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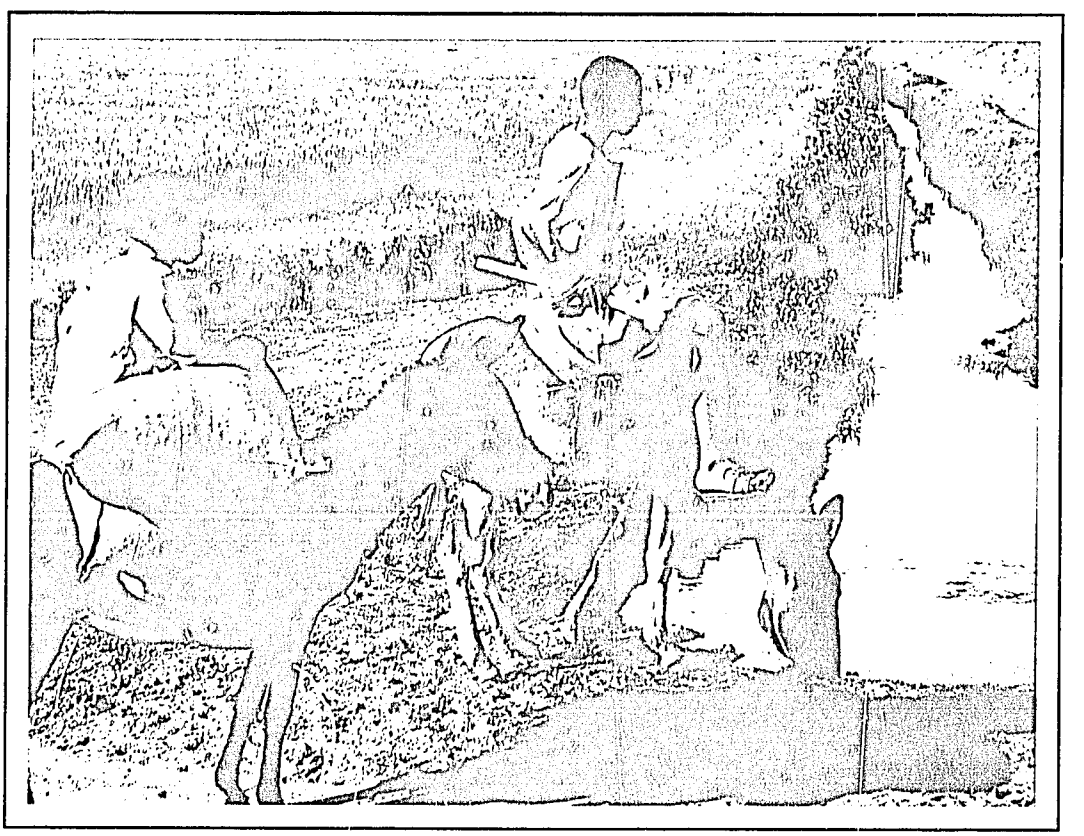
Wheat in Heat-Stressed Environments: Irrigated, Dry Areas and Rice-Wheat Farming Systems

D.A. Saunders and G.P. Hettel, editors



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Wheat in Heat-Stressed Environments: Irrigated, Dry Areas and Rice-Wheat Farming Systems

Proceedings of the International Conferences

Wheat in Hot, Dry, Irrigated Environments
Wad Medani, Sudan
1-4 February 1993

Wheat in Warm Area, Rice-Wheat Farming Systems
Dinajpur, Bangladesh
13-15 Feburary 1993

D.A. Saunders and G.P. Hettel, editors

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On the cover: Sudanese boys water their animals in a canal of the Gezira Irrigation Scheme, which is Sudan's oldest organized agricultural area. About 85% of the country's wheat (background) is grown on this land bordered by the Blue Nile and White Nile. Photo by Gene Hettel.

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401 **Participants, Wheat in Warm Area, Rice-Wheat Farming Systems, Dinajpur, Bangladesh 13-15 February 1993**

Preface

These are the fourth proceedings resulting from international conferences related to wheat production in warmer environments throughout the world. The meetings reported on in these proceedings were sponsored by the United Nations Development Programme and organized by the Agricultural Research Corporation of Sudan, the Wheat Research Centre of the Bangladesh Agricultural Research Institute, and the International Maize and Wheat Improvement Center.

The early emphasis in this project was on the development of wheats more adapted to warmer areas, particularly nontraditional wheat producing areas in the tropics and subtropics. Later, more attention was given to improving the management technology for wheat under these hotter environments.

In the published proceedings of the conferences in Mexico (1984), Thailand (1987), and Brazil (1990), one can see the progressive integration of disciplines, particularly breeders and physiologists/agronomists, and agronomists/soil scientists with pathologists and entomologists. These multi-disciplinary approaches are highly desirable to tackle the more complex problems emerging in agricultural production systems today.

The present proceedings continue this trend and result from two international conferences organized to specifically address the problems of two heat-stress environments that had previously received less attention.

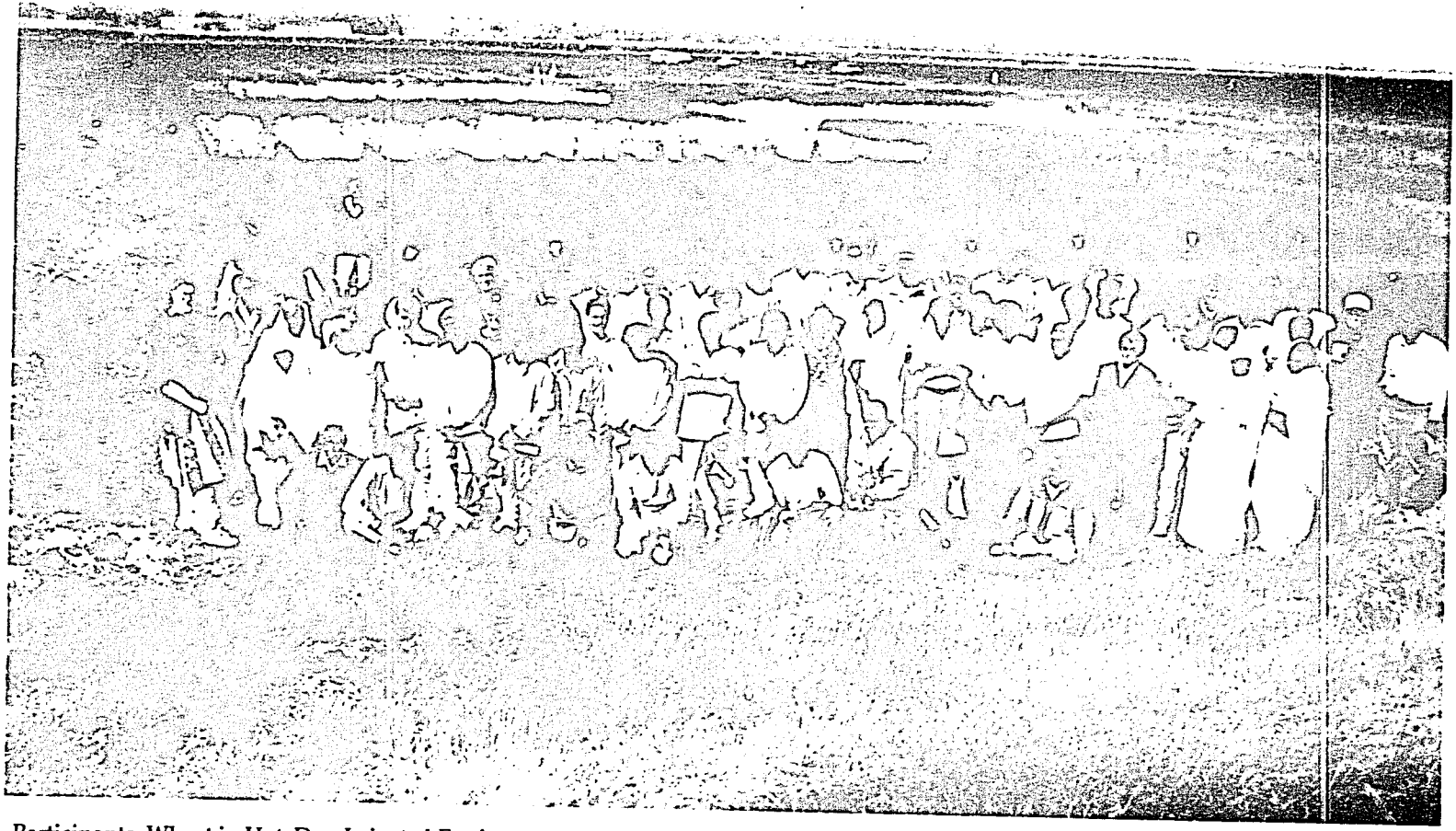
The first, at Wad Medani, Sudan, was held 1-4 February, 1993. Wad Medani is one of the hottest wheat-producing areas in the world and the conference was chiefly focused on the problems of heat stress under very dry, irrigated environments. It is considered that the discussions of selection methodology, crop management, and plant protection will have relevance to similar environments elsewhere.

