heavy importers of wheat. There is now great interest in growing wheat because of this increase in demand and imports. Research is in progress in Thailand, Philippines, Indonesia, Burma and Sri Lanka. There is potential to grow wheat, especially after rice, in areas with irrigation and light-to-medium textured soils. Rice is generally planted in June or July, during the rainy season, and wheat in November or December, during the dry season when there are cooler temperatures. In high elevation areas in the tropics, wheat can be grown after rice. Northern Thailand and Burma can grow wheat after rice on a commercial scale.

There have still not been rice-wheat cropping-pattern trials in Southeast Asia; most of the work is on varietal evaluation and agronomic management. Variety trials of wheat in northern Thailand and high elevation areas in Indonesia (Margahayu) have shown yields of up to 3.5 t/ha. However, in most trials, yields are generally low and unstable. There are years when yields are high, and years when they are low.

The First International Rice-Wheat Integrated Trial, which started in the Philippines, Burma and Thailand in late 1982, gave very low yield levels. The highest wheat yields at IRRI, Philippines, came from Trigo 1 (local check) with 1.55 t/ha; at Yezin, Burma, Abasolo 81 yielded 1.81 t/ha. At Ilagan, Philippines, Ures 81 had a yield of 0.43 t/ha and, in northern Thailand, CIANO79 yielded 0.94 t/ha. Yield levels in 1983 were far better. At IRRI, Philippines, wheat yields ranged from 0.58 to 1.96 t/ha. The highest yield was from C214-1, a variety developed by the Institute of Plant Breeding at the University of the Philippines in Los Baños.

Agronomic management studies at IRRI show low yield levels for wheat; however, they can be considered high

**Table 6. Yield and net returns of various cropping patterns tested at the Rice Research Institute, Dokri, Pakistan**

Cropping pattern	Yield (t/ha)		Net returns (US\$/ha)
	Crop 1	Crop 2	
Rice-wheat	4.58	0.95	618
Rice-barley	4.33	4.26	610
Rice-chickpea	5.08	0.66	893
Rice-lentil	4.91	0.62	756
Rice-chickling vetch	4.99	0.58	647
Rice-mustard	4.16	0.29	500
Rice-safflower	4.41	0.67	644
Rice-linseed	4.38	6.76	626
Rice	5.24	—	555

Source: Bhatti (1)

for tropical environments. Highest average yields in some experiments were only about 2.5 t/ha. Planting date and fertilizer-level experiments with wheat after lowland rice was conducted by the IRRI Multiple Cropping Department in Cagayan and at the IRRI Farm at Los Baños. Among four varieties (UPLW<sub>1</sub>, C220-5, C169-6 and INIA66) used in different planting-date experiments in Cagayan, C 169-6 showed the highest average yield (2.0 t/ha). Five planting-date trials were conducted at IRRI, using five varieties, UPLW<sub>1</sub>, INIA66, C220-5, ANZA and C169-6. There the highest average yield was from C220-5 (2.5 t/ha) followed by C169-6 (2.4 t/ha). In the fertilizer experiment at Cagayan, 2.58 t/ha was obtained with a nitrogen application of 120 kg/ha on the variety UPLW<sub>1</sub> (Trigo 1).

Better varieties and management techniques are needed for wheat to compete with other crops that can be grown after rice. Hopefully, this symposium will help us arrive at better technologies for Southeast Asia.

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## Simple Simulation Models for Agronomic Research

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### Abstract

*An increasing number of countries in the tropical belt have reacted to increased wheat consumption by establishing local wheat research and production programs. By means of simple simulation models based on climatic variables, potential wheat yields (root, shoot and grain yields) can be calculated for tropical environments. These models may be helpful for extrapolation of results to other geographical areas, where less detailed or no experimentation has been carried out, or for generalization over longer time periods. Such models can help identify suitable areas for wheat research, and determine optimum sowing dates, days to reach specific developmental stages and dates for supplementary irrigation. They may also help assess whether long or short-maturation cultivars should be used in a specific area.*

Wheat has one of its centers of origin in the tropical belt in Ethiopia. Here, it is fully integrated into the diet and into the farming systems, and long-term data on wheat performance are available (4). In several other countries in the tropical belt, wheat was introduced by European and Arab traders and settlers after the year 1500. Before the 1970s, wheat was mainly grown in the tropics as a cash crop for export or to feed expatriates (1,3,6,7, 13,15,23). In the 1970s, local wheat consumption increased (5), world wheat prices were subject to large price fluctuations (14) and wheat production for local consumption became more and more important, e.g., in Zambia and Thailand (6,8). In tropical countries, wheat production still needs to be integrated into the farming systems, and long-term data are scarce or not readily available. Possibilities and constraints need to be investigated before large-scale wheat production is undertaken (6,9); if not, costly errors may be made, giving negative stimuli to local wheat production. Following are examples of simple simulation models that may be of assistance in local agricultural research.

### Simulation Models and Calculation Methods

At present, modeling can be used for three sets of conditions or production levels (12):

- Production Level 1—Growth is limited by genotype and interaction with weather (temperature, radiation, etc.)
- Production Level 2—Growth is limited by water shortage and by weather conditions part of the time
- Production Level 3—Growth is limited by nitrogen shortage, water shortage and weather part of the time

Simulation of conditions whereby growth may also be limited by nitrogen, phosphorus, other minerals, water and weather conditions is not yet sufficiently advanced for practical use.

Models have been made that use day-to-day input or mean daily data averaged over a five (17) or ten-day period (18, 19,20,21). While in many areas day-to-day weather data are not available, monthly data are available. In models for both short-cycle spring or summer wheat (21) and long-cycle winter wheat (17), monthly data and long-term data

can be used. The computer is a useful tool to reduce the time needed for calculations, but simulations can also be performed with a desk calculator (18,20).

At Production Level 1, irradiation and temperature are two factors of importance for dry-matter production of a wheat crop during development from emergence to maturity. Biotic and abiotic factors other than global radiation and temperatures are assumed to be nonlimiting. Simple simulation models and calculation methods can define the phenological state of the crop, making use of heat sums expressed in degree days. This not only applies to Production Level 1, but can also be applied to levels 2 and 3 (17,18,19,20,21). Rate of plant development is governed by genetic properties and environmental conditions. Genotype accounts for the distinction in short, medium and long-maturation types (Table 1), while environmental factors cause variations in growth duration for one genotype between locations and seasons.

Presently, the effects of day length are difficult to describe quantitatively. The heat sum for the period from anthesis to maturity appears to be constant for wheat genotypes (22).

Potential yields (root, shoot and grain) can be calculated for crops sown at different dates, in different years and at different locations, as was demonstrated with a model developed for Zambia (21). Thus, simple simulation models can help, among other things, to eliminate areas unsuitable for production, to identify potentially suitable areas for research and production and to plan for sowing-date experiments at one or more locations. The influence of the duration of the vegetative period (to anthesis of the plant) on calculated yields for wheat sown at a given location at different dates can be evaluated (21). This may help in deciding whether to use short, medium or long-maturation cultivars. Using the heat sum, the maturation of various phenological development stages of wheat, as well of rice, maize and

**Table 1. Heat sum in degree days ( $^{\circ}\text{Cd}$ ) above a base temperature of  $0^{\circ}\text{C}$  for wheat and rice**

Genotype	Degree days ( $^{\circ}\text{Cd}$ )		
	Emergence to anthesis	Anthesis to maturity	Total
<b>Wheat</b>			
Short maturation <sup>a/</sup>			
Emergence January 1	820	900	1720
Emergence July 1	950	900	1850
Medium maturation <sup>b/</sup>			
Long maturation <sup>a/</sup>	1100	900	2000
	1175-1350	900	2075-2250
<b>Rice<sup>c/</sup></b>			
Short maturation			2850
Medium maturation			3400

Sources: <sup>a/</sup> Van Keulen and De Milliano (21)

<sup>b/</sup> Van Keulen and Seligman (22)

<sup>c/</sup> VanKeulen (18)

sorghum, can be calculated. This may be useful for agronomists and breeders when planning visits to experiments at various locations.

Van Keulen (12,19,20) developed a calculation method for estimating crop yields at Production Level 2 where, at times during the growing season, water may be a limiting factor. The degree of water shortage for the crop, during different periods, can be calculated. This gives an indication of what amount of irrigation water is necessary to achieve potential production and when to apply supplemental irrigation. Existing simulation models for Production Level 3 are still in a preliminary stage, for use only by specialized scientists (12,22).

### **Discussion**

One of the problems in interpreting the results of long-term yield trials is the assessment of the relative influence of genotype characteristics, environmental factors and management practices on the final results in a particular situation. This difficulty limits the possibilities for extrapolation of results to other areas, where less-detailed experiments have been carried out or for generalization over longer time periods. The use of models, in which the influence of such factors is described quantitatively, may be helpful in analyzing experimental results and applying them for the purpose of prediction. At present, simple models at Production Levels 1 and 2 may be useful to agronomists, breeders and planners.

Table 1 shows that the total heat sum for the development of wheat from emergence to maturity is considerably lower than for rice. One interesting challenge to breeders could be to increase this total heat sum; this might facilitate the introduction of wheat into warmer areas. Preventive breeding may also be an important element of overall crop improvement, in order to prevent

the increase of minor pests and pathogens already present in the ecosystem and to preclude future problems (2).

In the model by Van Keulen and de Milliano (21), actual grain numbers are not simulated; rather, a function is introduced in the model representing this sink-effect. When the maximum temperature is above 25°C in the ten-day anthesis period, only a fraction of available carbohydrates is translocated to the grain. This fraction declines with increasing temperatures, reaching 0 at 35°C. This model worked well for Zambia, but not for Niger. In Niamey, Niger, maximum air temperature during anthesis is between 35 and 40°C. In reality, a grain yield of 2.4 t/ha can be achieved, which is more than twice the amount calculated by the model (1.1 t/ha), even if the influence of maximum air temperature on seed set is removed. Evidently, the model needs further improvement for wider application, especially for areas where maximum air temperatures during the growing season exceed 30°C.

How existing cultivars behave under high temperatures is still a subject of study (10,11,24). Vernalization and photoperiod sensitivity can delay the rate of plant development until anthesis, but the delay may not be matched with an increase in number of grains per spikelet or per spike (10). Genotypes which are relatively insensitive to vernalization and photoperiod and, hence, early, appear to be best at many locations, especially at hotter, lower elevations (11). Most of the models mentioned here apply to genotypes (bread and durum wheats) which are relatively insensitive to vernalization and photoperiod and follow the universal heat sum well. Care should be taken with the application of data and experience collected in western high-input systems to other agricultural systems (6,17). Therefore, local research should precede production.

The computer has become a valuable assistant to the agronomist (16), and is a useful tool for performing simulations. The thinking, data interpretation and synthesis, however, still need to be done by man. Where money is a limiting factor, time is usually not as limiting. In these areas, the calculation methods mentioned can be performed with a desk calculator.

The use of simulation models for agrometeorological purposes in developing countries was recognized by the World Meteorological Organization. In 1983, they organized a workshop in Wageningen, Netherlands, to train students from various tropical countries (20). The Centre for World Food Studies also developed simulation models for different countries, such as Bangladesh, Thailand and Indonesia. Some of the models are available in a simple form for use by individuals and research centers.

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## IV. Seed

### Wheat Seed Production, Storage and Distribution in Bangladesh

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#### Abstract

*The initial expansion of high-yielding varieties of wheat in Bangladesh was facilitated by importing seed. However, researchers realized that it would be impossible to increase and sustain wheat production without an efficient seed production, preservation and distribution system within the country. Imported seed would not be a dependable source due to possible unavailability of foreign exchange for its purchase, the possibility of there being inadequate quantities of seed of appropriate varieties available for purchase, and possible delays in transport and distribution which would hinder timely planting in the country. In view of these problems, the development of low-cost technology for seed storage under farmers' conditions, as well as the establishment of national seed production agencies, was imperative. The production, storage and distribution of wheat seed are here discussed as factors which have contributed to the dramatic expansion of the area under wheat in Bangladesh.*

In Bangladesh, the initial expansion of high-yielding varieties of wheat was facilitated by the importation of seed. Environmental conditions, such as the short growing season, high humidity and possible premature monsoon rains, were then thought to preclude successful seed production in the country. However, research personnel realized that it would be impossible to increase or sustain the wheat production area without an efficient seed production, preservation and distribution system within the country. The reasons for this were:

- Foreign exchange might not be available for seed imports every year;
- Adequate quantities of seed of appropriate varieties might not be available for purchase, and
- Delays in arrival of seed and its internal distribution could hinder the timely planting essential for good yields:

In view of these problems, the development of low-cost technology for seed storage under farmers' conditions,

as well as the establishment of a national seed production agency, was imperative. Surveys conducted in 1976 (1) and 1977 (8) indicated that about 80% of the seed required annually was stored by farmers. Had they not stored wheat seed, the dramatic expansion of the area under wheat would not have been possible.

In spite of the spectacular success of on-farm storage, some seed is always lost due to spoilage caused by early rains, insect and rat damage, flooding, loss of viability due to the failure or inability of the farmer to dry his seed stock, or consumption of the seed because of the failure of the rice crop. Also, the demand for wheat seed increases or decreases depending on weather conditions. For example, since 60 to 70% of the wheat crop is rainfed, favorable rains just prior to the wheat season make more land available for planting, and the demand for seed will be high. Thus, a strong national (private or public) seed production effort

is needed to arrange for adequate seed stock during years of high demand and/or seed loss. In addition to these problems of on-farm storage, private seed stocks invariably become mixed over time. A good national seed program can ensure an annual injection of seed of pure varieties into the agricultural system.

### **Seed Production**

Wheat, of course, is most suited to temperate regions, where temperatures are relatively lower and the growing season longer. In Bangladesh, a maximum of 115 days on average are available for the production of wheat under conditions that can lead to favorable yield. The earliest possible time for seeding presently available varieties is late October or early November; however, high air and soil temperatures at that time result in poor stands, low tillering and premature heading. Seeding in December, although more favorable in terms of temperature, results in decreased yield and in smaller and occasionally shriveled grains due to the further shortening of the growing season. Mid to late November is the period most favorable for planting wheat, a time range that is quite limited.

Temperatures may fluctuate dramatically during the growing season, and these fluctuations affect vegetative growth and flowering of wheat plants. However, Bangladesh is fortunate in that relatively cool and favorable temperatures prevail from late November to late February. In more tropical countries, temperatures remain high or show little variation between day and night. In those countries, production of good quality wheat seed is, of course, even more difficult.

In Bangladesh, the risk of pre-monsoon rains is always high. These rains delay harvesting and affect viability of the

seed in the field. Even if the crop is harvested in time, rain may delay threshing, resulting in the deterioration of grain quality and predisposing the seed to fungal pathogens. Further, during the months of March and April, there are occasional hailstorms; they are usually localized, but may damage the crop severely. Relative humidity also rises rapidly during the peak harvesting month of March. Unless seed is dried properly, moisture content will be excessive and will result in a predisposition to fungi, insect damage and decreased viability due to higher respiration rates.

Despite these problems, it would seem that successful seed programs can be conducted in any country where a wheat crop is economically grown, problems are adequately identified, care is taken to produce seed on the most favorable sites and inputs are available to ensure successful preservation.

### **Production of quality seed**

Rainfall and temperature data of different zones of the country over several years must be examined before being able to select sites for wheat seed production. It is essential to choose relatively dry areas with irrigation facilities and with crop rotation patterns that permit the maximum amount of time favorable for wheat growth. Poorly drained soils and very sandy soils with poor water-holding capacity should be avoided.

Mid-November is the best time for planting wheat in Bangladesh. The mean temperature goes down to about 23°C during this time, facilitating good stand establishment and tillering of the crop. Wheat planted in mid-November and harvested in either late February or early March usually escapes high temperatures at the grain filling stage and rainfall at maturity. Crops planted later will produce increasingly higher proportions of small and shriveled grains.

On average, no more than 100 mm of rain falls during the wheat season. To ensure good yields, the crop should be irrigated at crown root initiation, heading and grain filling (subject to the moisture status of the soil). A 34% yield reduction has been observed if the crop is not irrigated at least twice (4). Fertilizer application in adequate quantities is also essential, with the amounts adjusted to site requirements.

#### Classes of seed

In order to maintain varietal purity and quality, four classes of seed are produced at different stages of seed production (2):

- Breeder seed
- Pre-foundation seed
- Foundation seed
- Certified seed

The standards for breeder, foundation and certified wheat seed fixed by the National Seed Board, are given in Table 1.