The second conference was held at Dinajpur, Bangladesh, 12-16 February, 1993. Bangladesh has increased wheat production enormously since the mid-1970s and forms part of the huge rice-wheat rotation area that is estimated to cover some 12 million hectares in South and Southeast Asia. The conference discussed many of the problems unique to this rotation such as the tailoring of rice and wheat varieties to optimize total production, soil management for wheat following puddled rice, plant nutrition, particularly with reference to sustainability, and soilborne and foliar diseases.

Both meetings highlighted the continuing efforts of wheat scientists to increase and stabilize wheat production in hot environments, and particularly indicated that wheat breeders are striving to reduce their dependence on purely empirical methodologies for selection for heat tolerance. Both meetings, too, indicated that improved crop, disease and pest management can radically reduce the effects of elevated temperatures on wheat yield.

It is hoped these proceedings will be valuable reference material for wheat scientists in warmer, more marginal wheat production areas throughout the world.

David A. Saunders
Technical editor



Participants, Wheat in Hot, Dry, Irrigated Environments.

Opening Address

Ahmed Ali Genelf
Minister of Agriculture, Animal Wealth, and Natural Resources
Khartoum, Sudan

In addition to Dr. Borlaug, I would like to recognize the presence here today of the distinguished scientists from the different international institutes, particularly CIMMYT and ICARDA and Global-2000. They are to be lauded for their very fruitful interactions, which have resulted in the end products we are receiving now, that is wheat adapted to our hot and arid environment. Wheat production in Sudan, especially in the central plains, is now truly becoming successful. It is a great model of scientific cooperation between our researchers and these institutions. I am very glad to see this cooperation expanded and extended in an effort to promote this successful model of producing wheat in hot and arid climates especially since wheat consumption worldwide continues to increase—and the hot and arid countries are no exceptions to this trend.

I would like to recognize the efforts of the Government of the Netherlands in financially supporting our wheat program in Sudan and for extending support so many times. I also thank the United Nations Development Programme (UNDP) for its interest in and support of our efforts.

Ladies and gentleman, our commitment to food security in Sudan extends from our aspirations to make Sudan play a logical and normal role in food production. We were not satisfied with the level of utilization of our vast natural resources in the past. The economic and political environments must allow the people of Sudan to utilize the country's natural resources. We believe some progress has been achieved in this direction. Political stability in the last few years combined with the right economic policies have furnished a favorable climate for the people to utilize these resources.

As a result, we have made some progress in the production of different crops, especially cereals, including wheat. In the last year, the agricultural rate of growth was around 31% and this was reflected in the overall domestic product rate of growth, which was more than 11%. In 1993, we expect agricultural production to grow an additional 39% and this should logically be reflected in an increased rate of growth of our national income of not less than 15%. By all standards, this would be one of the highest rates of growth in the world.

This great progress can be attributed to the achievements of our scientific community here at the Agricultural Research Corporation. It has allowed Sudan to produce wheat successfully in hot and arid, irrigated areas.

I am sure that it will be a function of this very august forum to promote continued interaction among members of the scientific community. We all know that we have to expedite our efforts to try to solve the problems of food production worldwide. We have a particularly critical situation here in Africa where we have been hit by drought; many of the African countries are

suffering from a very significant deficit in their food production. This really makes the challenge bigger and bigger. But I am most confident that the scientific interaction that I see in this very gathering will enable us to successfully meet this challenge.

Even with the level of achievement in Sudan regarding wheat production and agricultural production in general, there are still important issues to face because of structural changes in our economy. As you know, we have now made the switch from a controlled economy to a free market economy. The great issue now is how can we reduce the costs of our agricultural production while at the same time increasing our productivity. I am sure that any breakthroughs and successes in these areas will augment the production of wheat in the very special environment of Sudan.

Again, I would like to thank all of you for attending this very important workshop. I wish you very fruitful and successful deliberations and you can be assured that we will be following your various recommendations. I hope that during this very tight program you will find an opportunity to move around our station here and see the various aspects of our agricultural research.

KEYNOTE

The Political, Socioeconomic, and Institutional Obstacles to Empowering the Farmer with Improved Production Technology

N.E. Borlaug
Consultant, International Maize and Wheat Improvement Center (CIMMYT),
El Batan, Mexico

Your excellencies Minister Eltayeb and Minister Geneif and distinguished delegates, it is a real privilege and a pleasure for me to be here today to participate in this Conference on Wheat in Hot, Dry, Irrigated Environments. We owe a lot of the recent advances in growing wheat in the nontraditional warm environments to the early efforts of the late Dr. Glenn Anderson. It was he who wrote the original proposal for this work and submitted it to the United Nations Development Programme (UNDP) shortly before he passed away in 1981. Twelve years later, we are gathered here in Wad Medani to discuss many of the accomplishments of this project. I am pleased to see in the audience today many scientists who have participated in training at Mexico sponsored by the UNDP project as well as other agencies.

Today, I would like to provide some insight into the various factors that have to be manipulated to provoke change in agriculture. The first of these, of course, are the biological factors that have to do with developing varieties that have good adaptation to the local climate and soil, built-in high genetic yield potential when they are properly grown, and disease resistance—at least to the major diseases that are likely to cause problems in the area under consideration. It's not just a question of developing varieties with these attributes, but there also has to be an organization that will multiply the seeds and deliver them to the farmers.

The second group of factors involve soil fertility and cultural practices. It has been my experience in many places that seedbed preparation has to be the first and foremost consideration. I remember the first times I visited Gezira here in Sudan in 1961 and 1964. I saw poor stands of plants that ultimately had to be blamed on uneven seedbeds. One has to start there, not only to assure a good plant stand, but to distribute irrigation water uniformly if it's irrigated agriculture. Now, I am not picking on Sudan; the same was true in Pakistan, in India, and even in Mexico.

With a good seedbed in place, the right date of planting is the next consideration. The correct date of planting varies with the variety and farmers have to take advantage of the lowest temperature regimes of the season—especially if they are in a high temperature area like Sudan, which is close to the upper limits of where wheat grows well. Next come proper fertilization and weed control. I've seen all too often farmers buy fertilizer and then they simply end up growing more weeds. Generally, there's not much of a market for weeds over grain and this is one of the common defects in many parts of the world. When I was here last year, I couldn't believe how much good wheat I saw compared to when I was here in 1986. In collaboration with the Sudanese

Ministry of Agriculture, the Crop Research Center, and the Extension Service, the Sudanese have done a marvellous job of putting all the pieces together.

Finally, after one has come to grips with the biological factors and agronomic practices, these components must be put together into a "production package" and then distributed to farmers. Some assumed that good research would eventually find its way to farmers' fields. Maybe so. But we in the Cooperative Mexican Wheat Program—and later CIMMYT—were never that passive. We decided that when we had something that was better than what was being used by farmers, we immediately transferred it to them. This was part of our philosophy and the results were manifest in many different ways. Indeed, good research will eventually find its way into farmers' fields, but with constant population growth, we couldn't wait for new technology to find its own way to farmers. Since there was no extension service in Mexico when we began in the 1940s, we in research were the extension people.

I would like to recognize the squadrons of "young" Mexican scientists with whom I have worked over the years. They are not young any longer—many have retired from government service. However, I had the good fortune and pleasure of bringing three Mexican scientists here to begin the program in Sudan and two—Drs. Marco Quiñones and José Antonio Valencia—are both here today. I feel very proud that these are two members of the extraordinary team that I was privileged to train in Mexico. They are not only good researchers, but they are good extension people because they understand how to put the package of production technology together, they understand the mentality of the farmers and the scientists—both in research and extension, they understand the government policymakers and the political leaders, and they are capable of dealing with all of those groups—to me, this is a very vital part of any crop production effort.

There are always psychological barriers along the road to success. However, everywhere I've ever worked in developing countries, I find that if a good package of technology is demonstrated to show its real potential on farmers' fields, the farmers are usually very receptive. When dealing with trying to provoke production change, we have to destroy the "status quo" philosophy. Fear of the change frightens many people, but if we stand still with a promising production technology, in effect, we walk backwards because every year there are more people that need to be fed.

It's my experience that when we get older, we become more conservative. I suppose I'm that way today when it comes to some of the new things in biotechnology and the use of computers because I feel that I don't have time to go back and get "up to speed", so I keep using tools I am more familiar with. I think this personifies what I've seen in senior scientists in many parts of the world and, in some cases, they have been very difficult to convince to try new tools.

And then there are the administrators. I became aware of administrative barriers during the early days in Pakistan and India. These bureaucrats, as we call them, are the people who handle the papers and put them in the right places; they become ultra-conservative because they are "protecting" the general public, but mostly they are simply afraid of change, which is what we as scientists are promoting. Then in most ministries, in both developing and developed nations, there are legions of economic planners, who know all about economics and they make very complicated plans with which we have to deal. Finally,

we have to learn to deal with the political leaders because they make the final decisions that will determine 1) if there will be seed of improved varieties available to permit the package of technology to be distributed to farmers, 2) if there will be fertilizer of the right kind available and if it will it be at the village level in time for planting, 3) if there will be water six weeks before planting starts, and 4) if there will be credit so that small farmers can afford the package.

I am now in my 49th year working with these kinds of problems in agriculture. I lived continuously outside of the United States for the first 40. During the last nine, I have taught one semester each year at Texas A&M University. The rest of the time, I have continued to work out of my office at CIMMYT in Mexico.

How is it that a major research program on wheat was started in 1943 in Mexico, the home of maize? Few know that wheat was brought to Mexico in early colonial times by the Spanish. When I arrived in the country, 60% of the wheat was imported. Nine years prior to this in 1934 in the State of Sonora in northwestern Mexico, Governor Rodolfo Elfas Calles was tremendously enthusiastic about agriculture and he established a modern 100-hectare farm with excellent buildings, a good set of machinery, and the best livestock that money could buy. The talented Edmundo Taboada managed the farm for the first couple of years and he was particularly interested in wheat. He had selected some 30 or 40 varieties that he brought in from other countries to make crosses. Then he was called to Mexico City to organize the whole research program for the Ministry of Agriculture. Because of Taboada's efforts, farmers in northwestern became interested in wheat. Unfortunately, inexperience in breeding for disease resistance led to disastrous stem rust epidemics in 1939-41 that essentially wiped out the whole crop. This was the environment in which I found myself when I arrived to establish a wheat breeding program.

Needless to say, the animosity of the farmers towards anyone who was involved with the agricultural sciences was pretty high. We were ignored—maybe that was the best treatment at the time as far as we were concerned. In those days, it took 10 to 11 years to develop a rust-resistant wheat variety. The dogma of the time dictated that, in order to have a variety that was adapted, a breeder had to make a cross and then make all subsequent selections in the soil and climatic conditions under which the variety was to be grown commercially—that meant one generation a year. When I had seen that there had been three successive stem rust epidemics in the main wheat growing area of Mexico, only three years before I arrived, I knew I didn't have 10 or 11 years before the next epidemic, and when it did occur I would be thrown out of the country.

To speed up the breeding process, I started what was later to be called "shuttle breeding". With this methodology, segregating populations were planted on an irrigated coastal plain in northwestern Mexico (at the 28°N latitude and 30 masl) in November when the days were getting shorter. We created artificial rust epidemics and selected the best plants for height, rust resistance, and grain type. We then "shuttled" the resulting seed back to the high elevation (2650 masl) of the Toluca Valley (18°N latitude) for planting when the days were growing longer. In four and a half years, we had the first varieties, which were very good ones. We used the same procedure for the first two seed multiplications.

All this took place before there was knowledge of photoperiodism and it's importance in cereal grains. It had been known for several years when I was in graduate school that photoperiod was important in certain kinds of horticultural crops, but it was thought that cereals were not very sensitive. However, it turned out quite differently.

How did this little wheat breeding program in Mexico have an impact in so many places around the world? Mexico itself became self-sufficient in food production in 1956. By 1959, I turned the wheat breeding program over to my young Mexican colleagues and I considered becoming a banana breeder in Central America. But the Rockefeller Foundation had other ideas. They sent me to work with the FAO to look at wheat production problems in North Africa, all of the Middle East, and India and Pakistan. As I travelled through these regions, I saw a shortage of trained people. However, in India and Egypt, I saw many young people who had fresh doctorates or masters degrees from Europe, Canada, the U.S., Australia, and many other different places. So, I made a proposal that we bring young scientists from these countries, who had just finished their university training, to Mexico for an intensive 6-month training course in plant breeding, plant pathology, agronomy, soil irrigation, and cereal technology. The idea was approved and the first trainees (an outstanding group of individuals) came to Mexico in the fall of 1961. Each year after that, a new group came.

During this early period, we organized the First International Wheat Yield Nurseries with the help of the trainees, who brought with them to Mexico about 200 g of the main wheat varieties of their home countries. The seed was disinfected and grown in seed plots. The next generation of seed was sent abroad to many parts of the Near and Middle East. I think that first year there were only 35 locations, but soon there were 75 and then 125. The data that were compiled from these nurseries began to show immediately what we hadn't known for sure before about the importance of photoperiod.

Also included in those first nurseries were the best spring wheats from Canada, North Dakota, South Dakota, Minnesota, and Wisconsin not to mention our own Mexican material and wheats from Guatemala, Ecuador, Peru, Chile, and Argentina. Soon we discovered that the commercial varieties from Canada and the northern U.S., which had good disease resistance and good milling and baking qualities, almost always ranked last in yield in every location under 48° latitude. Yet the semidwarf Mexican wheats yielded well almost everywhere since they were insensitive to day length because they were developed through the shuttle breeding methodology in Mexico.

The Mexican Program was the first foreign technical assistance program in the agricultural sciences. It preceded by five years the Marshall Plan, which assisted the Western European countries in their recovery from the disasters of World War II. It also preceded by six years President Truman's declaration that "the United States has a moral obligation to help developing nations improve their agriculture." So you see the Mexican Program was really a pioneer in this arena.

By the early 1960s, trainees returning home from Mexico always took back with them 10-g samples of any wheats in the Mexican breeding plots they liked. Through letters or through messages carried by other young trainees from the same country who came to Mexico the next year, it soon became

apparent that some of these wheats were very promising. There was particular interest in Pakistan and India where food shortages were becoming all too common.

In 1963, I was invited by the Government of India to visit its wheat research program. By then, the success story of the dwarf Mexican wheat varieties had spread to many countries in the Near East by the young scientists returning from Mexico. M.S. Swaminathan at IARI had obtained seed of five of the first semidwarf Mexican lines through the USDA International Wheat Stem Rust Nursery and was intrigued by their potential for increasing Indian wheat production. He wanted my opinion on whether these lines might be useful in the Indian breeding program. Since these particular lines were obsolete, I was reluctant to voice an opinion without seeing their performance in the field.

As luck would have it, I would have this opportunity in Pakistan, which was the next stop on my itinerary. And with what transpired there we see the resistance to change that we were up against at that time. I had been invited by the Minister of Agriculture of Pakistan to review their wheat breeding nursery at Lyallpur (now Faisalabad). Now I could see how the lines I saw in India were performing elsewhere in the region. Accompanying us as we visited the experimental plots were two young Pakistani scientists who had been in training program in Mexico. I was disappointed to see the performance of the Mexican semidwarf wheats in the demonstration and breeding plots. They were inferior to the Pakistani wheats under the conditions of the tests. However, I could see that these wheats had been planted at the wrong time and had not been properly fertilized and irrigated, consequently I was sure that the methods used in growing the demonstrations were not optimum for the Mexican wheats under Pakistani conditions. When I mentioned this to the Director of Research, he responded that "this is the way wheat is planted in Pakistan."

After dinner, the two young trainees who had accompanied us to the plots that day took me aside and said that they had something to show me in the morning before I left for the airport. In the pre-dawn they awoke me with tapping on my guesthouse window. We walked to the most remote corner of the experiment station and there they were—four plots of Mexican dwarf wheats about half as wide as this auditorium and three times as long—beautiful, just as beautiful as they were back home in Mexico. I asked why they didn't grow the demonstration nurseries with the same technology? They responded that they were not allowed to do so by the experiment station administration.

This story illustrates one of the real obstacles to change. From Pakistan, I went on to Egypt and I found the same thing—some beautiful plots of the Mexican wheats hidden in a remote corner. I am not pointing a finger at Pakistan or at Egypt because I've seen the same thing in the U.S. When the Mexican wheats finally escaped from Mexico to the U.S., it was the farmers themselves and some scientists who brought it. The Mexican wheats had taken over 30% of the hard red spring wheat region of northern U.S. before the experiment stations in that part of the country produced their own varieties of high yielding dwarf wheats.

So my message to all of us here today—including myself, especially at my age—is don't be so ultraconservative. Let's try to keep our minds open to new ideas because change will come and if we are not careful, we'll be left behind.