*Breeder seed*—Breeder seed is the purest seed produced by the sponsoring plant breeder or institution for the initial increase of foundation seed; it is produced on a very small scale. In Bangladesh, the production of adequate quantities of certified seed from breeder seed takes nearly four years.

*Pre-foundation seed*—A promising line is multiplied and purified prior to its formal release as a variety. This is done

in order to be able to supply a relatively large amount of seed to the National Seed Producing Agency at the time of its release. By this method, the amount of time between the formal release of a variety and its general release to the public is minimized.

*Foundation seed*—Breeder seed and/or pre-foundation seed received from the research program is used for the production of foundation seed and is grown on seed multiplication farms. The program for the multiplication of foundation seed is formulated on the basis of distribution targets for certified seed as fixed for a given year. The seed corporation must ensure the production, processing, preservation, packing and distribution of foundation seed to certified seed growers. In Bangladesh, foundation seed is produced on 16 seed multiplication farms which occupy a total area of some 900 hectares and produce about 1500 tons of seed annually.

*Certified seed*—Foundation seed produced in the seed multiplication farms is planted by contract growers for production of certified seed. The contract grower areas are selected according to the following criteria:

- Availability of irrigation water
- Accessibility of roads
- Suitability of the soil
- Topography of the land
- Proximity to seed processing centers

**Table 1. Standards for breeder, foundation and certified wheat seed as fixed by the National Seed Board, Bangladesh**

Class of seed	Minimum germination (%)	Minimum pure seed (%)	Maximum foreign matter permitted (%)				Maximum moisture content (%)
			Inert matter	Other wheat varieties	Other crop seeds	Weed seeds	
Breeder	90.0	94.5	0.7	0.3	0.5	8 seeds/kg	12.0
Foundation	80.0	96.0	2.0	1.0	0.5	0.5	12.0
Certified	80.0	92.0	2.5	2.5	0.5	0.5	12.0

In addition to seed, inputs such as fertilizer, pumps, pesticides and credits are provided to the grower. The field staff of the Seed Producing Agency supervise and guide all operations, from sowing to threshing.

A seed production zone must be located in close proximity to a seed processing center. In each zone, there may be three to five seed units which comprise 120 to 240 hectares of land each. In each seed unit, there are four to eight blocks comprising 30 to 60 hectares each (3). The Seed Certification Agency certifies the seed plots after inspection and issues certificates. They also certify the seed lots after final processing and storage.

The seed growers deliver their certified crops to the seed processing/purchasing center immediately after harvest. The Seed Producing Agency accepts only certified seed of approved standards and makes payment to the growers at the rate fixed in consultation with the local Price Fixing Committee. Contract growers receive a premium price 20% higher than the Government procurement price (7). About 9,000 hectares are brought under certified seed production in Bangladesh every year; total production is about 14,000 tons.

#### **Seed production at the farmer level**

Most farmers cannot buy wheat seed every year, and those who successfully store their own seed have the advantage of being able to plant whenever they wish. A farmer in Bangladesh keeps as seed a portion of the grain after threshing and cleaning; as a result, over a period of years, the quality of the seed goes down due to mixtures with other varieties of wheat or other crop seeds. This can be avoided if farmers are trained by

extension personnel to clean (rogue) a portion of the wheat field for seed production. Good quality wheat seed can then be obtained if the farmer is able to harvest the crop during sunny periods, facilitating the proper drying of the plants and the seed.

#### **Storage**

The storability of wheat seed in a specific environment is largely determined by its prestorage history. Untimely harvesting and threshing, inadequate drying and careless handling increase quality losses from field exposure, high moisture content and mechanical damage (6). Excessive seed moisture is the greatest single factor causing losses in viability and vigor; delayed harvesting and inefficient drying may contribute considerably to the low quality of seed.

#### **On-farm storage**

Low-cost technology for storing wheat seed, developed through research in the mid-1970s, has been adopted by most wheat farmers in Bangladesh. After threshing and cleaning, the seeds are dried in the sun for at least six or seven consecutive days. This natural drying lowers the moisture content of the seed to about 10%. It is then allowed to cool overnight and is stored in containers, such as tins, metallic drums, earthen pots or polyethylene bags. A total of 25 different forms of on-farm seed storage have been reported in Bangladesh (5).

The container most preferred by wheat farmers for on-farm seed storage is a 200-liter petroleum or insecticide drum. The seed stored in these drums is usually found to have germination above 80% (5). However, since the price of such drums is high (US\$ 10 to 12), most farmers cannot afford to buy them. Moreover, the capacity of these drums is 186 kg and the majority of the farmers require containers with a capacity of less than 70 kg.

Storage in 20-liter biscuit or kerosene tins is very effective. They have the advantage of smaller capacity (18 kg) and lower price (US\$ 1). Unlike other containers, seed can be placed in tin containers immediately after sun drying (i.e., without overnight cooling). Since the tin is thin and is a good heat conductor, the heat is quickly dispersed.

The insertion of a double plastic bag inside fertilizer or gunny sacks also makes them useful for seed storage; germination of over 80% may be maintained in these bags. Their storage capacity (about 37 to 74 kg) meets the requirements of the average farmer, and they are very cheap and generally available. However, for protection against rats, the bags should be kept within earthen containers or on suspended platforms (5).

Wheat seed is also kept in bamboo and mud storehouses (kuti); these are used for rice storage but do not adequately prevent dampness. Earthen pots are also occasionally used, but do not prevent dampness either due to their porosity. Such containers should be coated with tar and sealed for most effective use. If containers are relatively airtight, there is no need to redry the seed during the storage period; otherwise, seed should be dried five to six times.

A survey conducted in 1982 indicated that about 12% of the seed samples collected had been treated with insecticides. Some farmers use natural insecticides such as nim, biskatali and tobacco leaves as insect repellants. Further research is needed to determine the efficacy of natural insecticides in controlling insects in stored seed.

#### **Seed corporation storage**

Taking into account the adverse environmental conditions for any type of seed storage in the tropics, only a

combination of recommended practices, well-maintained storage facilities and careful seed packaging will guarantee that, once harvested, high quality seed will reach the farmer without loss of viability. The seed processing center should be provided with moisture-proof seed storage, with the capacity to store the total quantity of seed produced. In Bangladesh, seed is stored in gunny sacks for ease of handling but, since the duration of storage is usually six months, the bagged seed is periodically dried by forced-air drying; germination is checked frequently.

#### **Control of pests and diseases**

Pests which have to be controlled in storage include rodents and insects. Specific measures should be undertaken in buildings used for storage to prevent the entry of rats; insects are more difficult to control. Insects live in cracks and crevices of buildings, in old bags and may also come from the field with the seed. Floors and walls can be sprayed with appropriate long-term residual insecticides for control. In Bangladesh, insecticides are not used for treating seed, since leftover or unused seed may be used by the farmer for consumption. Hence, fumigation by Phostoxin is done as a regular practice.

#### **Seed Distribution**

##### **Distribution by the seed corporation**

The price of seed is fixed by the Bangladesh Government prior to distribution. The seed is bagged, sent to distribution points and, finally, sold to growers. An excessively high price of seed will discourage the farmers from planting wheat, while an excessively low price will encourage the misuse of costly seed for consumption and also discourage on-farm preservation. In Bangladesh, the price of wheat seed supplied by the seed corporation is

fixed at 15 to 20% more than the grain price (7). In order to enable the farmers to buy at least a small quantity of quality seed, such locally produced seed is made available in distinctive 10 to 20 kg bags. This practice also reduces the chances of unscrupulous private seed traders selling poor quality seed.

District-wide requirements for wheat seed are set by the extension department every year well ahead of the wheat season and on the basis of the target fixed for that year. The distribution program is set up by the seed corporation, in consultation with research and extension personnel. With a view to making seed easily available to growers, it is sent from the seed processing centers to district sales centers just before the sowing period. The seed is sold from the sales centers directly to the growers. For quick and easy distribution, the sales centers are located close to main roads or railroads.

#### **On-farm seed distribution**

The farmer who stores an excess quantity of seed often sells it to neighboring farmers or in the local market. About 5 to 10% of wheat seed is distributed in this way in Bangladesh.

A large number of on-farm demonstrations are conducted with new varieties by research in collaboration with the extension department. Cooperating farmers are encouraged to keep seed from the variety he finds promising for use the next year. He is also encouraged to sell a portion of that seed to other farmers. On-farm demonstrations are one of the most efficient methods for the introduction and distribution of new varieties to the farmer.

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## **Production, Storage and Marketing of Wheat Seed in India**

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### **Abstract**

*Both the production and productivity of wheat has increased in India to an appreciable extent since the introduction of the semidwarf varieties from Mexico, and concerted efforts have been made in the multiplication of quality seed. Production has gone up from 12.25 million tons in 1965-66 to 42.5 million tons in 1983-84; productivity has increased from 913 to 1863 kg/ha. Certified seed production has increased from approximately 50,000 tons in 1974-75 to 230,000 tons in 1983-84. Marketing of seed is arranged through public and private-sector agencies. To curb the sale of spurious seed, seed law is enforced through the 1966 Seeds Act. Heavy dependence on a few varieties and the spread of karnal bunt (*Neovossia indica*) pose a serious threat to wheat cultivation in the country. Breeder seed multiplication needs to be strengthened, and a buffer stock of seed maintained for stability in production.*

In increasing crop production and yield, seed plays a vital role. It is not just another agricultural input, but rather a dynamic instrument used to achieve specific agricultural production objectives. There cannot be a more potent tool for peace, progress and prosperity than seeds for developing countries, such as India, Pakistan, Nepal, Burma, Bangladesh and Indonesia, where agriculture is the backbone of the national economies. The discovery of dwarf plant types in the world's popular food-grain crops, e.g., wheat and rice, and the spread of seed of adapted and high-yielding varieties may be considered much more significant and revolutionary than the discovery of atomic power.

The 1960s was a turning-point in the history of agriculture on the Indian subcontinent, with the introduction of the semidwarf wheat varieties, such as Sonora 63, Sonora 64, Lerma Rojo 64 and Mayo 64, along with a large number of segregating materials from CIMMYT, Mexico (1963-64). About the same time, the rice varieties Taichung and Nitan were introduced from Taiwan (1964) and IR8 from IRRI in the Philippines (1965). The introduction of

these varieties, and their further development through multidisciplinary crop improvement projects, brought new hope for increasing food production in India and paved the way for the reconstruction of native varieties to cater to the needs of varying ecological conditions.

### **The Seed Industry**

Farmer acceptance of the introduced varieties in all parts of the country led the Government of India to extend its support to supplying good quality seed, as well as fertilizers and pesticides. Wheat production has increased from 12.25 million tons in 1965-66 to 42.5 million tons in 1983-84, with productivity going up from 913 kg/ha to 1863 kg/ha.

In the early 1960s, the seed industry in the country was poorly developed. The private sector produced small quantities of flower and vegetable seeds, and the public sector attempted to disseminate improved seed from small government-owned farms, but with little success. In order to meet the growing demand for quality seed, the government

established the National Seed Corporation (NSC) in 1963, and passed the Seeds Act in 1966. The NSC was charged with promoting the development of a seed industry, from production through processing, storage and marketing, and to establish a system for quality control. However, large quantities of quality seed could not be produced in the absence of an organized seed industry at the state level. In 1966, a team, consisting of experts from the World Bank and FAO, visited India and identified Pantnagar as the best location for launching the seed project, with the close coordination of the G.B. Pant University of Agriculture and Technology. Thus, the Tarai Development Corporation (TDC) was established in 1969, with the assistance of the World Bank, and was an important landmark in the production of seed in India. The TDC undertook large-scale production of cereals seed, particularly wheat seed, which constituted more than 75% of the total seed production of the corporation. From 7,013 tons of certified quality wheat seed produced in 1969-70, production had increased to 37,500 tons by 1983-84; this will be further increased to 75,000 tons by 1988-89.

#### **National seed program**

Based on the success of the TDC, the Government of India decided to reorganize and expand the seed industry in the country, taking the TDC as a mother-project. In February, 1975, a working group was established to prepare proposals for a National Seed Program. Under this program, a State Seed Corporation (SSC) was established in various states. At present, nine states are participating in the program and have established SSCs, similar to TDC, which are responsible for seed production, processing, quality control and marketing.

#### **Wheat Seed Production**

With the growing consciousness among farmers of the advantage of using certified seed of good quality, demand in the country has increased many times. From the total production of about 50,000 tons of seed in 1974, i.e., before the beginning of the National Seed Program, present availability of wheat seed in the country is 230,000 tons. This amount is sufficient to cover about 10% of the area under wheat cultivation. The government is very anxious to increase seed production to be able to cover at least 20% of the wheat area by 1988-89. Thus, the country has set a target of doubling wheat seed production (to 500,000 tons) through private and public-sector agencies over a period of five years. The important varieties under production in the country are: Sonalika(II53-388 x An)Yt54 x N10B)LR), UP262(S308 x Bajio 66), HD2285(249-HD2160/HD2186), WL711(S308 x Chris)Kalyansona), HD2009(Lerma Rojo 64A x Nai 60), UP368(LR64 x Sonora 64), HD2204(HD2092/HD1962-E4870-K65), HUW37(Kalyansona x S331) x HD1982), HP1102(8156(B) x NAD 63), WH147 (E4870 x C303)(S339 x V18), Raj 911 (Vo229) and DWL5023 (Cr"S"-Ld"S" x Gr"S"). At present, Sonalika (RR21) is the most popular variety in India because of its high yield, wide adaptability, rust resistance and suitability for late sowing in fields following paddy crops. It currently covers an area of approximately 10 million hectares.

For the maintenance of genetic purity and consistency of seed production, the country is producing three categories of seed, breeder, foundation and certified seed.

#### **Breeder seed**

The breeder who develops a variety is generally responsible for the maintenance and production of the pure seed of that variety. About 2,000 plants,

true to type, are selected and threshed individually. Progeny rows are grown and progenies containing off-types are removed before harvest; the seed of the remaining progenies are mixed to form breeder seed. Breeder seed is monitored by a committee composed of representatives of the Indian Council of Agricultural Research, the NSC, the State Seed Certification Agency (SSCA) and the breeder.

#### **Foundation seed**

Foundation seed production of all Indian varieties is arranged by the NSC; the SSC undertakes the production of varieties on the state level. Because of increased demand for certified seed of certain varieties, it has become necessary to undertake a second stage of foundation seed production, which is known as Foundation Seed Stage II. Certification and "grow-out testing" of all foundation seed lots are carried out by the SSCA. The grow-out test serves as both a postcontrol test for the foundation seed and a precontrol test for certified seed.

#### **Certified seed**

Certified seed production is carried out by public as well as by private agencies. The certification is optional, and is carried out by an independent certification agency. The only varieties which come under review for certification are those which have been released by either the State or Central Subcommittee on Release of Varieties and duly certified by the Central Seed Certification Board.

The public sector companies that arrange for seed production through registered seed growers are shareholders in the corporation and, thus, directly linked with the development of the corporation. However, production with contract growers is also arranged to help achieve target quantities.

In order to have better quality control, certification work is carried out by the staff of U.P. Seeds and Tarai

Development Corporation (UPSTDC) as well as the SSCA. This system provides an opportunity for more inspections of seed plots; it also provides counter checks. The seed producers are advised to harvest their seed crops when they have appropriate moisture content, preferably 13%, to avoid mechanical damage. For the convenience of the seed producers, and to have effective quality control, a representative sample of raw (unprocessed) seed is drawn from the farmer's field and tested; only that seed which meets the prescribed standards is accepted at the plant.

After arriving at the plant, the seed is again tested to confirm that the lots meet the prescribed standards. Those lots meeting the standards are then processed, i.e., cleaned, graded, treated, packaged and labeled. Generally, drying is not required as seed is received during the dry period and moisture content in the grain at intake time varies between 9 and 10%. The corporation has well-equipped processing plants with a total capacity of 65,000 tons; this is being expanded to 80,000 tons. Similarly, other seed corporations in the country have processing facilities in accordance with their production program.

The UPSTDC has its own quality control system and does not rely totally on the SSCA. Certain standards which are not prescribed in the Indian Minimum Seed Certification Standards have been incorporated into its seed production program. For instance, no standard has been prescribed for loose smut (*Ustilago nuda tritici*), but the corporation is testing for infection by a technique called the mycelium test in every lot of wheat seed it receives. Lots having more than 0.5% infected seed are subjected to special treatment with a systemic fungicide, Carboxin or Carbendazim. Similarly, lots having high amounts of rod kernel or spotted kernel are not accepted. This procedure

is unique and is not presently followed by any other corporation in the country, although there is an awareness that such a system should be adopted by others.