Wheat Production in Nigeria

L.B. Olugbemi
Institute of Agricultural Research, Ahmadu Bello University, Samaru, Zaria, Nigeria

Abstract

Wheat is presently produced commercially in Nigeria entirely under irrigation within latitudes 10 to 14°N where night temperatures during most of the growing period (November-March) range from 10 to 15°C. The mean maximum temperature ranges from 30 to 35°C. Recommended for cultivation are Samwhit varieties numbered 1 through 8. As a result of the ban on wheat importation into Nigeria, effective January 1987, local wheat production rose from about 50,000 t/year to an estimated 150,000-180,000 t/year within four years. This increase was due partly to the encouragement given to wheat farmers by the government and the good price received by farmers for their harvest. With the partial lifting of the ban towards the end of 1992, many farmers are shifting to other crops like vegetables and rice.

Introduction

Wheat is presently produced commercially in Nigeria under irrigation within latitudes 10-14°N and mainly between altitudes 240-360 masl where night temperatures are in the range of 10-15°C during most of the growing period (November-March). The absolute minimum and maximum temperatures during the period range from between 5 and 8°C and 30.0 and 32.5°C, respectively, for Samaru, latitude 11°11'N (Olugbemi 1990).

In order to boost food production in the country, the government in 1976 promulgated a decree establishing 11 River Basin Authorities (Olugbemi 1980). Three of these—the Hadejia-Jama' Basin (Kano/Jigawa States), the Sokoto-Rima Basin (Sokoto/Kebbi States), and the Chad Basin (Borno/Yobe States), which are located within latitudes 10-14°N—were to promote wheat production. When fully developed, the three river basins were to provide about 345,000 ha of irrigated land with about 50-60% of it sown to wheat. However, this target could not be achieved due primarily to inadequate funding and inconsistency in government agricultural policy.

Research

The Institute for Agricultural Research, Ahmadu Bello University, Zaria, began wheat research in Nigeria in 1959. The main objectives of the research program are to identify cultivars of bread wheat that, under Nigerian conditions, are high yielding, responsive to fertilization, resistant to diseases, and of good breadmaking quality. To meet these objectives, attention is being paid to the screening of varieties/lines of Mexican origin that have proven to be suitable for cultivation in Nigeria.

In 1965, Samwhit 1 (Tousson) and Samwhit 2 (Florence Aurore 8193)—both tall non-Mexican varieties—were released for yield and breadmaking quality, respectively. In 1971, two Mexican varieties, Samwhit 3 (Sonora 64) and Samwhit 4 (Lee//N10/B/3/GB/GB55/4/GB56) were released. These are semidwarf, earlier maturing, more resistant to lodging, and more responsive to

fertilizer application than Tousson and Florence Aurore 8193. In 1974, Samwhit 5 (Siete Cerros), which is high yielding and of average breadmaking quality, was released. In 1990, three additional Mexican varieties—Samwhit 6 (Pavon 76), Samwhit 7 (Bulbul), and Samwhit 8 (Sonalika) were released. Pavon 76 was released for its high grain quality and Bulbul and Sonalika for their earliness. Samwhit 5 is the most widely cultivated variety in the country.

Level of Production

Following the wheat importation ban, effective January 1987, the level of wheat production in the country rose rapidly. This was due to the encouragement to the local wheat farmers given by both the Federal and state governments as well as the good price paid for local wheat.

According to the figures supplied by the wheat growing states, about 214,000 ha of land were planted to wheat during the 1988-89 crop season (Olugbemi 1991).

Kano State, with a cultivated area of about 175,000 ha, accounted for more than 80% of the total area under wheat. At a mean estimated yield of 2 t/ha, the total production for 1988-89 might have reached 428,000 tons. The actual production, however, was estimated to be between only 150,000 and 180,000 tons due largely to poor management. Even so, this was a remarkable increase over the estimated production figure of 50,000 tons the year before the importation ban.

The increase in production resulted from the financial assistance given to the wheat growing states by the Federal government, which enabled those states to supply inputs and irrigation pumps to the wheat farmers at subsidized rates, up to 50% in some states. As a result of this assistance to the wheat farmers, almost all the states in the federation including those between latitudes 4-9°, some of which are located in the forest zone, claimed that wheat could be produced commercially in their ecological zones; obviously this enabled them to benefit from the Federal government's financial assistance.

Another reason for the boost in wheat production was the good price, which rose to about US$500/t in 1992.

Management

Several management practices aimed at obtaining optimum yield under Nigerian conditions have been established. These are outlined in the following sections.

Sowing time

The recommended sowing time in Nigeria is November to early December when night temperatures are relatively low. Many farmers, however, do not sow until late December to early January, sometimes as late as the end of January. Such late sowing is attributed primarily to delays in land preparation arising from late removal of the preceding rainfed crop (e.g., rice, cowpea). Late-sown wheat usually develops and matures very rapidly under the prevailing high temperatures, resulting in considerable yield losses and sometimes poor quality grains.

Seeding rate

Depending on planting method, a seeding rate of 120-140 kg/ha is recommended. High seeding rates are required for hand broadcasting, which is the practice adopted by most farmers. Some farmers drill seed with tractor-driven planters in rows 20 to 30 cm apart.

Fertilizer application

One of the important objectives of the wheat improvement effort in Nigeria is to identify varieties of bread wheat that, among other requirements, are responsive to fertilizer applications without lodging. The Mexican varieties possess this desirable characteristic. Under Nigerian conditions, 100 to 130 kg N/ha, as split applications, half at planting and half three to four weeks after planting are adequate. Phosphorus at a rate of 45 to 60 kg P_2O_5 at planting is recommended; the lower rate is for sandy soils. A higher application rate may result in higher grain yield, but at a diminishing return.

Water supply

A range of 5- to 12-day irrigation intervals is recommended, depending upon the type of soil and stage of crop growth. Sandy soils such as the Sokoto-Rima Basin require irrigation at five-day intervals, but the more compact and heavy soils of the Kano River Basin require a lower frequency of every 9 to 12 days. In practice, irrigation every 9 to 12 days from sowing to the boot stage and at weekly intervals after that is considered adequate. If the optimum irrigation frequency is followed, 9 to 11 irrigations are given.

Weeding

Seeding at the recommended rate is important in order to minimize weed infestation. For small-scale farmers, weeding is usually done by hoe and hand pulling. On large farms, chemical weed control is employed. Chemicals used include chlortoluron + Antor (1.0 + 0.50 kg a.i./ha) or chlorbromuron + Antor (1.0 + 0.50 kg a.i./ha), which are applied at about four weeks after planting.

Pest control

The pests frequently encountered include termites (*Microtermes lepidus*), aphids, and stem borers (*Sesamia calamistis*). Bird and rat damage is also now assuming more importance.

For termite control, application of carbofuran at 1.0 kg a.i./ha at planting is recommended. Similarly giving effective control is aldrin 2.5% dust, applied in the furrows at 0.5-1.0 kg a.i./ha at planting or broadcast at a rate of 1.5-2.0 kg a.i./ha and thoroughly mixed with the soil before planting.

Most insecticides such as Rogor can effectively control aphid attack. Stem borer attacks, which are usually low (about 5%), can be controlled by applying carbofuran at 1.0 kg a.i./ha at planting.

Bird scarers are used to control birds, whose attack at grain-filling can be a great problem. Poison and trapping are used to control rats.

Utilization

To maximize the use of the very limited quantity of wheat produced locally, the Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria, in collaboration with the West and Central African Sorghum Research Network has conducted extensive studies on wheat/sorghum and wheat/maize composite flours for bread and confectionery production. Some highlights of these studies include:

- Acceptable bread can be produced commercially from wheat composite flour containing up to 30% sorghum or maize.

- The higher the quality of the wheat used, the better is the quality of the composite bread.

- Bread produced from composite flours is susceptible to crumbling after one day. Addition of a small amount (0.5%) of cassava starch flour will give the bread a more spongy, closer texture and reduce the crumbling. However, cassava flour tends to reduce bread loaf volume and slightly shortens shelf-life.

- In order to produce wheat composite bread of comparable loaf size to that of pure wheat, it is necessary to use a greater weight of composite flour per loaf.

- The higher the level of nonwheat substitution, the lower is the nutritional status of the resulting bread. For this reason, it is essential to incorporate a high protein substance, such as legumes, into wheat composite products.

- For confectioneries (e.g., bread rolls, cookies, and puff-puff) and biscuits, up to 50-60% substitution with sorghum or maize gives acceptable products; higher levels cause a raw sorghum or maize after-taste with rough, hard, and broken surfaces. In the case of biscuits, substitution higher than 70% produces biscuits that crumble.

Future Prospects

It is likely that the level of local wheat production in 1991-92 rose marginally above 180,000 tons partly due to increased fadama (fertile river flats) area put into wheat production and partly to improved management practices by farmers. However, it would appear that the partial lifting of the ban on wheat importation towards the end of 1992 has reduced the wheat area for the 1992-93 season. Many farmers feared the price of local wheat would fall drastically and have opted to grow vegetables and/or rice. Their fears have not been unfounded. Before the partial lifting of the ban, 1 ton of wheat flour sold for as much as US$800, but within one month after the lifting, the price decreased to about US$500.