The grow-out test of about 20% of the certified seed lots is carried out to ascertain the quality of seed marketed by the corporation. To pin-point mistakes in production, processing and marketing, the identity of seed of different farmers is maintained by allocating separate seed lots.

### **Storage**

The moisture content of seed is a very important factor, influencing its longevity in storage. Wheat seed is harvested during the dry part of the year (April and May), when moisture content is low. However, mechanical drying becomes necessary when seeds get wet due to rains at the maturity stage. Wheat seed is stored over the monsoon, when relative humidity is high, until the planting season in November and December. During this period, seed is likely to take up moisture, and it deteriorates if not properly stored. Because of this fact, the corporation has chosen comparatively drier places for storage, and also uses polyethylene-lined bags for moisture-proof packaging.

Pests are a real threat to proper seed storage in India. The rice weevil (*Sitophilus oryzae*), the lesser grain borer (*Rhizopertha dominica*), the Khapra beetle (*Trogoderma granarium*) and the rust flour beetle (*Tribolium castaneum*) infest wheat seed during storage. To eliminate pests, fumigation with aluminum phosphide is carried out once a month and spraying with pesticides once every two weeks. While fumigating the seed stock, precaution is taken that moisture content in the seed is below 14%, as fumigation at a higher moisture content damages the seed.

Wheat seed is also invaded by pathogens during storage, the most common being *Aspergillus*. To avoid damage by fungi, the seed is treated with fungicides.

To avoid moisture penetration through the floor, seed bags are stored on wooden pallets after laying a vapor barrier. Proper ventilation and insulation are provided to lower heat in the warehouses. When seed is stored in metal bins, frequent aeration by means of a blower is carried out to remove any heat generated inside the seed columns. The government is currently putting greater emphasis on creating proper storage facilities to avoid damage to seed during storage. Under this program, bulk seed storage warehouses will be constructed without refrigeration or dehumidifying equipment; for storage of breeder and foundation seed, such equipment is being planned.

### **Marketing**

The demand for wheat seed in the country is growing extremely rapidly. This increase in demand is by no means accidental or temporary. Since the new varieties of wheat are shorter in duration and relatively insensitive to day length, many areas where wheat cultivation was virtually unknown, West Bengal, Assam, Tripura and Meghalaya in the east and Karnataka and Maharashtra in the south, have become important wheat-growing areas. The cultivation of wheat in Bangladesh has also assumed importance.

### **Assessment of demand**

Until recently, data on seed demand has been inadequate. Sometimes demand has exceeded supply and sometimes seed of certain varieties has gone unsold. Under the National Seed Program, the government is now holding seed conferences well before the beginning of each new planting season, and the seed demand and supply for the different states is

discussed and ascertained; the strategy for seed production for the next three years is also formulated. In addition to seed conferences, a standing committee consisting of the chief executives of the state and central governments and the seed corporations has been constituted, and will monitor the performance of the different organizations and provide guidelines for future programs.

#### **Marketing organization**

The corporation undertakes the marketing of seed through public cooperatives and private-sector agencies. Through the distributor/dealer network, the corporation has 38 distributors and 1,400 dealers functioning throughout the country.

#### **Movement of seed and maintenance of buffer warehouses**

The corporation has always attempted to move as much wheat seed as possible to buffer warehouses in the different marketing areas before the rains. The bulk of the movement is by railroad and the balance by road transport. By maintaining buffer warehouses in the different marketing areas, the corporation is able to reduce transportation costs by transporting early; there is also the benefit of seed reaching end-use areas in time. Proper care is taken during the movement of seed, so that it does not take up moisture and is not attacked by pests.

#### **Pricing**

Prices are normally fixed on the basis of cost of production plus a reasonable profit margin. Normally, the cost of certified seed is 100% higher than the market grain price; the producers receive about 30% of this amount.

#### **Seed legislation and seed law enforcement**

The Seeds Act, enacted in 1966, deals with regulations regarding the sale of seed and the establishment of suitable law enforcement machinery, such as the appointment of seed inspectors, the certification of central and state seed

laboratories, the hiring of seed analysts, the appointment of appellate authorities and the setting of penalties for offenders. In December 1983, the government, through an ordinance, included seeds in the Essential Commodities Act; since then, licencing of all seed agents has become necessary. The Act also provides heavier penalties for traders indulging in the sale of spurious seed.

#### **Problems in Seed Production, Storage and Marketing**

##### **Heavy dependence on a few varieties**

At present, Sonalika is the most popular variety in India and covers 70 to 90% of the wheat area in the northern and eastern states. Large coverage under one variety is not a happy situation, particularly since this variety has started showing susceptibility to yellow and brown rusts (stripe and leaf rusts).

In order to avert heavy losses due to diseases and pests, diversification with suitable new varieties is necessary. The production of varieties such as HD2285, HP1102 and HUIW37, which could replace Sonalika, should be carried out on a comparatively larger scale. There is also a need for developing new varieties with wide adaptability and suitability for late sowing, as well as high yield potential.

##### **Spread of karnal bunt (*Neovossia indica*)**

The occurrence of karnal bunt (*Neovossia indica*) disease is no longer erratic. For three years, the presence of the disease has caused the rejection of otherwise good-quality seed produced by seed industries in India. Unfortunately, there are no control measures, and almost all of the varieties under seed production are affected in varying degrees. The

varieties with high yield potential, such as HD2009, WL711, UP262 and UP2003, are worst hit. Research needs to be undertaken for the development of varieties with both good yield potential and resistance to karnal bunt, and for the identification of fungicides for controlling it. The fungicide must be economical for application to seed lots and, hopefully, also for farmer use.

#### **Pre-harvest rain**

The occurrence of pre-monsoon rains at the maturity stage of the seed crop in 1982 and 1983 rendered large quantities of seed unfit for storage and planting. The repeated drenching of the standing crop resulted in the sprouting of kernels on the spike. Even the seed saved from these crops lost germination during storage because of moisture gain. Therefore, there is a need for initiating research programs for developing varieties suitable for early planting, to either escape pre-monsoon rains or withstand them.

#### **Lack of availability of breeder seed**

If the seed program is to succeed, quick multiplication of newly developed varieties needs to be undertaken before their identity is lost. It has been noticed that, because of the lack of availability of breeder seed, promising varieties evolved by breeders get lost, even before coming into the channel of seed production. It is emphasized that the breeder must assume responsibility for multiplication of breeder seed of newly developed varieties and provide it to the institutions or agencies responsible for the multiplication of foundation and certified seed. This weak link in the seed multiplication program at the initial stage has caused great setbacks in the cause of the Green Revolution.

#### **Seed loss through natural calamities**

For stability in production, maintenance of a buffer stock of seed is necessary to meet the challenge of seed loss through natural calamities, such as floods and droughts. To achieve this, a financially backed buffer-stocking program with adequate storage and revalidation facilities needs to be developed at the national level.

## V. Economics

### Wheat in the Tropics: Economic and Policy Issues

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#### Abstract

*Interest in wheat production in the warmer tropics stems from rapidly increasing wheat consumption and imports in many tropical countries. One billion people in the tropical belt (23°N to 23°S) now consume over 22 million tons of wheat, 83% of which is imported. In many tropical countries, wheat (usually bread) has become the staple food, especially of urban consumers. Wheat consumption has increased because of consumers' rising incomes and interest in convenience foods and a diversified diet. More importantly, governments have encouraged rapid increases in wheat consumption through favorable pricing policies for bread, including subsidies in many countries. Exporting countries have also promoted wheat consumption through export promotion and food aid. Large-scale investments in capital-intensive milling and baking industries have entrenched interest in continuing wheat imports. Governments concerned about rising wheat imports should consider policy alternatives as part of an integrated food policy analysis that includes consumer price policies for bread and competing staples, cereal import and food-aid policies, removal of incentives to the milling industry, promotion of nonwheat food staples, including composite flours, and increased domestic agricultural production. Domestic wheat production is only one alternative for increasing agricultural production. The comparative advantage framework enables an assessment of the real returns to the country of resources used in wheat production versus alternatives. These returns are likely to be highest where wheat enables an increase in cropping intensity, using available land, labor, water and mechanical services to a fuller capacity. The place of wheat in the farming system also needs to be carefully evaluated, with particular attention to the need for timely planting, which is critical for successful wheat production in the warmer tropics. These economic issues should be addressed at an early stage in any proposed wheat consumption/production program.*

Most people in the industrialized countries begin their day with a cup of tea or coffee, whose major ingredients originated on a small farm or plantation in one of the tropical countries, such as Brazil, Ivory Coast or Sri Lanka. At the same time, the people of these tropical countries, especially those in urban areas, are likely to begin their day with bread for breakfast, bread made from wheat grown on the farms of one of the industrialized countries. At first sight, this may appear to be a reasonable exchange, but closer examination raises a number of disturbing questions.

Unlike tea or coffee, bread has become a basic food staple to many people in the tropics, providing a significant proportion of their calories, not only for breakfast but also for lunch and, sometimes, dinner as well. Wheat imports by many tropical countries are growing very rapidly, and now constitute a significant proportion of foreign exchange expenditures. While people in the tropical countries may not be "addicted" to bread in the same way as are the coffee and tea drinkers, they are increasingly dependent on bread for

their daily food supply. The extent of wheat imports and their rapid increase underlie the current interest in producing wheat for the more tropical environments.

In this paper, a number of questions will be addressed. What are the major trends in wheat consumption in the tropical belt? How dependent are tropical countries on imported wheat? What are the major factors promoting these trends? How can we judge if these trends are in the economic interests of the country? What policy alternatives are available to governments whose objective is to reduce wheat imports? Finally, some of the major economic issues will be outlined which must be addressed in deciding on a domestic wheat production program.

### **Overview of Trends in Wheat Consumption and Imports in the Tropical Belt**

In this paper, the conventional definition of the tropics will be used, i.e., the area lying between the Tropic of Cancer (23°N) and the Tropic of Capricorn (23°S). To a remarkable extent, these latitudes define the areas of the world where wheat is not currently grown commercially at altitudes below 1,000 meters (Sudan is the only exception). A number of countries are dissected by these latitudinal delineations. Countries have been excluded from the analysis that have large wheat-producing areas above or below these lines (i.e., India, Saudi Arabia and China). Other countries which are largely tropical, such as Sudan and Burma, have been included. Brazil is a more difficult case; most of its wheat is now grown south of 23°S latitude, but future expansion will take place only in the more tropical zones.

Hence, Brazil has been arbitrarily included as a tropical country. With these definitions the tropical belt consists of the following countries:

- Africa—all Sub-Saharan Africa except Lesotho and South Africa
- Asia—the two Yemens, Sri Lanka and Southeast Asia, from Burma to the Pacific countries
- Latin America—Guatemala to Brazil and Paraguay, including the Caribbean countries

This group of tropical countries has a population of about one billion people, roughly equally divided between Africa, Asia and Latin America. In the period 1980 to 1982, they produced 4.3 million tons of wheat annually, most of it in Brazil and Ethiopia. This was only about 2% of total wheat production in the Third World and less than 1% of world wheat production. At the same time, these countries imported about 20 million tons of wheat, about one-third of all wheat imported by developing countries. That is, imports supplied about 83% of total wheat consumption in the tropical belt (Table 1).

From 1980 to 1982, there were 40 tropical countries that consumed over 100,000 tons of wheat each. Only six of these countries (Ethiopia, Kenya, Sudan, Zimbabwe, Yemen Democratic Republic and Brazil) produced over 100,000 tons of wheat, mostly in highland areas (Table 1). Outside of this group, almost all were entirely dependent on imported wheat. By the early 1980s, nine of these countries were importing close to one million tons or more of wheat annually (Nigeria, Indonesia, Sri Lanka, Philippines, Vietnam, Cuba, Venezuela, Peru and Brazil).

Per capita consumption of wheat in the tropics varies substantially from less than 5 kg per year in Thailand to over 100 kg per year in Cuba. Per capita consumption is much higher in Latin American tropical countries (50 kg/year)

than in Asia and Africa (about 16 kg/year) (Table 2). In the Latin American tropics, wheat now accounts for over one-quarter of staple food calories compared to less than 10% for the Asian and African group; however, consumption is expanding much more rapidly in the latter group. Several countries have had an annual growth in per capita consumption of over 10% annually, e.g., Nigeria, Indonesia and Vietnam.

For the developing world as a whole, wheat consumption has expanded extremely rapidly over the last two decades as wheat and, to some extent, rice have substituted for coarse grains and roots and tubers (Table 2). This substitution has been greatest in the

**Table 1. Summary of annual wheat production and imports in tropical countries, 1980 to 1982**

Region	Population (millions)	Countries consuming over 100,000 t	Countries producing over 100,000 t	Production (million t)	Imports (million t)	Percent of consumption imported
Africa	360	15	4	.54	4.3	74
Asia	403	11	1	.19	5.7	100
Latin America	255	14	1	2.63	10.0	80
Total	1018	40	6	4.36	20.0	83

Source: FAO data tapes

**Table 2. Summary of trends in wheat consumption in the Third World, 1980-1982**

Region	Per capita consumption (kg/yr)	Staple food <sup>a/</sup> calories from wheat (°/o)	Growth of per capita wheat consumption <sup>b/</sup> (°/o/ year)
Tropical Africa	19	6	4.2
Tropical Asia	14	6	4.2
Tropical Latin America	50	25	1.6
Average, tropical countries	25	15	2.8
Large mixed cereal economies: India, China, Mexico	65	28	3.2
Countries where wheat is the staple food	123	71	2.8

<sup>a/</sup> Staple foods include coarse grains, roots and tubers

<sup>b/</sup> 1961-65 to 1980-82

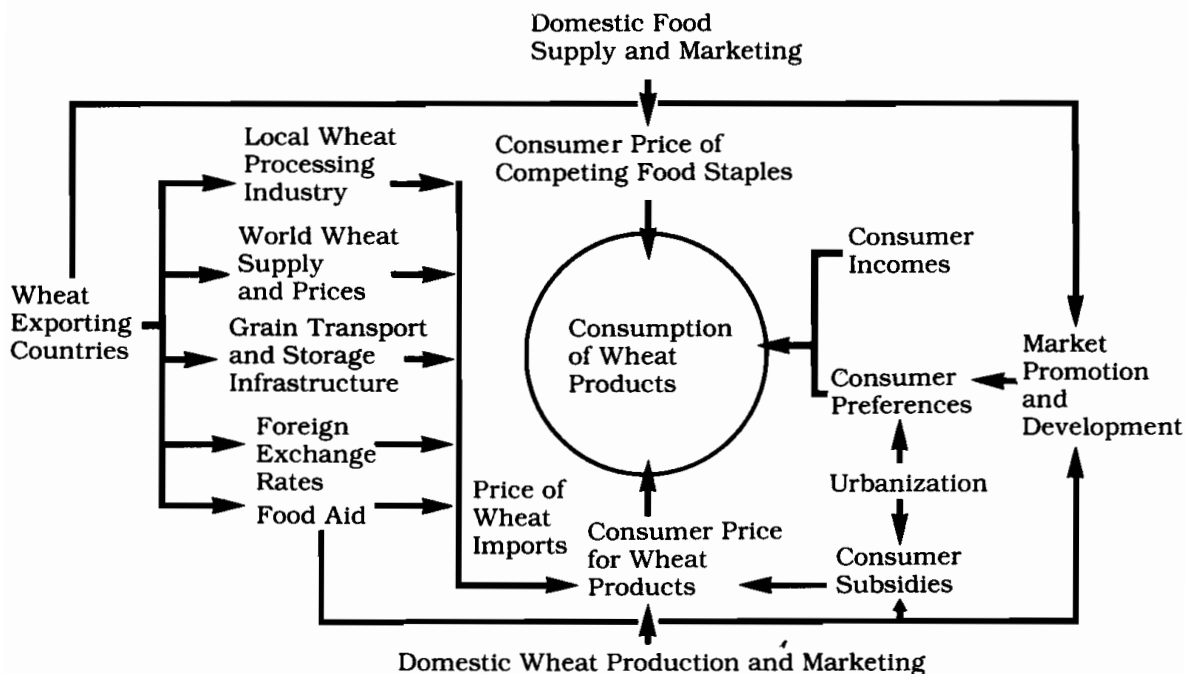
mixed cereal economies of China, India and Mexico and in the tropical belt countries. In the first group, however, increased wheat consumption has largely been met by increased production while, in the tropical belt, about 90% of the increase in consumption has been imported. From 1970-72 to 1980-82, wheat imports by the tropical countries doubled.