The flour price reduction has yet to be fully reflected in bread prices which have decreased only 10% so far. Bakers, while acknowledging the fall in flour price, point to the increasing costs of other essential ingredients such as sugar, yeast, and fat as well as increasing labor costs.

In order to regain and maintain the confidence of wheat farmers in Nigeria, the government must continue to give incentives. In addition, flour millers should be required to pay a certain levy for imported wheat, to be used exclusively for boosting local wheat production.

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Wheat Improvement in Egypt with Emphasis on Heat Tolerance

E.H. Ghanem
Wheat Research Section, Agricultural Research Council, Giza, Egypt

Abstract

A history of wheat varietal development in Egypt since 1914 is provided. With the planting of new, heat-tolerant varieties over large areas, wheat production has almost doubled in Middle and Upper Egypt over the last 10 years. Sakha 69 has been primarily responsible for increasing yields to above the 5 t/ha level in Middle Egypt, while the highly heat-tolerant Giza 164 has resulted in increasing average wheat yield in Upper Egypt to more than 5 t/ha.

Introduction

Wheat is the main winter cereal crop in Egypt in terms of area and production. Its area amounted to about 850,000 ha in 1992 producing a total of 4.67 million tons with an average of 5.5 t/ha. The majority of the area is sown under surface-irrigated conditions on old land; sprinkler irrigation is practiced in the newly reclaimed desert areas, while wheat cultivation has been introduced under rainfed conditions on the North Coast with limited possibilities for supplemental irrigation. Area, production, and average yields are listed in Table 1.

Strategy and Objectives of the Program

The aim is to develop high yielding varieties that combine desirable agronomic attributes along with good quality. Moreover, the program responsibility is to define the optimum package of management practices to be disseminated to growers to achieve the potential of the newly released high yielding varieties. Additionally, a sound seed multiplication system and vigorous extension efforts are prerequisites for raising the national yields.

In general, the program objectives can be described as follows:

- Developing high yielding cultivars that are responsive to high doses of applied N and are efficient for fertilizer use.

Table 1. Area and production of wheat cultivated on old land during 1912-1992.

Year	Area (ha)	Average yield (t/ha)	Total production (millions of tons)
1912	539,048	1.55	0.832
1922	614,379	1.60	0.975
1932	713,199	2.00	1.424
1942	662,366	1.90	1.255
1952	589,078	1.84	1.084
1962	611,355	2.59	1.586
1972	520,729	3.09	1.608
1982	577,148	3.48	2.007
1983	554,641	3.58	1.986
1984	495,114	3.65	1.806
1985	498,287	3.74	1.863
1986	506,868	3.79	1.919
1987	576,895	4.70	2.708
1988	597,361	4.73	2.825
1989	643,922	4.69	3.167
1990	751,633	5.45	4.099
1991	822,783	5.06	4.165
1992	758,326	5.61	4.256

- Producing stable varieties having wider adaptability to minimize yield fluctuations and to ensure sustainable agricultural systems.

- Breeding for disease, mainly rusts, and aphid resistance. Aphid infestations are increasing and symptoms of BYDV are obvious in wheat fields.

- Improving stress tolerance, i.e., salinity (in N. Delta Region and the Fayoum Governorate), drought (on the Northern Coast and newly reclaimed areas), and heat (in Middle and Upper Egypt Regions), particularly during the grain-filling period in April and May (Table 2).

- Improving quality and nutritive value of the wheat varieties.

- Increasing the production per unit of water and land so as to maximize water use efficiency.

- Producing early-maturing varieties that could be harvested during late March or early April, thus allowing the cultivation of cotton, or short-duration crops like soybeans, sunflower, or mungbean before maize, sorghum, or rice. In addition, there have been positive results regarding transplanting of cotton, which could allow an expansion of wheat area before cotton. In these ways, wheat area and cropping intensity could be increased.

- Defining optimum cultural operations for the newly released varieties.

- Demonstrating new wheat varieties coupled with recommended cultural practices at the farm level.

- Providing basic seed (breeder and foundation) to seed multiplication agencies to ensure production of high quality seed in various multiplication stages.

Wheat Breeding and Improvement: History and Achievements

Wheat improvement in Egypt started as early as 1914 when the varieties Baladi 116 (*Triticum pyramidale*) and Dakar 49 and Dakar 52 (*T. durum*) were selected from local materials. The two durum wheats were adapted to Upper Egypt conditions as they can tolerate the prevailing high temperatures. Baladi 116 was also adapted to various environments, including Upper Egypt. These varieties did not endure due to low productivity and disease susceptibility.

Table 2. Average maximum and minimum temperatures in Middle and Upper Egypt during the 1991-1992 season.

	Middle Egypt						Upper Egypt					
	Beni Suef		El Fayoum		El Minia		Assiut		Qena		Aswan	
Month	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Nov. 91	26.8	11.6	26.5	13.1	27.0	9.7	23.8	11.2	29.8	13.6	28.6	16.4
Dec. 91	22.4	7.6	21.8	8.5	22.6	5.8	20.6	7.8	24.3	8.9	22.6	9.1
Jan. 92	20.8	5.0	20.3	6.1	21.6	2.6	17.0	5.4	22.7	6.7	22.6	7.7
Feb. 92	22.5	5.9	22.0	7.3	23.8	4.2	19.0	5.8	25.3	7.6	20.5	8.5
Mar. 92	25.6	8.5	25.1	9.9	26.9	6.9	23.9	10.7	30.3	11.1	26.6	14.6
Apr. 92	30.1	12.0	30.1	12.9	31.9	11.4	28.9	12.9	34.5	15.9	32.8	18.2
May 92	34.1	16.2	34.0	17.2	34.8	15.5	33.7	19.7	39.0	20.7	34.1	23.9

During the 1920s, genetic materials were introduced from India, out of which some cultivars such as Hindi D, Hindi 62, and Tosson were developed. Tosson was tolerant to heat in Middle Egypt, but was not suited to Upper Egypt's conditions.

By 1942, a program was developed to breed for material resistant to stem rust (*Puccinia graminis*) using material introduced from Kenya. This resulted in the development of Giza 139, which was effective in controlling stem rust; unfortunately it was susceptible to leaf rust (*P. recondita*). Its cultivation was limited to the Delta Region as it did not tolerate the heat in Upper Egypt. From 1950, breeding work was expanded based on greater parental diversity rather than on a greater number of crosses of the limited and related parents. As a result, the varieties Giza 144 (N. Delta), Giza 145 (S. Delta), Giza 146 and 151 (Middle Egypt), and Giza 147 and 148 (Upper Egypt) were released. All of these varieties were resistant to stem rust; Giza 144 was resistant to both stem and leaf rusts and became more popular in the Delta region, but was attacked by stripe rust (*P. striiformis*) in 1967.

The three varieties Giza 146, 147, and 148 were suited to Upper Egypt. Giza 146 became common in Middle Egypt. Giza 147 was more tolerant to heat compared to both Giza 146 and 148 and as a result occupied most of the wheat area in Upper Egypt during the late 1950s and early 1960s.

During the 1960s, crossing work was further intensified and strengthened due to the introduction of useful sources of genes for rust resistance. As a result, Giza 155 was developed, which is resistant to stem and stripe rusts along with a high degree of tolerance to leaf rust. It was also early maturing, moderately resistant to lodging, and outyielded any of the cultivated varieties by at least 20%. Moreover, its area was expanded in the various zones of the country due to its wide adaptability. It tolerated heat in Upper Egypt better than any other variety. By the late 1960s and mid-1970s, it occupied more than 80% of the wheat production areas.

Giza 156 had better yield potential compared to Giza 155, but it is comparatively more susceptible to stripe rust and therefore is recommended for cultivation in Middle Egypt only as it does not tolerate the high temperatures prevailing in Upper Egypt.

The releases of Giza 155 (1968) and 156 (1972) were responsible for increasing the national average yield from 2.6 t/ha during 1968 to more than 3 t/ha during the early 1970s, underlining the success of the breeding effort.

In 1962, dwarfing genes were introduced into the breeding program, which resulted in the development of several HYVs with lodging resistance and responsiveness to high N rates in the mid-1970s. In 1973, the short-statured, high yielding varieties Mexipak, Super X, and Chenab 70, which have a medium tolerance to heat, were recommended for cultivation in Middle Egypt, the Delta, and the Sohag Governorate of Upper Egypt. Cultivation of Mexipak stopped in 1977 due to its shattering and disease problems. By 1979, national average yield had reached 3.3 t/ha.

The widespread cultivation of Chenab 70 during 1976-77 resulted in a change of the leaf rust race spectrum due to the rapid build-up of the pathogen population on this variety. Area planted to this variety has declined and it is no longer recommended.

In 1978, further progress was achieved with the release of Sakha 8 and Giza 157, both of which showed good resistance to the three

rusts and shattering. Sakha 8 was tolerant to heat and highly tolerant to salinity, which made it a popular variety in areas with salt problems including Upper Egypt. However, Giza 157 was medium-tolerant to heat, so it was recommended for cultivation only in the Delta and Middle Egypt. Also, the durum variety Mexicali (= Stork'S') was recommended for Middle and Upper Egypt as it proved to be heat-tolerant during the wheat growing season as well. The three varieties Giza 157, Sahka 8, and Mexicali occupied more than 220,000 ha during the 1979-80 season. Giza 158 was released in 1980. Despite its earliness and heat resistance, it did not become popular because it was shorter than any other variety at the time. Three medium-tall varieties appeared very promising in yield trials during 1984. Sakha 61 was recommended for cultivation in the Delta Region; Sakha 69 exhibited medium tolerance to heat and was recommended for both the Delta Region and Middle Egypt; Giza 160 showed high tolerance to heat and consequently was recommended for Upper Egypt and the New Valley.

During 1987, four new bread wheat varieties (Sakha 92 and Giza 162, 163, and 164) and two durums (Beni Suef-1 and Sohag 2) became available. Sakha 92 and Giza 162 and 163 were recommended for the Delta Region; heat-tolerant Giza 164 was recommended for Upper and Middle Egypt while Sohag 2 was also recommended for Upper Egypt. During the 1990s, the bread wheat varieties Giza 165 (for Upper Egypt) and Gemmeiza 1 (for the rainfed Southern Delta and Northern Coast regions) were released and the durum variety Beni Suef-1, with only average heat tolerance was recommended for Middle Egypt.

It should be clearly stated that the Wheat Program has adopted a new strategy for releasing different HYVs for specific locations to meet specific stress resistance requirements such as for the rusts in the Delta Region, salinity in the Northern Delta and Fayoum Governorate, heat in Upper and Middle Egypt, drought in the North Coast, and aphids in all areas. This strategy has resulted in rapid and stable wheat yield increases at the national level (Table 3).

In order to introduce wheat cultivation to the newly reclaimed desert areas under new irrigation schemes and to increase crop intensity in the country, the production of early maturing varieties has become essential. Moreover, the release of early maturing wheat cultivars might be advantageous in Upper Egypt to escape the high temperatures prevailing during the grain-filling stage in April and May.

Recently, breeding of wheat varieties tolerant and/or resistant to heat was further strengthened through the introduction of more bread and durum wheat germplasm from CIMMYT and other international programs.

Table 3. Increases in average wheat yields in the Middle and Upper Egypt Governorates during the 1971-92 period.

Governorates	71-72	81-82	87-88	91-92
Middle Egypt				
Giza	3.23	3.93	5.15	5.78
Beni Suef	3.02	3.46	5.86	5.77
El-Fayoum	2.81	3.29	5.39	5.40
El-Minia	3.55	3.48	4.84	5.88
Average	3.15	3.45	5.26	5.67
Upper Egypt				
Assiut	3.60	3.43	5.40	5.67
New Valley	-	-	-	3.41
Sohag	3.02	2.91	4.55	5.12
Qena	2.46	2.58	3.54	5.14
Aswan	2.06	2.50	2.98	4.63
Average	2.91	2.96	4.45	5.26

During the 1990-91 season, 19 bread wheat and 16 durum genotypes were tested at Shandweel, Mataana, and New Valley. During 1991-92, one set of 16 bread wheat varieties and another set of seven durum varieties were planted on 20 Nov. and 25 Dec. 1991 in both Sudan and Egypt.

Results show that testing genotypes under different environmental conditions may be the best tool to identify stress-tolerant genotypes under hot conditions where some introduced materials outyield commercially grown cultivars. More introduced materials will be tested in the future as this approach might help to accelerate the release of HYVs adapted to the high temperatures during the wheat growing season under conditions of Middle and Upper Egypt.

Impact of the Main Heat-Tolerant Varieties

Giza 146 and 147, released in the late 1950s, dominated Middle and Upper Egypt, respectively, by the early 1960s. Giza 146 with its medium heat tolerance resulted in a 0.4 t/ha increase in average yield for Middle Egypt where average yield reached 2.1 t/ha. Similarly, Giza 147 increased average yield by 0.4 t/ha in Upper Egypt where average yield reached 1.8 t/ha.

In the late 1960s, Giza 155 was released as a heat-tolerant, high yielding variety with wider adaptability. This variety alone occupied more than 80% of the total wheat area in the country, which caused a 0.7 t/ha yield increase in Middle Egypt where average yield reached 2.9 t/ha; average yield reached 2.5 t/ha in Upper Egypt.

Sakha 69 was released in the early 1980s as a medium-tolerant variety with wide adaptability. It is suited to the conditions of Middle Egypt, but not Upper Egypt. This variety and other recommended HYVs raised average yield in Middle Egypt to 5.6 t/ha during the 1991-92 season. The durum varieties Beni Seef-1 and Sohag 1, 2, and 3 showed suitability and adaptability to Middle and Upper Egypt, but the impact of these varieties has not been large as durum area in Egypt is less than 25,000 ha.

Due to seed multiplication difficulties, the highly heat tolerant variety Giza 160 currently occupies only a limited area.

The rapid seed increase and wide utilization of Giza 164 as a highly heat tolerant variety in Upper Egypt has resulted in increasing average wheat yield in the region to more than 5 t/ha during the 1991-92 season.

Conclusion

Wheat production has almost doubled in Middle and Upper Egypt over the last 10 years due to the rapid increase of area planted to the newly released heat-tolerant varieties that have replaced low-yielding and less adapted genotypes along with the accompanying improved management practices.

Wheat Cultivation, Research Organization, and Production Technology in the Hot Dry Regions of India

J.P. Tandon
Directorate of Wheat Research, Karnal, Haryana, India

Abstract

Wheat production in India has always been regarded as a gamble with seasonal temperatures. Major parts of the country have tropical to subtropical climates where average winter temperatures remain high. The greatest risk of damage is in the drier areas (the Central and Peninsular Zones) where temperatures remain warm and the duration for wheat growth is rather short. Some 20 research centers are located in these two zones, which are responsible for the large range of improved varieties being sown under the various cultural situations in these regions. Recent research achievements and production technologies for these hot zones of India are discussed.

Introduction

India is one of the largest wheat producers of the world. The crop is grown on around 24 million hectares and production was estimated to be 55.2 million tons during 1991-92. More than 90% of the area is sown to bread wheat (*Triticum aestivum*), which is grown throughout the country. Macaroni wheat (*T. durum*) accounts for around 8% of area and its cultivation is prevalent in rainfed areas of Central and Peninsular India. In recent years, durum cultivation has been introduced in irrigated areas of the North Western Plains. A small area is under emmer wheat (*T. dicoccum*), which is grown mainly in the southern states and to some extent in Gujarat.

The crop is grown in most parts of the country, but the largest concentration (nearly 70%) lies in the northern plains. Central India accounts for about 20% of the area under wheat, while the remaining 10% is contributed equally by the peninsular states and the Himalayan regions. Nearly 78% of the Indian wheat crop is irrigated and national average yield is around 2.3 t/ha.

The major wheat states are Uttar Pradesh (37%), Punjab (14%), Madhya Pradesh (14%), Haryana (8%), Bihar (8%), and Rajasthan (7%), which account for nearly 88% of area and 94% of production. The highest average yield (3.67 t/ha) has been recorded in the state of Punjab over an area of 3.16 million hectares. Average yields are low in Bihar (1.68 t/ha), Madhya Pradesh (1.3 t/ha), and Maharashtra (1.19 t/ha).

India has achieved remarkable progress in increasing wheat production and productivity over the last 25 years. Over the 1967-90 period, wheat area expanded at an annual rate of 2.5%. Among all the food grain crops grown in India, wheat has shown the highest growth rates in production (5.2%) and in productivity (3.1%). It is estimated that to meet increasing demand, a minimum of 75 million tons of wheat will be required by

the end of the century. Since there is very little scope for further increase in area, this must be achieved through increasing productivity.

Wheat in the Hot Areas of India

Wheat production in India has always been regarded as a gamble with seasonal temperatures. Major parts of the country have tropical to subtropical climates where average winter temperatures remain high. From a consideration of various aspects including temperature, the country is divided into five main wheat zones: 1) Northern Hills Zone, 2) North Western Plains Zone, 3) North Eastern Plains Zone, (4) Central Zone, and 5) Peninsular Zone. Table 1 shows the mean temperatures and rainfall recorded during the potential wheat crop season (five-year average).