### Factors Influencing Wheat Consumption in the Tropics: A Cross-Country Regression Analysis

Figure 1 is a schematic representation of the complex of factors influencing wheat consumption in the tropics. On the right side are the factors which influence demand through their effects on incomes and food preferences. On the left side are factors related to supply that influence the quantity and price of imported wheat relative to local food

staples. A number of government policies, such as consumer subsidies, food aid and exchange rates, as well investments in the marketing, transport and processing infrastructure, influence the demand for and the supply of wheat, particularly through their effects on consumer prices.

Many of these factors are confirmed by cross-country regression analyses of per capita wheat consumption in 39 countries, as shown in Table 3. The strongest determinant of per capita wheat consumption in this group of countries is per capita income, which is also closely correlated with urbanization ( $r = .83$ ) (the high correlation between per capita income and urbanization does not allow the inclusion of both variables in the regression analysis). Increasing income has a strong effect on wheat consumption, with an estimated income elasticity of 0.6 (i.e., a 1% increase in income leads to a 0.6% increase in



**Figure 1. Major influences on wheat consumption and imports in the Third World**

wheat consumption). However, the negative coefficient on the quadratic term for per capita income indicates that consumption stabilizes at about 45 kg per capita at a per capita income of about US\$ 3000, i.e., about the income level of Singapore and Venezuela.

Wheat consumption is also negatively related to the consumer price of bread. A 10% increase in bread prices leads to a decrease in wheat consumption of 6%. Food aid also seems to influence consumption. As expected, those countries which import wheat as food aid tend to consume more wheat than other countries at a similar level of income. More interesting is the positive effect of wheat imported as food aid in the past. An early objective of food aid was to develop markets for surplus wheat stocks of the major exporters, particularly the USA. Finally, wheat consumption is negatively related to domestic production of cereals which, in this group of countries, does not include wheat; however, this effect is not very strong. An increase in local cereal production of 1% leads to a reduction of wheat imports of only

0.27%. Following is a more detailed examination of each of these factors influencing wheat consumption.

#### **Incomes and urbanization**

Wheat consumption in tropical countries has initially been established in urban areas (3,12,14,15,21). In most countries, the consumption of wheat in urban areas is at least double that of rural areas. Figure 2 demonstrates that, as per capita national wheat consumption increases, the difference between rural and urban consumption tends to decline. Likewise wheat, usually as bread, is initially consumed by middle to high-income groups but, with increasing levels of consumption, it becomes more important to lower-income groups. In most tropical countries, wheat consumption has increased with rising incomes faster than any other food staple. Wheat and, to some extent, rice substitute for coarse grains and roots and tubers, whose consumption often declines with rising incomes (see the example of Brazil in Figure 3).

**Table 3. Estimated cross-country regression equation for wheat consumption in tropical countries, 1979 to 1981**

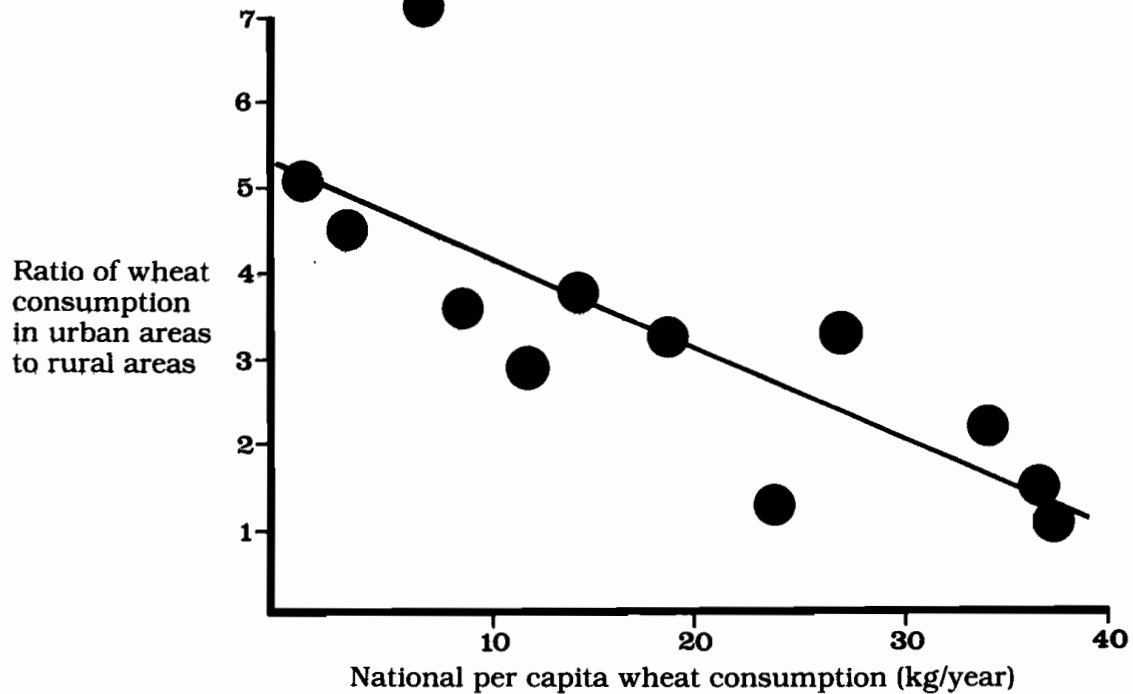
$$\begin{aligned} \text{WHEATCON} = & 25.22 + .027 \text{ GNP} - .462 \times 10^{-5} \text{ GNP}^2 - .178 \text{ PRBREAD} - \\ & (.0053)^{**} \quad (.118 \times 10^{-5})^{**} \quad (.052)^{**} \\ & .058 \text{ DCP} + .861 \text{ FA} + .091 \text{ CUMFA} \\ & (.020)^{**} \quad (.414)^* \quad (.036)^{**} \end{aligned}$$

WHEATCON = Wheat consumption per capita (kg/person, 1979-81 average)  
 GNP = Gross national product per capita (1980 US\$)  
 DCP = Domestic cereal production per capita (kg/person, 1979-81 average)  
 FA = Wheat imports as food aid per capita (kg/person, 1979-81 average)  
 CUMFA = Historically cumulative food-aid wheat imports (kg/person, 1955-75)  
 PRBREAD = Price of bread, 1979-81 (US cents/kg)

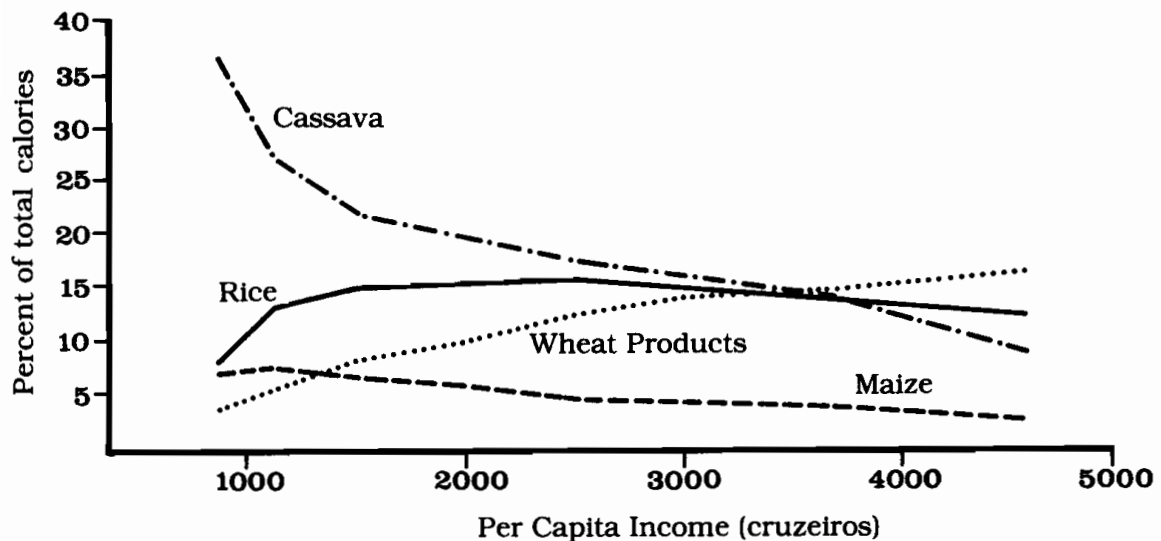
$n = 39, R^2 = 0.81$

Standard error of estimates are given in brackets

\*, \*\* Significant at the 5% and 1% levels, respectively



**Figure 2. Relationship between the ratio of urban to rural per capita wheat consumption and national per capita wheat consumption in tropical countries**



**Figure 3. Rice, cassava, wheat and maize as contributors to apparent per capita energy consumption according to income class, northeast Brazil, 1975-76**

**Source: T.T. Poleman. 1981. Quantifying the nutrition situation in developing countries. Food Research Institute Studies 1:1-58.**

These changing consumption patterns reflect the preference for bread as a convenience food in urban areas. Less time and cooking fuel is also required for the consumption of wheat-based foods (10,12,17).

On the supply side, urbanization also favors wheat consumption based on imports. With plentiful supplies of wheat in world markets, lagging domestic production of staple foods and poor infrastructure for transporting and marketing domestic food supplies in urban areas, there has been a natural tendency to import wheat to feed urban consumers, especially in countries where large cities are located on the coast.

### **Bread prices**

Food pricing policy in many tropical countries favors low bread prices relative to competing staples. About one-quarter of the tropical countries for which we have price data subsidized bread prices in the 1970s. Sri Lanka, Sudan, Ivory Coast, Ecuador and Brazil are all countries where bread subsidies have led to rapid increases in wheat consumption (3,12). Many other countries have imported wheat duty-free and at a significantly overvalued exchange rate. If bread prices are converted at the black market exchange rate, nearly half of the tropical countries, especially in Africa and Latin America, had declining real bread prices in the 1970s (3). In Africa, this largely reflects exchange rate policy while, in Latin America, a combination of overvalued exchange rates and increasing bread subsidies in a number of countries have led to declining real prices.

The result of these policies is that, in many countries, wheat flour and bread are cheap relative to locally produced food staples, such as rice, maize and cassava. In several countries, e.g., Nigeria, Ivory Coast, Sudan, Brazil and

Ecuador, wheat flour based on imported wheat was cheaper than locally produced coarse grains, such as maize or sorghum. Food pricing policy in these countries may explain half or more of the growth of wheat consumption. There are, of course, important exceptions. Southeast Asian countries such as Thailand, Burma and the Philippines maintain high bread prices. A number of countries, such as Colombia, Senegal and Sri Lanka, have phased out bread subsidies and per capita wheat consumption has fallen.

### **Food aid**

Although food aid has declined in importance relative to commercial food imports, it has been and remains important to a number of tropical countries. Over 80% of food aid is provided as wheat, and this proportion is only slightly lower for the tropical countries. Food aid has encouraged wheat consumption in these countries by reducing the price of wheat products, establishing a milling and baking industry and developing consumer tastes and preferences for wheat (9,19). The development of markets for commercial wheat is still an important objective of food aid and our cross-country regression analysis indicates that it has been relatively successful. Sudan, Sri Lanka, Somalia and Mauritania are examples of tropical countries that receive substantial amounts of food aid and have relatively high per capita consumption of wheat.

### **Government Policy Alternatives with Respect to Wheat in the Tropics**

Interest in wheat production in the tropical countries reflects a desire to promote greater self-sufficiency in food. Many governments have seen the rapid

increase in foreign exchange expenditures for wheat imports as an area where foreign exchange can be saved and, at the same time, domestic agricultural production be promoted. Food security is also sometimes an important objective, as governments seek to reduce exposure to fluctuations in world market prices. However, except for 1974-75, world market prices for wheat have been relatively stable over a long period.

The reasons for increasing wheat consumption are complex and need to be analyzed within the specific food policy environment in each country. Wheat consumption is bound to increase in most countries. As consumer incomes increase, there is a natural tendency to diversify diets. However, in many cases, the policies of governments, food-aid donors and exporting countries have reinforced and greatly accelerated this trend. This comes about as a result of food-pricing policies that favor bread and by an implicit policy of supplying urban consumers from food imports (in most cases, wheat). At the same time, policies have encouraged investments in marketing, storage and processing for imported wheat. These investments act like a "wheat trap" because, once established, it is very difficult to reverse the trend toward importing wheat (2,5).

The milling and baking industry has grown extremely rapidly over the last decade in tropical countries that do not produce wheat (for example, between 1975 and 1980 wheat flour production increased at an annual rate of 23.4% in Brazil, 7.6% in Indonesia, 11.1% in Kenya, 11.7% in Cuba, 14.4% in Guatemala and 7.2% in the Philippines) (5). This is a highly wheat-specific industry that cannot be converted into the processing of locally produced staples, even if they are in surplus supply. It is ironical that, in the last few years, the largest flour mills in the world

have been established in the nonwheat-producing countries of Indonesia, Sri Lanka and Nigeria. Investment and trade policies (such as high tariffs on wheat flour imports) have encouraged rapid expansion of flour milling in many tropical countries (5).

With this background, and given an objective of reducing wheat imports, a number of policy alternatives are available for tropical countries.

### **Food pricing policy**

Undoubtedly the quickest way to reduce wheat imports is to raise consumer prices for wheat products. There is ample evidence that wheat consumption is quite sensitive to prices. Removal of consumer subsidies and, in some cases, imposing a tariff on wheat imports to compensate for overvalued exchange rates are the major instruments for adjusting bread prices. The objective should be to restore incentives to consume domestically produced food staples. It has been shown elsewhere that, based on world prices, the ratio of the price of wheat flour to rice and maize should be about 0.7 to 1.0 and 1.6, respectively (3). At these prices, bread will be considerably more expensive than rice and maize.

The political sensitivity of bread prices is recognized. However, it should also be recognized that the longer such a decision is delayed, the more difficult it is to correct the imbalance. Thailand is a country which has maintained high bread prices and, as a result, per capita consumption is low (4 kg/year); there it is still relatively easy to regulate bread prices. In the Sudan and Ecuador, bread subsidies have promoted per capita bread consumption of over 80 kg/year in the capital cities. It would now be very difficult to manipulate bread prices in these countries, since bread is such an important food staple to a politically powerful section of the population.

Finally, it should be clarified that, in many tropical countries, low bread prices have produced few benefits to the poor. Rather, the middle and upper income groups, which are the main bread consumers, have captured the benefit of these policies, while the farmer, especially the small farmer who produces local staples such as maize, has been the main loser (5,14,16).

#### **Policies toward the wheat processing sector**

An integrated wheat strategy should carefully rationalize investments in wheat processing, especially large-scale capital and foreign exchange-intensive milling and baking plants. Little justification is found for the establishment of a milling industry, given the need to efficiently use scarce capital and promote employment. Removal of tariff protection on flour imports should effectively arrest the growth of this industry, until such time as local wheat production might be established. Importing wheat as flour maintains much greater flexibility in future food-policy decisions and also reduces the power of one of the strongest voices, that of the millers, in food-import policy. Finally, most tropical countries produce white flour, milled at an extraction rate of 70 to 75%. Legally mandated higher extraction rates (e.g., in Sudan), which produce off-white flour and breads, would allow savings in wheat imports.

#### **Import policy and food aid**

We have noted that cereal imports by the tropical countries have emphasized wheat and, to a lesser extent, rice. Maize imports have largely been destined for feeding livestock. Yet maize is usually the cheapest cereal in world markets, and is a staple food of most tropical countries, especially for the poor. With consumer prices that reflect import prices, maize has considerable potential as a food import. Some difficulties arise because most countries

consume white maize, while yellow maize dominates world markets. Yet, with the favorable price incentives and export promotion seen for wheat, there should be no reason why maize cannot play an important role in world food trade. Donor agencies could help by targeting food aid to countries in accordance with their staple food. For tropical countries, this would mean more emphasis on food aid in rice and coarse grains.

#### **Promotion of convenience foods based on local food staples**

Bread-making technology has largely been imported from the industrialized countries. At the same time, until recently, little research has been conducted on the preparation of local foods to meet the preferences and convenience needs of urban consumers. There has been considerable research on composite flours which mix wheat flour with maize, millet or cassava flour for bread making (11,17). This appears to be technically feasible, but the greatest obstacle in most countries is that pricing policy favors wheat flour and provides no incentives to use mixtures.

Meanwhile, private and public agencies of wheat-exporting countries have conducted vigorous and apparently successful market-promotion programs for wheat products. Government policy should convert these efforts into the national interest, perhaps by requiring that these export interest groups conduct research and promotion that balances wheat with local food staples.

#### **Increasing domestic agricultural production**

In an integrated wheat strategy, increased agricultural production must receive high priority. Producing wheat domestically is only one option. Alternatives include 1) promotion of

export crops which will generate foreign exchange for importing food and 2) promoting the production of other food staples to substitute for wheat imports.

The comparative advantage framework is a useful way of assessing the economics of each of these alternatives. As an example, it can be assumed that one hectare of wheat yields 2 tons of grain. If imported wheat costs \$200/t in the capital city, and it costs \$20/t to transport domestically produced wheat to the capital, then the value of one hectare of domestic wheat would be equal to  $2 \times (200-20) = \$360/\text{ha}$ . Local wheat production will require imported fertilizer and other inputs; if these cost \$100/ha, the net gain would be \$260/ha. However, these same domestic resources of labor and land might be invested in export crops such as cotton. If one hectare of cotton yields 0.8 tons of lint per hectare at an export price of \$1,000/t, and requires \$200/ha of imported inputs, net gains would be \$600/ha, sufficient to import over 3 tons of wheat. In this case, cotton would have the comparative advantage. However, if wheat yields 4 t/ha (for the same inputs), wheat would have the comparative advantage. All of these calculations employ the world price equivalent of the commodity rather than the domestic price, since the world price reflects the real cost to the country.

The value of the comparative advantage analysis is that it demands a look at the alternatives. The above example shows that, in focusing on wheat alone, it might be concluded that there is a net gain from wheat production. However, with the country's welfare rather than wheat production as the objective, the alternative uses of the scarce domestic resources available and their contribution to national income must be taken into account.

### **Economic Issues in Establishing a Domestic Wheat Industry**

The economics of domestic wheat production must be examined at two levels, the comparative advantage or profitability to the country, and the profitability to the farmer. At the same time, there will be a number of marketing and milling issues to be resolved in establishing a new industry. Some of these issues will be mentioned only briefly, since they will be discussed in more detail in the papers that follow.

#### **Economic profitability**

Four issues will be dealt with that determine economic profitability to the country. First, the foreign exchange savings generated by domestic wheat production will be critically dependent on the technology employed. Highly mechanized wheat production schemes which have been tried in several African countries, with even harvesting being mechanized, are expensive from a foreign-exchange point of view and are unlikely to be efficient in a low-wage economy (6,13,17). One-third or more of the foreign exchange saved is spent on imported inputs and machinery. Investment in large-scale irrigation schemes is also extremely costly (over US\$ 10,000/ha) and foreign-exchange intensive. It is unlikely that it will pay to develop large-scale irrigation schemes in the tropics, specifically for wheat production (1,2,20). Even small-scale irrigation schemes for wheat have failed to generate satisfactory returns (8).

Second, areas with high yield potential and irrigation or adequate moisture will also usually have high-value alternative crops such as rice, cotton or other cash crops that are adapted to tropical areas. While it seems logical to emphasize areas where wheat gives the highest yields, it may well be that wheat's greatest comparative advantage will be

in areas where wheat yields are relatively low, but where there are few alternatives. (The rapid expansion of wheat in Bangladesh on residual moisture after rice illustrates this point). A similar issue arises in those tropical countries with limited highland areas suitable for wheat, but where there are a number of alternative land uses with high returns (4).

Third, the greatest potential for wheat in the tropics is likely to be as a second or third crop after a main crop, such as rice or cotton. An early variety of wheat that fills a gap in the cropping calendar and enables increased cropping intensity may also allow more efficient use of farmers' labor, land and water resources.

Fourth, the economic profitability of wheat in many countries is critically dependent on transportation costs from the producing region to the consumption center. For example, in 1979, it was estimated that transport costs for wheat from the north of Nigeria to Lagos were about US\$ 65/ton at the real exchange rate. Assuming a CIF price of wheat of about \$200/t, the cost of imported wheat in the north would have been about \$265/ton (200 + 65), while the real value of domestically produced wheat at Lagos would be about \$135/ton (200-65), or only half of its value in the north. Given these wide margins, it may have been profitable to produce wheat for local consumption in the north, but quite unprofitable to substitute it for wheat imports in Lagos. In some countries, this issue is further complicated by the location of flour mills on the coast for imported wheat. If wheat is to be produced in the interior for local consumption, there may be a need to establish small-scale wheat mills in the producing area (6).

#### **Farmer compatibility**

The key issues in the acceptance of wheat production by farmers are profitability, risk and compatibility with

their current farming systems. The last two are related; one of the most critical determinants of wheat yields in the tropics will be timely planting. Hence, it is essential to examine the current farming system and the extent to which the farming calendar and available resources will allow planting during the optimal period. Expected yields under farmers' conditions must be carefully evaluated through extensive field testing within the cropping system and resources available to farmers. Several wheat development projects have been wildly optimistic about expected farmer yields. Even where wheat fits well into the cropping system, there is always a learning curve for the adoption of a new crop.

Profitability depends on both the input and output prices facing farmers. It is not difficult to make wheat production profitable. The phenomenal expansion of wheat production from a very small base in Saudi Arabia reflects high subsidies on water, machinery and fertilizer, and the highest producer price in the world, over US\$ 1,000/ton. The issue is to find that combination of price incentives which promotes an efficient industry. The basic guidelines for setting a domestic wheat price will be the price of imported wheat (adjusted for exchange rate overvaluation) and the price of competing agricultural products.

Once a domestic producer price has been set, a mechanism will be needed to ensure that this price is actually received by farmers. In most countries, wheat millers enjoy a degree of monopoly power. They also prefer the *status quo* of using only imported wheat, whose supply and quality is predictable and which can be handled in volume. In the initial stages, the government food procurement agency will probably have to act as a wheat buyer, since it will be in a much better position to negotiate with the millers.

## Conclusions

Wheat consumption will undoubtedly continue to expand in tropical countries. However, if governments pursue policies that remove incentives to consume wheat, this expansion will be relatively slow and will reflect a natural tendency by consumers to diversify diets as their incomes increase.

Governments that wish to reduce dependence on imported wheat should consider domestic production of wheat as only one among a set of policy alternatives. A decision to produce wheat domestically should be taken in the context of the wider food policy environment, and after a careful assessment of the comparative advantage of wheat. It is impossible to make general statements about the economics of wheat production in the tropics. However, it appears that the best prospects for efficient wheat production in the warmer tropics are where wheat will enable two or even three crops a year, where moisture limits production of other crops or where small-scale irrigation is available, and where wheat can be produced using the labor and machinery already utilized by farmers in the production of other crops.

These economic issues should be analyzed at an early stage, before the commitment of a large amount of resources to a domestic wheat research and production program.

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## **Wheat in Chiang Rai, Thailand: A Preliminary Look at Comparative Advantage**

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### **Abstract**

*A preliminary assessment is made of the comparative advantage of wheat versus alternatives for two production domains in the Chiang Rai province of Thailand, the rainfed uplands and the banded lowlands without dry-season water. The assessment is preliminary, because wheat technology is not yet well specified. Using technology and cost assumptions that favor wheat, results indicate that wheat does not have a comparative advantage on rainfed uplands; for saving or earning foreign exchange, more resources are used for wheat production than for that of maize or mungbean. However, wheat may have a comparative advantage in certain lowland areas, if agronomic problems and cropping-systems conflicts can be resolved.*

Thailand, like many other developing countries in more tropical environments, is importing and consuming large and increasing quantities of wheat. Currently, wheat imports total about 200,000 tons per year, with a current value of about US\$ 40 million; they are said to be increasing on the order of 10% per year (3). As a consequence, Thai researchers, in cooperation with CIMMYT, have undertaken the task of developing technology for local wheat production. The purpose of this paper is to add an economic dimension to their work by offering a preliminary assessment of the comparative advantage of wheat for one province in northern Thailand. It is restricted to the production of wheat for import substitution; production for home consumption is not addressed.

### **Wheat Production Domains**

Any study of comparative advantage is conducted for specified production and consumption locations. This study sets consumption and production locations at Bangkok and Chiang Rai province, respectively. Chiang Rai was chosen

because of its relatively favorable agroclimatic and economic circumstances, including such factors as a relatively long cool season, relatively abundant dry-season rainfall (1) and relatively large areas of idle land in the cool, dry season. This province is far from homogeneous and, as part of the study, several wheat-production domains were identified. Each of them is reasonably homogeneous with respect to possibilities for wheat production; they include rainfed uplands, lowlands with inadequate dry-season water and other domains.

#### **Rainfed uplands**

This domain is comprised of cropland below 600 meters altitude that is not banded or irrigated. Maize, the major rainy-season crop, is harvested by early to mid-September, leaving more than a month before the wheat-planting season. In much of this domain, wheat can be grown after maize, but would compete with other second crops (mungbean, peanuts and a second maize crop) for land and other resources. This domain is characterized by relatively light-textured soils and covers some 56,000 hectares, approximately 17% of Chiang Rai cropland.

### **Lowlands with inadequate dry-season water**

This domain is comprised of banded cropland, planted to flooded rice in the rainy season, but left idle in the dry season because of insufficient or poorly managed dry-season water. Water for rainy-season flooded rice is mainly from rainfall, with some also coming from traditional irrigation systems. Water control (the ability to flood and drain at will) is poor, because water moves directly from field to field, rather than through subcanals. Wheat would have to be grown, for the most part, with residual moisture. Irrigation water, even for stand establishment, would commonly not be available. Wheat would not compete for land with other second crops, as none are generally grown. However, the wheat-planting season conflicts with the rice-harvest period (late November to mid-January). This domain is characterized by heavy clay soils and covers approximately 200,000 hectares or about 60% of Chiang Rai cropland.

### **Other domains**

Two other domains have been identified, but are assigned a lower priority. One is similar to the lowland domain described above, but is fully irrigated in the dry season, permitting farmers to plant a second crop of flooded rice. The other domain is also lowland, with relatively light-textured soils on river floodplains. Farmers use this land with pump irrigation in the cool season for high-value crops, such as tobacco and garlic.

### **Wheat Production Technology**

Wheat production technology for more tropical environments is not yet well specified. Numerous issues in crop improvement and management remain unresolved (7). Consequently, the present assessment of the comparative advantage of wheat is preliminary, as is the specification of wheat production technology itself.

For the purposes of this study, "best-bet" wheat production practices were identified in cooperation with technical scientists. Rainfed upland wheat production practices were specified as:

- Land preparation by four-wheel tractor (two passes);
- Manual planting in rows with a seed rate of 125 kg/ha of INIA66;
- Fertilizer dosage of 30 kg/ha nitrogen and 38 kg/ha phosphorus, applied basally, and
- Manual weeding and harvesting, and mechanized threshing.

These practices result in a yield of about 1,000 kg of wheat per hectare.

Lowland wheat production practices and yields were specified as similar to those described above, except that land preparation is by rototiller. A sharply reduced labor input was also specified for weeding; wheat after flooded rice faces fewer weed problems than does wheat after maize.

If anything, the specified practices tend to consistently underestimate wheat production costs. For example, adequate land preparation for rainfed upland wheat after maize will likely require more than two tractor passes; similarly, pre-irrigation and straw mulching may be needed for acceptable lowland wheat yields. These associated costs are ignored. More important, the specified lowland wheat technology assumes that the conflict between rice harvest and wheat planting seasons can be resolved at no further costs to the farmer.

### **Policies Affecting the Profitability of Wheat Production**

Thailand's economic and agricultural policies increasingly tend to favor free trade (3). Most agricultural inputs are

imported with negligible tariffs or taxes. Similarly, export taxes on such products as maize and mungbean are very low. Reserve requirements and premiums which serve as taxes on rice exports have historically been quite high and, by depressing the price of the food staple, have kept wage rates artificially low (5). Currently, however, rice export taxes are low and the effect on wages seems negligible (16). Furthermore, price distortions, due to an over or undervalued currency, are virtually nonexistent.

The major policy effect on the profitability of local wheat production is a tariff of US\$ 43.60 per ton on wheat imports (3, United Flour Mills, personal communication). This serves to make wheat in Thailand artificially expensive. Currently, wheat imports cost approximately US\$ 249/ton (CIF Bangkok flour mill), or US\$ 206/ton without the tariff. Adjusting for internal transport charges, this converts to a farm-level market price (tariff included) of US\$ 227/ton or B5.2/kg or a real price (tariff excluded) of US\$ 190/ton or B4.4/kg (US\$ 1 = B23).

It should be noted that the real expense incurred in importing wheat is best estimated by the tariff-free price. The tariff itself does not represent a cost to the Thai economy, but rather a transfer from one sector (millers and wheat consumers) to another, the government. Proceeds from the tariff are available for education, irrigation infrastructure, national defense, etc.

It is also worth noting that private-sector sources suggest that a reasonable wheat price might be closer to US\$ 165/ton, lower than the real price. This will be referred to as the private sector-suggested price.

### **Private and Social Profitability of Wheat Production**

The private and social profitability of wheat production was calculated for both rainfed upland and lowland environments. Full specification of technical coefficients, farm-level market prices, real prices (adjusted to compensate for policy-induced price distortions) and enterprise budgets may be seen in a longer version of this paper (4). Estimates of net private and social profitability of wheat and alternatives, by domain, may be seen in Table 1. Also to be found are estimates of break-even yields (yields needed to repay production costs), using farm-level market prices, real, undistorted prices and private sector-suggested prices. It should be noted that there is a tendency to underestimate costs and overestimate wheat profits; some wheat production costs are underestimated as noted earlier, and only internal transport charges (not full marketing margins) are used to calculate farm-level wheat prices. Full marketing margins are used for maize and mungbean.

The preliminary assessment of the comparative advantage of wheat indicates that, even under favorable assumptions as to costs and yields, it would seem that wheat cannot compete with maize or mungbean on rainfed upland areas in Chiang Rai, unless the wheat import tariff is maintained. When real prices are used, wheat appears to demonstrate strongly negative social profits.

On lowlands, however, wheat appears to be highly profitable, regardless of whether market or real prices are used. Further research will be needed, particularly for the lowland areas, to better specify wheat production technology before a more detailed analysis of costs and returns can be made. Particular attention needs to be given to resolving the conflict between wheat planting and rice harvest dates.

Table 1. Private and social profitability of wheat and two alternatives by domain, Thailand

Variable	Rainfed uplands			Lowlands (inadequate dry-season water)
	Wheat	Maize	Mungbean	Wheat
Net private profits <sup>a/</sup>				
Yield (kg/ha)	1000	1500	450	1000
Price (\$/ton)	227	111	326	227
Total revenue (\$/ha)	227	167	147	227
Tradeable costs (\$/ha) <sup>b/</sup>	66	21	11	52
Nontradeable costs (\$/ha) <sup>c/</sup>	111	104	86	96
Returns to land (\$/ha) <sup>d/</sup>	50	42	50	79
Net social profits <sup>e/</sup>				
Price (\$/ton)	190	117	333	190
Total revenue (\$/ha)	190	176	150	190
Tradeable costs (\$/ha) <sup>b/</sup>	64	20	10	51
Nontradeable costs (\$/ha) <sup>c/</sup>	110	103	86	95
Land (\$/ha) <sup>f/</sup>	50	50	50	0
Net social profitability (\$/ha) <sup>g/</sup>	-34	3	4	44
Breakeven yields <sup>h/</sup>				
At farm-level market price, with tariff (kg/ha)	1030	1577	450	652
At farm-level real price, without tariff (kg/ha)	1179	1479	438	768
At mill-suggested price (kg/ha)	1358	--	--	885
Research cost ratio <sup>i/</sup>	1.27	0.98	0.97	0.68

<sup>a/</sup> Based on unadjusted farm-level market prices

<sup>b/</sup> Costs of inputs that are imported or exported and represent a foreign exchange cost

<sup>c/</sup> Domestic resources, without a foreign exchange cost

<sup>d/</sup> Calculated as a residual

<sup>e/</sup> Based on real prices adjusted for policy-induced price distortions, e.g., wheat tariff

<sup>f/</sup> Estimated from the residual, calculated under net private profits for the best alternative use of land

<sup>g/</sup> A positive number indicates comparative advantage for that crop

<sup>h/</sup> The minimum yield required to repay costs

<sup>i/</sup> A ratio of less than 1 indicates comparative advantage

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## **The Local-Use Approach to the Introduction of Wheat in a Nonproducing Country: Thailand**

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### **Abstract**

*Wheat in the more tropical countries has a previously unrecognized potential for increasing basic food production in the off-season. In northern Thailand, the acceptance of wheat prepared in ways to suit traditional cooking methods and preferred tastes has been good; some farmers have already begun planting wheat for home consumption. Home-scale bakeries are being established, creating a local market for wheat. This local-use approach to the introduction of wheat is providing local farmers with valuable experience, and wheat production can later be expanded from this beginning.*

One of the major problems of introducing wheat into nonproducing countries is that of finding a market for that wheat as production commences. The large, mechanized flour mills are not keen to accept the small lots of wheat of differing quality that is initially produced by the farmers. The farmers, on the other hand, want to see a market before they begin planting wheat. In Thailand, this problem may have been by-passed through a local-use approach, which encourages farmers to begin planting wheat for their own consumption. In the 1983-84 season, nearly 1,000 kg of wheat seed was planted for home consumption.