The normally sown irrigated wheat crop is seeded during November in most parts of the country. However, these sowings are sometimes staggered from November through late December or even into January, depending on cropping sequence. The harvest is spread over a period starting from February (in the southern states) to mid-May (in the hilly regions). In the major wheat producing states of Punjab, Haryana, and Uttar Pradesh, the crop is harvested in late March through mid-April, whereas in Bihar and Central India harvest is in mid-March. However, the rainfed crop is sown slightly earlier (late October) and accordingly harvested a couple of weeks earlier than the irrigated crops.

The irrigated crops are sown when mean daily temperature falls below 22°C since most irrigated varieties are not adapted to establish at temperatures higher than that. The rainfed varieties can stand slightly higher temperatures and thus are sown earlier to take advantage of soil moisture built up by the monsoon rains. The crop starts maturing immediately after the average temperatures reach around 25°C, which is highly dependent on latitude and altitude. The low latitude regions of the southern states start warming up earlier. Similarly, low altitudes get hotter early. The crop is frequently exposed to temperatures higher than the tolerance limits indicated above during the early growth stages and also during the grain-filling stages. The situation with regard to the grain filling stage becomes more acute in the case of late-sown crops. In general, the temperatures tend to remain lower and more favorable for a longer duration in the northwestern parts and remain higher and

Table 1. Mean temperatures (°C, five-year average) and rainfall recorded during 1989-90.

	Average temperatures during crop season							Total rainfall during the crop season (mm)
Zone	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	
NHZ	18.4	15.2	10.7	9.7	10.8	14.0	18.5	493
NWPZ	24.6	19.7	14.4	13.3	15.4	19.6	26.3	118
NEPZ	26.1	21.9	17.4	15.6	19.1	22.9	27.7	220
CZ	26.2	22.8	19.2	18.5	20.6	24.6	29.8	36
PZ	25.2	22.1	20.6	20.8	23.0	25.8	29.7	43

NHZ = Northern Hills Zone; NWPZ = North Western Plains Zone; NEPZ = North Eastern Plains Zone; CZ = Central Zone; PZ = Peninsular Zone.

within tolerance limits for a shorter duration in the eastern, central, and southern parts of the country.

It is estimated that the currently available varieties are capable of yielding around 6.5 t/ha in the northwestern plains where a growth duration of around 145 days can be achieved for the irrigated crop. However, this potential is reduced to about 4.5 t/ha in the hotter southern parts where the crop duration does not exceed 100 days. In the eastern and central regions, this potential is around 5.5 t/ha. Experimental yields higher than these are frequently recorded in each of the regions in well managed trials.

Wheat Research for Hot Dry Regions

About 60 research centers are located throughout India. In the hot dry regions, there are 11 research centers in the Central Zone and 9 in the Peninsular Zone. All wheat improvement research is conducted through the All India Coordinated Wheat Improvement Program (AICWIP), which is run by the Directorate of Wheat Research. All improved germplasm, particularly in advanced bulk stages, is equally shared by all relevant centers (see Appendix).

Recent Research Achievements

Varietal improvement

In the AICWIP programs, all new varieties must combine high yield potential with resistance to rusts prevalent in the region since fungicidal treatments are not recommended for the control of these diseases. In the Central and Peninsular Zones, leaf and stem rusts are important. The new varieties should also possess adaptability to a wide range of cultural variables such of varied sowing dates, fertilizer levels and irrigation schedule. They are also evaluated for other aspects such as grain quality and tolerance to insects, salt, and heat. As such, varietal improvement is a cooperative effort in which all research disciplines cooperate and contribute. Some of the latest varieties released for hot dry region of India are shown in Table 2.

Identification of superior donors for abiotic and biotic stresses

Each of the research disciplines places considerable emphasis on the identification of sources of tolerance/resistance to various abiotic and biotic stresses. These sources are then used in the varietal development program.

Abiotic stresses—Some sources of tolerance to some of the abiotic stresses are as follows:

- Heat tolerance during germination: Hindi 62, Kharchia 65, C 306, Narbada 4, Pissi local, NI 8223, HI 1101, Malvi local, Jijaga Yellow, and HI 8351.
- Heat tolerance during grain-filling: HD 2285, HD 2402, HD 2270, AKW 381, and NP2 (*dicoccum*).

Table 2. Varieties recently released by the AICWIP for the hot, dry regions of India.

Cultural situation	Central Zone	Peninsular Zone
Irrigated, timely-sown	HI 2077 GW 190 HI 8381	HD 2380 MACS 2496 DWR 162
Irrigated, late-sown	GW 173	HI 977 HD 2501
Rainfed conditions	Sujata A 9-30-1	MACS 1967
Salt-affected soils	KRL 1-4 Raj 3077 WH 157	KRL 1-4 Raj 3077 WH 157

- Drought tolerance: Hindi 62, Kharchia 65, C 306, HI 1011, Narbada 4, Hyb 65, Pissi local, Bijaga Yellow, and HI 8351.

- Salt tolerance: Kharchia 65, KR1 1-4, KRL 3-4, and KRL 1-2.

Biotic stresses—Leaf rust (*Puccinia recondita*) and stem rust (*P. graminus* f.sp. *tritici*) are the most important diseases of wheat grown in the hotter parts of India. Screening for resistance to these is a continuous process since the resistance of old varieties breaks down and they must be replaced with new ones. A large number of stocks highly resistant to leaf and stem rusts are continuously identified and confirmed for resistance before use in breeding programs since these diseases are controlled exclusively through the cultivation of resistant varieties.

Foot rots caused by *Sclerotium rolfsii*, *Fusarium* sp. and *Helminthosporium* sp. are important under rainfed conditions, but no resistant stocks are available for these diseases. Limited varietal differences are exploited by avoiding the release of highly susceptible varieties.

Insect pests and nematodes are not important. Although stem borer (*Sesemia inferens*) is recorded frequently, no specific work is in progress on this pest.

Agronomy

In addition to the wheat improvement program, several other projects work on agronomic aspects. Under the wheat program, major emphasis is placed on evaluation of varieties in advanced stages of testing for stability of performance over a wide range of cultural variables such as date of sowing and fertilizer and irrigation levels; Any specific responses of the new varieties to these variables are investigated. Table 3 summarizes the average performance of wheat genotypes over three years of multi-locational testing in the Central and Peninsular Zones. More details of specific recommendations are given under production technologies for the hot regions.

As shown in Table 3, yield levels in the central zone are higher at all levels of agronomic variables as compared to the Peninsular Zone, primarily due to the relatively shorter duration in the Peninsular Zone.

Table 3. Response of Indian wheats for hotter environments to selected agronomic variables.

		Yield (t/ha)	
Variable	Date/rate/level	Central Zone	Peninsular Zone
Date of sowing	End October (E)	4.23	3.70
	Mid-November (N)	4.59	3.95
	Mid-December (L)	3.35	3.37
Fertilizer rates	0N:0P:0K	2.62	1.76
	40N:20P:14K	3.42	3.00
	80N:40P:27K	4.05	3.98
	120N:60P:40K	4.42	4.12
Irrigation levels	One irrigation	2.86	1.87
	Two irrigations	3.37	2.58
	Full irrigation	4.67	3.98

Production Technology

As indicated earlier, wheat in India is exposed to damage from hot temperatures throughout the country. The greatest risk of damage is in the drier areas where temperatures remain warm and the duration for wheat growth is rather short. Such areas even include some high productivity regions, e.g., parts of Haryana, Rajasthan, and Punjab in the North Western Plains Zone. The situation is more acute in the Central Zone consisting of Madhya Pradesh and Gujarat and the Peninsular Zone made up of Maharashtra, Karnataka, and other southern states, and there are certain special recommendations.

Improved varieties

There is a large range of improved varieties being sown under the various cultural situations in the two hot dry zones (Table 4).

Date of sowing

Mid-November is the optimum (timely) sowing time for the normal-sown crop, while late-sown varieties are seeded in the first half of December. Under rainfed conditions, the optimum time of sowing is late October.

Seed rate

In the Central Zone, the seed rate is 100 kg/ha while in the Peninsular Zone where the temperatures remain relatively warmer, it is 125 kg/ha. For late-sown crops, the seed rate is increased by 25%.

Table 4. Improved varieties recommended for the hot, dry regions of India.

	Central Zone		Peninsular Zone	
Cultural situation	**BW**	**DW**	**BW**	**DW**
Irrigated, timely-sown	LOK 1 WH 147 HD 2236 HI 1077 GW 190	HI 8381	HD 2189 DWR 39 HD 2380 MACS 2496 DWR 162	HD 4502
Irrigated, late-sown	LOK 1 J 405 Sawati HD 2327 GW 173		HI 977 HD 2501	
Rainfed, timely-sown	C306 Sujata Harbada 4 Hyb 65 Mukta	JU 12 Machdoot A 9-30-1	NI 5439	N 59 Bijaga Yellow MACS 1967
Salt-affected soils	WH 157 KRL 1-4 Raj 3077			

BW = bread wheat, DW = durum wheat.