In the more tropical countries where wheat is being introduced, rice is the staple food, and the possibility that wheat might be accepted into the traditional diet is often not considered. However, wheat has an important potential to increase basic food production and improve nutrition in these areas, since 1) rainfed wheat can be an additional food crop during the cool, dry season when nothing was previously grown and 2) the nutritional value of wheat is high, with nearly double the protein content of rice, as well as much higher amounts of vitamins B and E. Also, many areas,

such as northern Thailand, that are suitable for growing wheat are rice-deficient areas. These factors formed the initial stimulus for the local-use approach.

### **Including Wheat in the Local Diet**

The local utilization of wheat is already something of a reality in Thailand. One of the keys to the acceptance of wheat by the local people has been the development and adaptation of foods that fit into the typical Thai diet, conforming with the traditional ways of preparing food as well as with the preferred tastes. Wheat is utilized in three forms in the preparation of the mainly Chinese-type foods:

- As whole wheat, boiled and added to rice and curries, fried with vegetables and used for desserts;
- As cracked wheat in boiled porridge with vegetables and pork, in chili paste eaten with rice, in tabooleh salad with chilies and in desserts with coconut milk, and
- As whole-meal flour, in flat, yeast, baked or steamed breads, in noodles and as gluten for meat substitutes.

There are two levels of utilization of wheat. The preparations made from whole and cracked wheat appeal to the housewife for everyday use because they are quick and simple to prepare. Also, small vendors use flour regularly to earn a living, selling noodles, breads, etc. in the market places. These vendors constitute the local market for wheat. This use of wheat in the whole or cracked form frees wheat production from the usual constraints imposed on it by flour quality.

When local wheat is used as flour, it is easy for the upcountry noodlemaker or baker to adjust his technique to suit the type of flour on hand, or to blend in a quantity of commercial white flour. (This approach can also be followed with triticale, whose utilization has been somewhat restricted up to now due to its flour quality.) These few factors indicate the great flexibility that wheat has as a basic foodstuff, a flexibility that should enable it to be accepted in one form or another in traditional diets.

### **Planting Wheat for Local Use**

The second key to the acceptance of wheat in Thailand was a series of village demonstrations to show the local people what sort of foods they could prepare from wheat if they chose to plant it. These demonstrations were held within the framework of various rural development programs of the Department of Agricultural Extension, schools and nongovernment organizations. As a result of these demonstrations, local people requested nearly 1,000 kg of seed wheat for planting for home consumption in the 1983-84 season. There were 27 sites of rainfed and irrigated wheat, planted in plot sizes that varied from 1/5 to 1 ha. The yields were generally low (0.6 t/ha or less), due to well-identified reasons, of which inexperience was one of the

principal ones. For the coming season, in spite of the low yields of the first attempt, requests for seed have increased.

After the 1984 harvest, the home economics officials from the Department of Agricultural Extension held Wheat Days in their areas. As a result, an additional 680 farmers expressed interest in planting wheat (1/10 ha each) for their own consumption; the department at this time has the ability to provide only 240 farmers with seed. In the nongovernment sectors, four of the internationally funded projects working with the development of the minority hill tribes and with opium crop replacement will also include in their programs the use of wheat for home consumption. The scope of the program for the future is for wheat to be included in many other rural development, vocational and nonformal education programs.

### **The Local Market for Wheat**

After just one year's experience, there is no doubt that wheat is acceptable to the local palate; in fact, there is even a demand for whole wheat seed and whole meal flour by those who are not planting it. Bread, noodles and the ubiquitous instant noodles are common wheat products already in use in Thailand. To enable these wheat products to be made in a typical Thai or hill-tribe village, some original methods have been developed and ancient ones revived. As a result, anyone will be able to buy wheat from a local farmer and become self-employed, baking bread or making noodles for sale in the market place.

One of the big advantages of local wheat would be its price; 7 to 10B per kg (US\$ .35-.50) for whole meal flour, depending on the source, as compared to at least 14B per kg (US\$ 0.70) for commercial white flour. Some experience has already been gained by small bakeries that grind their own flour from locally grown wheat. A charcoal-

fired oven has been used at one upcountry site for two years. Another baker, who started 18 months ago in Chiang Mai city, now expects to purchase some 5 tons of wheat from the coming season's crop. There have been other off-shoots of this work which, though small, indicate the manner in which wheat can become integrated into the local economy. One man, for example, has begun producing small tin ovens for home baking to earn additional income in his spare time. Thus, as well as the contribution it can make to food production, wheat is likely to increase job opportunities in rural areas. Just how great will be the potential effect of wheat on the local economy, while very real, is difficult to estimate at this stage.

The development of these local markets will allow time for an increase in the number of farmers with experience in wheat planting and production. Once the number of competent wheat farmers has reached a significant number (2000 to 5000), the wheat-growing areas can be quickly increased to supply the flour mills with a set quota. This is most important, as it will give researchers the opportunity to study the problems of production, storage, handling and quality, before being committed to supplying the large flour mills in Bangkok.

For this reason, there are plans with Chiang Mai University and the Department of Agricultural Extension to look at local markets at three sites during the coming year. One of them is Chiang Mai, the largest city in the north (population 100,000) which already has an annual demand for at least 10 to 15 tons of whole meal flour; two upcountry sites will also be included in the production areas. These local markets will also serve an extension function, as people begin to encounter wheat and realize that it has been grown in their own area.

### **Substitution of Wheat Imports**

The local-use approach should function in the plan for achieving crop import substitution for wheat through the following three steps:

- 1. Family use—Farmers first plant wheat for home consumption (small number of farmers, small-sized plots of 1/5 to 2/5 ha)
- 2. Local market—Local markets are developed, absorbing the increasing production (the number of farmers increases, but plots remain small)
- 3. Crop import substitution—Quotas for domestic wheat at flour mills are set and, after a large enough number of farmers are planting wheat, the areas planted by individual farmers can be quickly increased

Steps 1 and 2, which are already in progress, will provide the experience needed to move to step 3 with confidence. This move to step 3 will require the cooperation of farmers, flour mills and the Royal Thai Government.

### **The New Role of Wheat in More Tropical Environments**

While there are many problems concerned with wheat production, storage and quality in nontraditional wheat-growing countries, there is also great faith in their ability to solve these problems. The idea emphasized in this paper is that the role of tropical wheat should extend far beyond that of just substituting for imported wheat. Instead, it has the potential to increase the amount of basic food available. It can also provide new job opportunities in rural areas, thus boosting local economies. The brief experience in Thailand has shown that there is little problem with the acceptance of wheat as a food. Therefore, there is every reason to believe that wheat can play a role in directly helping to feed the people of the more tropical environments.

## **Problems and Benefits of Reintroducing Wheat into the Philippines**

**A.V. Rotor, National Food Authority, Manila, Philippines**

### **Abstract**

*In an attempt to revive wheat growing in the Philippines, an interagency ad hoc group is entering its third year of program expansion; it has determined a number of problem areas. This paper outlines these areas and analyzes them for current as well as for future action. The problems cited are categorized into technological, sociological, economic and governmental matters. Many of these problems had been anticipated and, therefore, served as bases for formulating major decisions and policies and in supporting a proposal to create a national wheat program.*

The Philippines once enjoyed a reputation as a wheat-growing country; this was during the Spanish regime, from the 17th to the end of the 19th century (1). However, the cultivation of wheat was limited to the northern part of Luzon and the highlands. Basically it was for home use, although a part of the produce was exported through the galleon trade between Manila and Acapulco (3).

The local wheat varieties have been permanently lost, as has their indigenous culture. There have been two previous attempts at reviving wheat cultivation in this century, and now a third one is being undertaken (2).

The areas of concern relating to the development of a local wheat industry are classified into four categories. Under each category, the major activities are briefly explained, with problem areas and future courses of action discussed.

### **Production and Post-Harvest Considerations**

#### **Determining potential wheat areas**

Based on the results of field trials and commercial plantings, the area suitable for wheat production appears to be the

northern provinces of Luzon; it offers a very limited number of hectares for wheat culture. There is a need to explore other regions of the country.

#### **Selecting and breeding of superior varieties**

Yields obtained from the present varieties, Trigo 1 (hard grain type) and Trigo 2 (soft type) are between one and two tons per hectare. These varieties leave much to be desired in terms of high and consistent yield levels, resistance to diseases, maturity class and baking quality.

#### **Improving packages of technology**

Packages of technology have been developed for wheat production. They can be used and adopted until better packages are available for specific locations and conditions. Production models have been set up, patterned after farming systems that have been successful in the last two crop years.

#### **Increasing seed supply**

Under an interim arrangement, the Ministry of Agriculture and Food certifies seed that is produced, while the National Food Authority (NFA) handles seed increase and production on a commercial scale. This cooperative arrangement is an attempt to solve the current shortage of seed and to supply projected expansion needs.

**Controlling fungal diseases**

The incidence of sclerotium and helminthosporium infections can cause near crop failures (5). Practical and inexpensive control measures are being developed, as well as methods of applying fungicides.

**Controlling weeds**

Weed control constitutes as much as 20% of wheat production costs on many farms. While available farm labor favors manual or mechanical weeding, this is a labor-intensive activity and is expensive.

**Developing post-harvest techniques and tools**

Paddy rice threshers used for wheat give low threshing recovery. Threshers are now being developed that are specific for wheat. Post-harvest technology is now a part of farmer training.

**Establishing an efficient marketing system**

Wheat is a new addition to NFA's grain marketing program. The flour mills should provide a market for local wheat as its volume increases.

**Economic Considerations****Projecting economic gains on the macro level**

Since 1975, total wheat imports have totaled 6,732,178 tons (4). The breakthrough in commercial production would definitely save precious dollars for the country. At an average yield of 1.5 tons per hectare, some 600,000 hectares of land are needed to meet present annual consumption. Since wheat is best in rice-based areas, following the regular rice crop, the displacement of some of the second rice crop and other cash crops is inevitable.

**Making wheat comparatively profitable with other crops**

Except for high-value cash crops, wheat should generate a return on investment comparable to that of maize, peanuts,

mungbean and rice itself. High production costs plus erratic yields have been responsible for a low return on investment and even losses. An increase in government farm price subsidy is under consideration.

**Improving quality to meet standards**

The inferior quality of locally produced wheat is at present a problem being faced by research and extension personnel. Meanwhile, products made from local wheat can be improved by blending with premium imported wheat.

**Organizing cooperative wheat farming**

In the absence of large farms within the wheat belt, wheat is grown on individual small farms; farmers are organized under prototype cooperatives. Wheat cultivation on a plantation scale is being considered in other areas.

**Social Considerations****Facilitating acceptance of the new crop**

A sustained information campaign is being carried out, along with field demonstrations, seminars and the training of farmer cooperators in the wheat program.

**Promoting direct uses of wheat in the home**

The conventional pathway of wheat is to the flour mill and then to the bakery before the end product reaches the consumer. Local growing of wheat is likely to revolutionize this system, but it will take time. The preparation of wheat products in the home is in agreement with the government's nutrition program.

## **Governmental Considerations**

### **Designing a national wheat program**

The present wheat development program comes under the Philippine Council for Agricultural Resources Research Development (PCARRD). It has an *ad hoc* interagency structure, with each of the six members conducting specialized and more or less independent projects. The objective of the wheat management committee of PCARRD is to elevate the present wheat program, now in its third year, to the national level. As a national program, it should gain more support for attaining industry status. This proposal is now under consideration (5).

### **Strengthening interagency coordination**

Cooperation among the agencies working on the wheat program should be strengthened, particularly in the expansion of commercial projects. Priority research is now focused on field problems being encountered by farmers.

### **Financing wheat farmers and providing crop insurance**

Crop loans and insurance should be provided to wheat farmers. Arrangements are being made with the Technical Board of Agricultural Credit (TBAC) of the Central Bank and the Philippine Crop Insurance Corporation (PCIC) as part of the proposed national wheat program.

The hope of developing a local wheat industry hinges on the expansion of the present program. To a large extent, it also depends on world issues affecting the commodity. The Philippines at present is bracing itself against an economic crisis. Wheat imports, which in 1982 alone reached 900,000 tons worth US\$ 156 million, are now being drastically cut to reduce the foreign exchange drain (4). Now is the time to revive the old, lost wheat industry.

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## The Relative Priority and Economics of Growing Wheat in Nigeria

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### Abstract

*The main aims of the Nigerian government policy of producing wheat on large-scale irrigation schemes were to substantially increase food production and to achieve import substitution objectives. Many years after the establishment of the projects, those objectives are still far from being fulfilled. Although wheat production appears more profitable than some cereal crop enterprises, average yields have remained lower than the potential. Timely planting, better input delivery and improved extension services are factors crucial to achieving production increases. Local market prices are higher than the government producer price and, therefore, farmers do not sell to the flour mills.*

Wheat has been grown traditionally in the river valleys in the northern parts of Nigeria for many years. However, early production was on a small scale, with the grain being sold in local markets as a luxury product used for making traditional dishes (4). Its importance in the diet of the people has increased dramatically in recent years with increases in income and population. Annual wheat importation rose from about 190,000 tons in 1969 to about 1.5 million tons in 1983, costing the country nearly US\$ 290 million in foreign exchange. A total of US\$ 1.95 billion was spent on food imports in 1980 (5), with wheat constituting the single largest item in Nigeria's heavy food import bill. The sudden popularity of wheat bread in the Nigerian diet, and the consequent increase in wheat importation, prompted the Nigerian government to encourage the production of wheat in substantial quantities domestically.

### Objectives of the Wheat Production and Water Resource Development Policy

Government encouragement of domestic wheat production for flour cannot be isolated from the agricultural policy of achieving self-sufficiency in food production and promoting the

welfare of the rural people. The main objectives of domestic wheat production are 1) to stimulate substitution for imported wheat in order to improve the balance of payment situation, 2) to promote agro-industrial development and 3) to enhance food production efforts (1).

The majority of the wheat consumed in Nigeria is in the form of bread. In order to facilitate the processing of wheat into flour, a flour-milling industry was considered, not only as an integral part of the package of wheat production, but also as an important agro-based infant industry that would have to be protected from foreign competition. This provided the justification for increasing the number of flour mills to five by 1980, with a joint capacity of 1.2 million tons of wheat per annum.

### Wheat Production and Water Resource Development

Since the early 1970s, increased emphasis has been given to the development of irrigation, as a means of achieving the full agricultural potential of the country (5). The Sahel drought of the early 1970s gave impetus to heavy public investment in irrigation schemes. About US\$ 398.4 million and \$2.95

billion were allocated to irrigation and water development in the 1975-80 and the 1980-85 development plan periods, respectively. Irrigated agriculture was expected to lead to a significant improvement in both the yield and output of crops. This would, in turn, reduce food imports substantially, and bring about a considerable savings in foreign exchange. By 1976, eleven river basin development authorities were created in the country to carry out the planned large-scale irrigation schemes. Nearly 2 million hectares of land were proposed to be under irrigation by the 1980-85 period, but less than 20,000 hectares were actually being cultivated by the river basin authorities by the end of 1980 (6).

Wheat production is linked with irrigation development, in that rainfed wheat production has been considered technically unfeasible in Nigeria from the onset. Therefore, the bulk of wheat production was planned to be grown on large-scale irrigation schemes. Water and temperature, the most important limiting factors in domestic wheat production, are adequate in three of the river basins that have been fairly well developed within the wheat zone of the country. These are the Chad, Sokoto-Rima and Hadejia Jama-are River Basin Development Authorities. Out of a total of 345,000 hectares planned for development of irrigated agriculture in the projects, about 163,854 hectares would be devoted to wheat. Assuming productivity of 2 t/ha, a maximum of 330,000 tons per annum could be expected; this is less than one-third of the current wheat imports (2). The irrigation schemes have been in production for more than seven years, and present domestic wheat production is estimated to be less than 40,000 tons, about 2% of total current consumption.

Other crops being grown in the irrigation schemes include tomatoes and other vegetables, maize, soybeans, cowpeas, rice, cotton, groundnut, millet and sorghum. However, only a relatively small area of land can be devoted to tomatoes and other vegetables, because they are highly perishable, and their production is very labor intensive. The areas grown to all of these crops is restricted during the dry season in favor of wheat, since it cannot grow at any other time of the year. Also, there are other agricultural development projects for boosting the production of these other crops under rainfed and irrigated conditions.

#### **Financial Costs and Returns of Producing Wheat, Maize and Sorghum**

Maize, millet and sorghum are among the traditional cereal crops whose production could be affected by increases in wheat production. Table 1 illustrates the costs and returns involved in producing one hectare each of irrigated wheat, rainfed maize and sorghum. These data represent the preliminary results from two separate studies that were carried out in the 1983-84 season, involving 50 farmers growing wheat in Kadawa village under the Hadejia Jama-are irrigation project, and 60 farmers in Daudawa village growing rainfed maize and sorghum with improved technology. Only farmers' production costs were included in the study. No attempt was made to estimate the capital cost of the irrigation scheme with respect to wheat. Labor represented a significant portion of the total costs, although unpaid family labor constituted about half of total labor costs; harvesting was the most time-consuming activity in cereal production. Poor land leveling increased the cost of irrigation. With the exception of maize, wheat gave a higher net income than most rainfed crops, such as sorghum, millet and groundnut.

### Comparative Market Prices of Staple Food Crops

Wheat substitutes for other cereals in production and consumption in Nigeria; Table 2 compares the price of wheat with the market price of some other staple food crops. The local market price for wheat remained higher than other cereal prices until 1980, when more wheat became available on the local market; it was being substituted for sorghum and millet whose production had suffered a setback because of bad weather and maize encroachment into the traditional sorghum/millet zones. Although the recently announced price of US\$ 585/ton leaves some profit margin for wheat growers, the local market price can be as much as three times higher, explaining why locally produced wheat is not getting to the mills.

### Conclusions

The policy to produce wheat under large-scale irrigation schemes has generated a number of criticisms:

- Import substitution through local wheat production has led to allocation of resources to wheat at the expense of crops more natural to the domestic environment (3);
- Despite huge investments, fewer farmers have benefited, as compared to schemes designed for rainfed agriculture. Because of the irrigation projects, many farmers have lost their land without adequate compensation (7);
- Very little attention was paid to the economic feasibility of the scheme during the planning stage, and

**Table 1. Comparative costs and returns of irrigated wheat and rainfed maize and sorghum, Nigeria, 1983-84**

Production factors	Costs and returns (US\$)		
	Wheat	Maize	Sorghum
Output (kg/ha)	(2500)	(2928)	(1650)
Value <sup>a/</sup>	1462.05	1522.56	900.90
Labor cost/ha	404.57	445.58	312.00
Cost of inputs other than labor			
Seed	77.06	15.60	15.60
Fertilizer	67.43	57.20	44.20
Herbicide	---	89.70	78.00
Depreciation of oxen and equipment	---	78.00	78.00
Water charges	48.17	---	---
Tractor charges	111.89	---	---
Total cost/ha	709.12	686.08	527.80
Net return/ha	753.38	836.48	373.10

<sup>a/</sup> Wheat was valued at about US\$ 0.59/kg, maize .52/kg and sorghum .55/kg

- Establishment of high-capacity flour mills presupposed continued wheat importation to ensure full utilization of available capacity. Both the mills and the irrigation projects have been in production for more than seven years without any significant supplies arriving at the mills from local sources.

Although serious doubts have been raised as to the ability of the projects to increase wheat production substantially in the future, it is too late to stop the construction of dams and canals now. The problem is that

the irrigation facilities developed for the production of wheat and other crops have not been efficiently utilized. The volume of wheat produced can be increased substantially if all the developed land for irrigation is allocated and cultivated. Average yield of wheat can also be increased considerably through timely planting, better input and services delivery and the provision of better extension services to farmers. Wheat importation should be gradually reduced to enable Nigerians to decide what proportion of locally produced wheat they require for traditional dishes and bread.

**Table 2. Average retail price of cereal crops in selected markets, Zaria, Nigeria, 1973 to 1983**

Year	Price per ton (US\$)			
	Sorghum	Millet	Maize	Wheat
1973	167.61	169.70	157.53	333.50
1974	188.34	169.46	183.95	393.39
1975	178.24	166.45	195.60	364.00
1976	246.74	241.54	278.33	364.00
1977	327.60	316.16	401.70	470.86
1978	423.67	453.05	432.12	732.03
1979	367.77	413.01	391.56	544.05
1980	389.87	400.01	456.82	519.48
1981	676.00	741.00	611.00	663.00
1982	559.00	702.00	572.00	663.00
1983	637.00	644.54	679.38	611.00

Source: Department of Agricultural Economics and Rural Sociology, I.A.R., Zaria, Nigeria

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## **Socioeconomic and Agroeconomic Implications of Growing Wheat in Sudan**

**F.M. Ali, Agricultural Research Corporation, Wad Medani, Sudan**

### **Abstract**

*The success in wheat research has enhanced the expansion of the wheat area in the Sudan; the intensification and diversification of cropping systems has increased the land available for wheat production from 9,000 to 307,000 hectares. A summary of recommended cultural practices is given. Wheat yields on experiment stations range between 3 and 4.5 t/ha, whereas commercial production yields are only .8 to 1.5 t/ha. The cost of wheat production, consumption and imports have increased; studies show that it would be more economical to grow wheat in the Gezira than to import it. The expansion in wheat production has contributed to an increase in farmer income, which has resulted in increased domestic household activities, social activities and leisure consumption; it has reduced the number of farmers migrating to other professions.*

Wheat has been regarded as a crop of the river-bottom environment north of Khartoum, where it has long been grown on a limited scale with traditional methods of production. However, in the 1960s, the small plantings and high cost of production, coupled with an increasing demand for wheat in the country, directed the attention of policy makers towards the areas of irrigated clay soils, where environmental and general climatic conditions are less suitable for wheat production.

The success in wheat research and the goal of the government to be self-sufficient in this commodity encouraged the expansion of the wheat area, mainly in the Gezira and New Halfa schemes. In the 1960-61 season, a large area was planted in the Gezira scheme, following recommendations from agricultural research; it had an encouraging average yield of just over one ton per hectare. The adoption of the intensified and diversified cropping system increased the land appropriate for wheat production in the Gezira and New Halfa to 252,000 and 46,200 hectares, respectively; the wheat area in the northern part of the country

remained at about 9,000 hectares. Wheat area, yield and production has fluctuated from season to season, as shown in Table 1.

### **Agronomic Aspects of Wheat Production**

Wheat is grown in the Sudan during the winter period (October to March) under irrigation. The winter is short with relatively higher temperatures and lower humidity than those found in the traditional wheat-growing areas of the world. Table 2 shows the long-term average maximum and minimum temperatures in the three main production areas.

Research recommendations for wheat production in the Sudan are available for the areas of land preparation, planting date, seeding rate and methods, fertilizer use, irrigation, weed, insect and disease control and varieties.

#### **Land preparation**

Plowing, disc harrowing and leveling is recommended to be carried out in September.

#### **Planting date**

The period from mid-October to mid-November is recommended as optimum

**Table 1. Area, average yield and total production of wheat in the three wheat-growing regions, Sudan, 1975-76 to 1982-83**

Season	Gezira			New Halfa			Northern region		
	Area (000 ha)	Yield (kg/ha)	Production (000 tons)	Area (000 ha)	Yield (kg/ha)	Production (000 tons)	Area (000 ha)	Yield (kg/ha)	Production (000 tons)
1975-76	238	924	220	48	667	32	12	1700	20
1976-77	212	1178	250	33	619	20	13	1745	23
1977-78	196	1121	220	30	762	23	15	1293	19
1978-79	207	598	124	15	452	7	13	1112	14
1979-80	152	1133	172	16	786	12	13	1428	18
1980-81	154	548	84	22	690	15	13	1507	20
1981-82	112	1000	112	18	1095	20	13	1562	20
1982-83	66	1428	94	20	1428	28	NA <sup>a/</sup>	NA	NA
Mean		991			812			1478	

<sup>a/</sup> NA = figures not available

Source: Yearbooks of Agricultural Statistics, Department of Economics, Ministry of Agriculture and Irrigation, Khartoum, Sudan

for sowing, both as a result of research findings and for practical reasons. Factors that must be considered by the farmer include the availability of capital and farm machinery, as well as irrigation water, for the various crops of the rotations in the different farming schemes.

#### **Seeding rate and method of sowing**

A seeding rate of 143 kg/ha is recommended, with the seed sown with a drill in rows 20 cm apart.

#### **Fertilizer use**

The only fertilizer recommended is nitrogen applied at sowing as side dressing at the rate of 86 kg/ha.

#### **Irrigation**

The general recommendation is to irrigate wheat every two weeks.

#### **Weed control**

Taking into consideration the high seed rate being used and its effect in smothering weeds, as well as the herbicides being used on other crops in the rotation and mechanical weed control during land preparation, no herbicides are officially recommended for wheat.

#### **Insect and disease control**

The only economically important insect pest in Sudan is the aphid and, to some extent, stem borers. Normally one or two sprayings of the appropriate insecticide are applied during the season. Rust problems are of importance in New Halfa and the northern part of the country; hence, only resistant varieties are recommended for those areas.

#### **Varieties**

The principal recommended wheat varieties for Sudan are Mexicani, Giza 155, Condor, Mukhtar, Shenab and Debera.

When wheat is grown following the above recommendations, yields as high as 3 to 3.5 t/ha are obtained on the experiment farms at Gezira and New Halfa. In the northern parts of the country, yields of 4 to 4.5 t/ha are achieved.

#### **Wheat Production, Imports and Consumption**

Consumption of wheat in the Sudan has continued to rise, due to increases in population, urbanization and the rising income of the people. Table 3

**Table 2. Average maximum and minimum temperatures during the wheat production period in the three wheat-growing regions, Sudan, 1941 to 1970**

Month	Wad Medani (Gezira) (central region)		Kassala (New Halfa) (eastern region)		Dongla (northern region)	
	Maximum (°C)	Minimum (°C)	Maximum (°C)	Minimum (°C)	Maximum (°C)	Minimum (°C)
October	37.8	21.6	36.9	23.2	38.7	21.1
November	36.5	18.0	37.5	20.6	32.9	15.4
December	33.8	14.5	35.0	17.0	29.0	10.7
January	33.6	14.0	34.3	16.0	27.8	9.3
February	35.1	14.7	35.4	16.4	29.7	10.2
March	38.4	18.2	38.6	19.2	33.9	14.1

Source: Sudan Meteorological Service Memo 5

**Table 3. Annual domestic wheat production, imports and consumption, Sudan, 1975-76 to 1979-80**

Season	Total domestic production (000 tons)	Amount saved for seed <sup>a/</sup> (000 tons)	Amount available for consumption (000 tons)	Imports		Total imports (000 tons)	Total consumption (000 tons)
				Wheat (000 tons)	Flour <sup>b/</sup> (000 tons)		
1975-76	264	56	208	120	—	120	328
1976-77	294	53	241	207	21	230	471
1977-78	317	52	265	143	24	170	435
1978-79	117	44	133	187	26	216	349
1979-80	219	38	181	298	33	335	516

<sup>a/</sup> Includes 5% extra for seed loss

<sup>b/</sup> Converted to wheat at extraction rate of 90%

Source: The Policy of Wheat Production in the Gezira Scheme (in Arabic)

shows domestic production, seed requirements for sowing with seed loss set at 5%, imports and total consumption. Table 4 presents results of studies on projected future wheat consumption, domestic production and imports.

#### **Cost of wheat production**

The costs involved in the production of wheat have continued to rise every year, as shown in Tables 5 and 6. This is mainly due to increases in the prices of production inputs. In spite of these high costs of production, it has been proven that wheat is a profitable crop for producers when yields exceed 950 kg/ha.

Taking into consideration the projected cost of production and prices of wheat in the international markets, and with the modest projected yields of 2,000, 1,430 and 2,500 kg/ha for the Gezira, New Halfa and northern regions, respectively, it was shown that it would be more economical to grow wheat in the Gezira scheme until the 1990-91 season than it would be to import it. The case of the New Halfa scheme can be seen to be different (Table 7).

#### **The Social Impact of Growing Wheat**

Sorghum is the staple food for most of the Sudanese, although wheat constitutes a major component of the diet in certain parts of the country, namely in the Northern Region and New Halfa, as well as in urban communities. With the increasing prices of sorghum grain, as well as the effort and fuel needed for sorghum food preparation, increasing numbers of Sudanese are shifting from sorghum to wheat. These and other factors have enhanced farmer enthusiasm for wheat cultivation. Regardless of the crop profitability, its cultivation is regarded as a means of supplying family consumption needs. In addition, the high degree of mechanization of wheat production ensures that it does not tax farmers physically to any considerable degree. Furthermore, the crop was introduced as an addition to other crops in rotations; thus, it leads to increased family income. These factors have resulted in increased domestic household activities, education, social activities, leisure consumption and gainful nonagricultural activities among farmers; it has also reduced the number of farmers migrating to other professions.

**Table 4. Projected wheat consumption, production and imports, Sudan, 1985-86 to 1991-92**

Season	Consumption (000 tons)	Domestic production (000 tons)	Imports (000 tons)
1985-86	643.8	287.4	356.4
1986-87	672.9	313.5	359.4
1987-88	703.4	313.5	389.9
1988-89	735.4	313.5	421.9
1989-90	769.6	313.5	456.1
1990-91	805.3	313.5	491.8
1991-92	843.0	313.5	529.5

Source: Ministry of Finance and Economic Planning. 1982. Comparative Study of Cost of Growing Wheat in the Sudan and Importing it from Abroad. Khartoum, Sudan.

**Table 5. Financial costs of wheat production in the Gezira Scheme, Sudan, 1976-77 to 1981-82**

Season	Cost per hectare (LS) <sup>a/</sup>						Total
	Land preparation	Agricultural operations	Material inputs	Harvesting	Land and water	Miscellaneous <sup>b/</sup>	
1976-77	6.62	4.76	45.33	10.00	—	4.76	71.47
1977-78	6.93	5.00	46.57	10.50	—	5.00	74.00
1978-79	11.43	7.98	28.12	11.90	—	11.31	70.74
1979-80	11.07	7.74	52.95	17.86	—	11.90	101.52
1980-81	17.98	8.21	64.60	20.24	—	14.28	125.31
1981-82	18.81	12.86	108.93	19.05	—	12.14	171.79

<sup>a/</sup> 1.3 LS (Sudanese pounds) = US\$ 1

<sup>b/</sup> Mainly on-farm transport and materials

Source: Ministry of Finance and Economic Planning. 1982. Comparative Study of Cost of Growing Wheat in the Sudan and importing it from abroad. Khartoum, Sudan.

**Table 6. Financial costs of wheat production in the New Halfa Scheme, Sudan, 1976-77 to 1981-82**

Season	Cost per hectare (LS) <sup>a/</sup>						Total
	Land preparation	Agricultural operations	Material inputs	Harvesting	Land and water	Miscellaneous <sup>b/</sup>	
1976-77	7.55	7.21	35.05	8.21	—	9.05	67.07
1977-78	8.48	8.19	38.12	18.38	—	8.19	81.36
1978-79	8.98	6.95	45.02	10.48	—	13.57	85.00
1979-80	20.83	13.88	51.43	14.28	—	NA	100.42
1980-81	12.31	15.48	77.50	14.28	—	3.12	122.69
1981-82	24.28	15.12	93.76	17.14	71.43	6.19	227.92

<sup>a/</sup> 1.3 LS (Sudanese pounds) = US\$ 1

<sup>b/</sup> Mainly on-farm transport and materials

Source: Ministry of Finance and Economic Planning. 1982. Comparative Study of Cost of Growing Wheat in the Sudan and Importing it from Abroad. Khartoum, Sudan.

**Table 7. Projected financial costs of imported and locally produced wheat, Sudan, 1982-83 to 1990-91**

Season	Cost per ton (LS) <sup>a/</sup>		
	Imported wheat	Local production <sup>b/</sup>	
		Gezira	New Halfa
1982-83	286.78	192.50	465.94
		(+94.28)	(-179.16)
1985-86	357.86	139.35	351.10
		(+218.51)	(+6.76)
1990-91	488.04	197.87	492.25
		(+290.17)	(-4.21)

<sup>a/</sup> 1.3 LS (Sudanese pounds) = US\$ 1

<sup>b/</sup> Numbers in brackets = saving or loss of locally produced wheat versus imports

Source: Ministry of Finance and Economic Planning. 1982. Comparative Study of Cost of Growing Wheat in the Sudan and Importing it from Abroad. Khartoum, Sudan.

## Comments

**D.L. Winkelmann, Director, Economics Program, CIMMYT, Mexico**

I have been asked to comment further on the demand side of wheats for more tropical environments. It has been demonstrated over the past five years that wheat is a surprisingly plastic crop. Given the evidence that we can increase the productivity of wheats in the tropics, the question must be asked: To what extent and where should we do so? Where will future wheat production be more promising, and where will it be less so?

Dr. Harrington has presented a way to get at the fundamentals of the issue, through assessing the real value of the resources that might be involved in the production of wheat. He discussed the application of comparative advantage (these proceedings), based on a technique called domestic resource cost analysis. One result of his analysis in parts of Thailand was the estimation of the yield range needed to make wheat competitive with its alternatives, both from the perspective of the farmer and from the perspective of society. In different local environments, very different yield levels appear to be needed to make wheat competitive. These differences are largely dependent on the alternatives to wheat and on the extent to which wheat production influences preceding and following crops.

Let us consider the demand for wheat and for wheat research in the tropics. We have heard mention of wheat prices being set by policymakers whose concern is especially for urban populations. We have been told that some countries need to dispose of wheat surpluses, and that, in some cases, they may have a desire to create dependencies; others saw generosity in the subsidizing of wheat for developing countries. We have also heard about

policies which perhaps reflect an ignorance about the potentials of environments.

Surely all of these considerations play a part, in greater or lesser measure, in decisions affecting the role of wheat in the more tropical regions of the world. Beyond this, however, Dr. Byerlee helped us to consider wheat consumption from other perspectives (these proceedings). He pointed out some apparent inevitabilities influencing this consumption. Urbanization and rising incomes historically favor wheat consumption. Beyond this, he identified some concerns—rural income distribution, diets for poor consumers, and food security—whose influence on wheat utilization must result from careful judgments of society-wide issues. He also discussed exchange rate overvaluation and relative prices which depart markedly from those on the international market. The utilization of wheat in tropical countries emerges from a mixture of such considerations.

It is important to realize, however, that a rising demand for wheat is an apparently inevitable consequence of urbanization—people want foods which are more convenient—and of rising incomes—people can insist on more diversity in their diets. Income is an especially important factor in developing countries. Remember the graph describing circumstances in northern Brazil (Byerlee, these proceedings), showing the relationship between income level and the consumption of particular commodities. As income increased, the direct consumption of maize declined, a common response, but the per capita consumption of rice and wheat increased.

The demand for wheat is going to continue to expand as urbanization continues and incomes rise. Some of that demand can be filled locally through more appropriate wheat technologies. On a related point, the importance of the opportunities for local production described by wheat imports is not well measured by the amount of foreign exchange which can be saved through local production. A simpler but still rough approximation is given by transportation costs, those of bringing in wheat plus those of sending out the compensating export.

All of these considerations discussed by Byerlee and Harrington provide a portion of the background for judging the critical question associated with the allocation of research resources to wheat. Along with other important considerations, led by the plant breeders' sense of the opportunities, they can help in deciding in which of the many environments scarce research resources should be focused. Good progress has been made, and more is in the offing as researchers pursue the still-emerging opportunities for wheat production in the tropics and subtropics.

## Closing Remarks, Symposium on Wheats for More Tropical Environments

**B. C. Curtis, Director, Wheat Program, CIMMYT, Mexico**

This symposium, sponsored through a grant from the United Nations Development Programme, was convened for the purpose of updating the information available on the status of research for the development of germplasm and cultural practices for growing wheat in some of the more tropical areas of the developing world. In attendance were a total of 57 people representing 22 countries, mostly from tropical regions with an interest in growing wheat. In addition, 38 CIMMYT personnel, along with 10 members of the wheat program outreach staff, participated in this conference.

CIMMYT's tropical wheat project developed as a result of intense interest on the part of several national programs to produce their own wheat in an attempt to eliminate the foreign exchange drain that occurs with heavy wheat importation. While the project has the word "tropical" in its description, it has been noted that this should not be construed to mean wheats for the hot, humid, rain forest environments. Wheat is essentially a temperate crop and the term, tropical wheat, is merely a simple way of referring to "wheats for the more tropical environments." Some of these more tropical environments are ones with a winter season with cooler temperatures and drier growing conditions.

In his keynote address, Mr. Mashler said that, in the late 1970s, he and the UNDP recognized the need to fund a project to aid in the development of wheats to fit into the nontraditional, more tropical areas. UNDP was motivated by the fact that wheat accounts for more than one-fourth of the world's grain production, is a staple food for one-third of the world's

population and has an upward consumption trend. With UNDP assistance, CIMMYT has expanded its research to develop wheats for the more tropical environments; funds were made available by UNDP in 1982 for a five-year period. Since the initiation of the project, much attention has been given to screening wheats for resistance to a number of diseases and for greater tolerance to heat-related stresses; more appropriate cultural practices are also being developed for growing wheats in the major soil types found in these warmer, nontraditional wheat-growing areas.

Discussions at this conference have focused largely around two questions:

- Can germplasm and cultural practices be developed that will make it feasible to grow wheat in more tropical environments than has been possible to date?
- It is economically sound to attempt to develop wheats for commercial production in these warmer areas?

The first question relates primarily to the technical aspects of whether the necessary traits can be bred into wheat and whether suitable cultural practices can be developed. Discussion on the second question has examined the likely comparative economic advantage of growing wheat in the warmer, tropical areas versus growing other crops, and the economics of satisfying consumer demand for wheat products in such areas through domestic production or through importation.

## Developing Wheat Varieties for More Tropical Areas

For purposes of discussion, target tropical areas are described as those environments below 1000 meters in elevation and between 23°N and 23°S latitudes; such environments are found in 85 countries around the world, and 57 of them have an interest in domestic wheat production to satisfy at least part of their growing consumer demand. The two major mega-environmental zones where tropical wheat may be grown are included in two broad classifications:

- The hothumid climates (in the cooler, drier months) (examples: Thailand, Philippines and Indonesia)
- The hot, arid climates (examples: Sudan and Senegal)

Wheat will need to be developed for both of these environments, as well as for the many macro-environments within each of these broad classifications.

The technical problems of tropical wheat development can generally be divided into two research areas, crop improvement (breeding and pathology) and crop management (production agronomy and economics).

Wheat production circumstances in these more tropical locations are far too variable to specify precisely the combination of traits needed. However, there are common production factors that appear to be important for all of the tropical wheat areas:

- Stable yield potential  
Agronomic characteristics:  
Early vegetative vigor  
Early maturity  
Lodging resistance  
Heat tolerance  
Drought tolerance  
Resistance to various soil toxicities

- Disease resistance
- Insect resistance
- Grain quality

The major problems for the adaptation of wheat for tropical conditions are summarized in Table 1.

There is some hope of transferring to wheat genetic resistance to diseases from other species that are closely or distantly related. The wide cross work of CIMMYT cytogeneticists and of those at other institutions should prove useful in this endeavor.

Successful resistance work is being carried out on head scab diseases in Brazil, China and Mexico. However, resistance breeding alone will not overcome the problem of diseases. A combination of genetic resistance (great or small), agronomic practices and chemical control will be necessary. Much research is needed for the development of various appropriate combinations, and different environments will likely require different combinations of factors. Combining all of the above-mentioned traits into one or more varieties will probably take a decade or more of intense breeding and evaluation.

## Agronomic Problems in More Tropical Areas

The major agronomic problems likely to face farmers who seek to produce wheat in more tropical environments are:

- Soil types (latisols, sandy, low-fertility soils, soils with micro-nutrient deficiencies, soils with high acidity)
- Waterlogging (hard pans from rice fields in a wheat-rice rotation, deficiency or nonavailability of nutrients)
- Seedbed preparation and tillage
- Stand establishment
- Planting dates

**Table 1. Problems for the adaptation of wheat for tropical conditions and variability available in existing germplasm**

Breeding	Variability
Heat tolerance:	**
In juvenile plants	*
In the fruiting period-flowering to ripening (sometimes referred to as the "stay green" trait where stems and leaves remain green while grains are ripening)	**
Drought tolerance, particularly late in the season	*
Earliness	***
Tolerance to acid soils	*
Lodging resistance	**
Disease resistance:	***
<i>Sclerotium rolfsii</i>	No resistance known
<i>Helminthosporium</i> complex which occurs in most of the tropics (Mehta of Brazil and Raemaekers of Zambia pointed out the difficulties of working with this disease)	**
<i>Fusarium</i> spp. Root rot Leaf blotch Head scab	*
Powdery mildew-vegetative	**
Leaf rust, the most important of the rusts (stem and stripe rust are not often found)	***
<i>Xanthomonas campestris</i> and other spp. of bacteria	*
Insect resistance (the stem borer, semi-looper and army worms, aphids, etc., are among the most important insects)	No resistance known

\* Some variation exists

\*\* Considerable variation exists

\*\*\* Extensive variation exists

- Weed control (appropriate herbicides are not yet identified for the tropics)
- Seed production and storage
- Harvesting practices
- Post-harvest technology (seed and grain storage, insects and grain spoilage)

Agronomy has played a tremendous role in the increase in wheat production in the world today. But, from what has been reported in this conference, the past inputs of agronomy are minor compared to the requirements that will be necessary for the successful production of wheat for tropical conditions. On-farm research and subsequent extension education will be critical for the generation and transfer of technology to the tropical wheat farmer.

### **CIMMYT's Crop Improvement Methodology**

CIMMYT screens a large number of lines each year in Mexico in a shuttle breeding program between Toluca and Ciudad Obregon. Hundreds of the more agronomically promising lines are then screened at Poza Rica (with a very hot environment) and Tlaltizapan (with a medium-hot environment) for heat tolerance and helminthosporium resistance. The best lines are then grouped into various international nurseries for helminthosporium resistance, drought tolerance, heat tolerance, early maturity, etc., and are sent to multiple locations in the world for further evaluation of the respective traits. This network of testing and evaluation, referred to as multilocal testing, allows for rapid assessment under target environments. Performance data are returned to CIMMYT for analysis and for the planning of new crosses to combine the traits necessary for adaptation to tropical conditions.

Breeding to combine high yield potential and other favorable characters for these more tropical environments will necessitate a tremendous effort and will require the cooperation and collaboration of wheat scientists in many countries. This multilocal concept is a must for the development of germplasm for the tropics. We at CIMMYT hope that, upon your return to your countries, all of you will be able to inspire your fellow scientists to join in this challenging and vitally important research effort.

### **Economics of Wheat Production in More Tropical Areas**

Many tropical countries are consuming ever-increasing amounts of wheat, virtually all of which is currently being imported. These consumption and importation trends give evidence of potential markets for domestic wheat production. Yet such countries are not traditional wheat producers, and they have environmental conditions which have not heretofore been considered suitable for the production of wheat, a temperate-climate crop.

Because of this growing demand for wheat and wheat products in nontraditional production areas, issues of the allocation of research resources are being raised. In establishing priorities for agricultural research, policy makers must consider a myriad of concerns, including economic development, income distribution, food security and foreign exchange, as well as the environment. One analytical procedure that can be used in this process is that of comparative advantage, which indicates the ability of various enterprises to contribute to national income. A basic question addressed in comparative advantage analysis is whether it is cheaper, in terms of domestic resources, for a country to import a product, such as wheat, or to produce it domestically.

While efforts to develop wheat germplasm and production technologies for more tropical environments are still in the initial stages, the test of comparative advantage must be applied at some stage to determine whether this research thrust is feasible, given the limited research resources available in the developing world. Some preliminary economics research in Thailand indicates that, while wheat does not now compete with other alternative crops,

with varieties better adapted to the environment and improved cultural practices, it could become a commercial crop in certain upland regions. Such preliminary evaluations, indicating minimum yield levels needed to make wheat a competitive crop, provide us with encouragement that science can be put to work to make wheat a profitable crop in areas in which it currently is not grown.

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## Appendix I

### Comments on the Symposium

**O. de Sousa Rosa, Centro Nacional de Pesquisa de Trigo, Passo Fundo, Rio Grande do Sul, Brazil**

The importance of the United Nations Development Programme's project on the development of wheat production in more tropical environments is fully recognized. In Brazil, technologies developed for the production of wheat under tropical and subtropical conditions have also been of value for stimulating the growth of soybean production and have led to experimentation with other crops in areas that were never before considered appropriate for agriculture. Thus, valuable results can be expected from the project, not only in the development of wheat production, but also in its secondary effects on the cultivation of other crops that may be of equal or even greater importance.

UNDP's choice of CIMMYT to head the project was a good one. The results already obtained by CIMMYT in the improvement of wheat production in the world are a proof of this, as are those which can be expected in the future.

Many countries which produce wheat in tropical and subtropical environments have already invested great amounts in the development of technology. These existing technologies can be of importance in the CIMMYT program and can be rapidly adopted by other countries with similar problems. It is important that researchers in those countries participate in the efforts that UNDP and CIMMYT are exerting to increase the production of tropical

wheat, not only as cooperators but with specific responsibilities for portions of the total research program. This can be accomplished through collaborative research with institutions in the various countries. The participation of these national institutions in research projects of international scope could stimulate them to a broader participation; it would also be an important factor for insuring the continuity and growth of the programs in which they have already invested.

Possibly the definition of the tropical wheat area should be revised to permit the inclusion of subtropical production areas outside the limits of 23°N and 23°S latitudes, areas which, because of ecological characteristics, are as limited or even more limited for the growing of wheat than are many of the tropical areas.

Within the program for the development of tropical wheat, the difference between technologies appropriate for rainfed and for irrigated farming systems is very great. The complexities of the rainfed systems are much greater and, therefore, the two areas might be considered separately, with different courses of action being followed for each of them.

This symposium has been of great value for the future development of tropical wheat, and the program has been efficiently planned and carried out. Its repetition in three or four years will further benefit the development of wheat for the more tropical environments.

## Appendix II

### Wheat Pests and Diseases

#### C. James, Deputy Director General, CIMMYT, Mexico

CIMMYT recognizes the importance of the many activities related to pests and diseases that are currently being conducted in Latin America, Africa and Asia.

Given the well-documented interaction between environment, plant and pathogen, and the important changes that occur when the status of one of them is changed, CIMMYT and its collaborators should take advantage of this opportunity to monitor and investigate the behavior of pathogens and their interaction with wheat grown in a tropical environment. The opportunity is unique because wheat, the world's major crop, is being moved into a totally different environment. Fundamental questions should be posed which will generate new knowledge to be shared with the global scientific community and used to evolve a practical strategy for managing pests and diseases on wheat grown under tropical conditions.

Under tropical conditions, the two major factors that will make it more difficult to control pathogens are:

- **Temperature**—For most pathogens, growth is a function of temperature; the higher the temperature, the higher the growth rate. Consequently, compared with temperate climates, epidemics will progress more rapidly, and a more effective and faster decision-making mechanism will be required to control epidemics.
- **Humidity**—Under some tropical conditions, humidity is significantly higher for longer durations. For most pathogens, this will result in higher sporulation, which in turn results in more inoculum, more spread and faster-growing epidemics.

Since these two major factors, temperature and humidity, can independently or additively increase the growth rate of epidemics, it will probably be more difficult to manage diseases in tropical environments. It is highly likely that integrated pest management techniques, utilizing more than one control method simultaneously, will have to be used to achieve satisfactory levels of disease and pest control. For example, there may have to be more effective levels of tolerance, in conjunction with the use of systemic fungicides in seed dressings to serve as antisporelants/sterilants.

Continued work on pests and pathogens on wheat grown in a tropical environment can also make an important contribution in two major areas:

- **New information of a fundamental nature on important phenomenon**—We have little information on the effect of temperature on the rate of mutation. If increased temperature

increases mutation rate, this will be extremely important, since mutations are currently responsible for the evolution of new races of pathogens which erode resistance under temperate conditions. A study to assess the ability of unspecialized pathogens to become specialized and more destructive would also be important.

- Practical strategy for managing diseases of wheat grown in a tropical environment—The availability of new information on the behavior of pathogens can be generated through collaborative research projects, and then applied to the development of a practical strategy for controlling diseases under field conditions. The overall goal of increasing wheat productivity and production in a tropical environment remains the principal objective of the study, with all other investigations contributing to that goal.

## Appendix III

### Participants, Symposium on Wheats for More Tropical Environments September 24-28, 1984

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