For rainfed crops, the seed rate is similar to the irrigated crop although in areas with extreme moisture stress, the seed rate is reduced to 75 kg/ha. These rates are valid for varieties with 1000-grain weights of around 38 g; when using varieties with different grain weights, adjustments must be made.

Row spacing

Row spacings of 20 to 25 cm for timely-sown crops and 15-18 cm for the late-sown crops are recommended. Crisscross sowing with row spacings of 22.5 cm is also recommended for late-sown crops. In rainfed conditions, the recommended spacing is 25-30 cm.

Irrigation schedule

Six irrigations at various crop growth stages, i.e., crown root initiation, tiller completion, late jointing, flowering, milk, and dough, are recommended. In the Central Zone, particularly in fields with lighter soils, more than the above number of irrigations is required and it may go up to 8-12.

Fertilizer application

Recommended blanket rates for the normal-sown irrigated crops are 80-100 kg N/ha nitrogen and 40-60 kg P/ha, depending upon cropping sequence and soil fertility levels. Lower N doses are used when the previous crop was a legume. Potash application is advised when soil test results show low levels.

Under the late-sown conditions, relatively lower doses of fertilization are recommended. Under rainfed conditions, 40 kg N/ha and 20 kg P/ha are recommended.

Disease control

Chemical control of the rusts is not recommended because the latest varieties are always resistant. To control foot rot, treatment with MEMC at 2 g/kg of seed or Brassical at 3 g/kg of seed is recommended.

Insect control

With the exception of termites, there are no major insect pests in the region. For termite control, seed treatment with aldrin 30EC at 400 ml/kg of seed is recommended. In the case of soil application, BHC 10% or aldrin 5% dust at 25 kg/ha after final plowing is recommended.

Appendix—Wheat research centers in the hot, dry regions of India.

State	Center	Controlling authority	Research Disciplines
Central Zone			
Gujarat	Junagadh[a]	GAU	Breeding, Agronomy, Pathology
	Sonosra	Lok Bharti	Breeding
Madhya Predesh	Indore[a]	JNKVV	Breeding, Cytogenetics (Triticale center)
	Indore[b]	IARI	Breeding, Pathology, Agronomy, Physiology
	Jabalpur	JNKVV	Breeding
	Powarkheda[a]	JNKVV	Breeding, Pathology, Agronomy Physiology, Entomology, Quality (Center for rainfed wheat)
	Sagar[a]	JNKVV	Breeding
	Bilaspur[a,b]	JNKVV	Breeding, Agronomy (Center for non tradition wheat areas).
Rajasthan	Kota[a]	SU	Breeding, Agronomy, Pathology, Quality, Entomology (Center for durum wheat)
	Udaipur[a]	SU	Agronomy
Peninsular Zone			
Karnataka	Dharwad[a]	UAS	Breeding, Genetics, Agronomy, Pathology, Quality
	Ugar[a]	UAS	Breeding
Maharashtra	Mahableshwar[a]	MPKV	Genetics, Pathology (Rust Testing Laboratory)
	Pune[a]	MACS	Breeding, Genetics, Pathology (Center for durum wheat)
	Niphad[a]	MPKV	Breeding, Agronomy, Pathology, Physiology, Quality
	Parbhani	MKV	Breeding
	Akola	PKV	Breeding, Agronomy, Pathology, Physiology, Quality
	Washim	PKV	Breeding
Tamil Nadu	Coimbatore[a]	TNAU	Breeding, Agronomy

[a] Center with components financed through AICWIP.
[b] Zonal Coordination Center.

Breeding Strategies for Improving Wheat in Heat-Stressed Environments

G. Ortiz Ferrara
CIMMYT/ICARDA, Aleppo, Syria
S. Rajaram
CIMMYT, Mexico
M.G. Mosaad
ICARDA, Aleppo, Syria

Abstract

Wheat has the largest cultivation area among crop plants. Traditionally, wheat has been grown at low latitudes only in high-altitude (>1000 m) environments (e.g., central Mexico, Ecuador, Kenya). During the last several years, there has been interest in wheat as an irrigated winter crop in tropical environments. Terminal heat stress is a common abiotic factor responsible for reducing yields in certain areas of West Asia and North Africa. There is a need to identify heat-tolerant germplasm and suitable agronomic practices for those stressed areas. This paper describes two current breeding strategies for improving wheat in heat-stressed environments. We discuss the genetic variability for heat tolerance, update the progress that has been made in breeding for tolerance to this abiotic stress, and point out some of the current empirical and analytical criteria being applied in the CIMMYT and CIMMYT/ICARDA wheat breeding programs.

Introduction

In wheat as in most field crops, progress has been made toward controlling environmental factors such as pH and soil fertility, pests and diseases, and to some extent water supply. Air temperature, however, is virtually impossible to regulate. Accordingly, stability for temperature differences must be incorporated genetically. In the field, effects of high temperature are often confounded by the effects of drought stress. It is well established that temperature affects rate of development as well as grain production characters of wheat (Evans and Wardlaw 1976, Feyerhem and Paulsen 1981). There are numerous reviews in the literature about how temperature affects different wheat characters and how the effects differ from one phenological stage to another (Geisler 1983, Fischer 1985).

The physiological relationships involved are complex, as are the combinations of genes for heat tolerance that must be added to the genes necessary for superior performance. Breeders must evaluate an enormous number of genotypes because the discovery of a plant with all the required genes is highly improbable. In fact, wheat varieties have been developed with tolerance to abiotic stresses, including heat, for many decades without a full awareness of the selective effects of the environments where the selections took place.

Although physiologists have demonstrated implicit correlation between heat tolerance and some associated traits (Acevedo et al. 1991, Fischer 1989), no precise and efficient tools are available for differentiation of specific variability, and, unfortunately, most plant selection and progeny testing are still

done empirically under natural field environments (Curtis 1991). The purposes of this paper are to present CIMMYT's and CIMMYT/ICARDA's breeding strategies to identify heat stress-tolerant germplasm, point out some of the current empirical and analytical criteria being applied, and to update the progress that has been made in breeding for this abiotic stress factor.

Breeding Strategies for Heat Stress Tolerance

Breeding for high temperature tolerance has been discussed elsewhere (Curtis 1991, Ortiz Ferrara et al. 1991, Nachit and Ketata 1991, Rajaram 1988, and Mann 1989). The international breeding program of CIMMYT uses two locations in Mexico for the evaluation of heat-tolerant material: Ciudad Obregon, Sonora (27° N, 39 masl), an irrigated desert environment, and Poza Rica (21° N, 60 masl), a humid tropical lowland site. Relevant nurseries at Ciudad Obregon are planted at the end of January instead of the optimum time during mid-November to ensure that flowering and grain-filling take place under high temperatures. This strategy is presented in Table 1, where the long-term average temperatures from November through May are shown. At Poza Rica, temperature stress occurs from the early growth stage through maturity. In addition, CIMMYT depends heavily on multilocational international testing and shuttle breeding to develop suitable germplasm. The segregating generations are shuttled between Mexico and cooperators in

Table 1. Long-term (1980-89), average maximum and minimum monthly temperatures (°C) in Wad Medani (Sudan), Obregon (Mexico), and Tel Hadya (Syria).

Location	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
Wad Medani					LP								
		NP											
Max.	38.3	37.3	33.7	32.5	34.3	37.8	38.2						
Min.	22.4	19.7	15.5	13.4	15.5	19.3	19.7						
Mean	30.3	28.5	24.6	22.9	24.9	28.5	28.9						
Obregon						LP							
			NP										
Max.	29.4	25.2	24.2	25.8	27.2	31.4	34.0	35.3					
Min.	12.6	9.6	8.7	9.0	9.6	12.9	16.0	17.3					
Mean	21.0	17.4	16.4	17.4	18.4	22.1	25.0	26.3					
Tel Hadya								LP				SP	
				NP									
Max.	27.4	18.8	12.8	11.0	13.2	17.4	24.8	29.1	33.9	36.6	36.8	34.4	27.4
Min.	11.8	6.5	2.7	1.5	2.0	4.4	8.8	12.1	17.1	20.7	21.0	17.3	11.8
Mean	19.6	12.7	7.8	6.3	7.6	10.9	16.8	20.6	25.5	28.7	28.9	25.8	19.6

NP = Normal planting; LP = Late planting; SP = Summer planting.

South America and Asia for selection of materials under high temperature conditions. Stability of performance under different high temperature environments is one of CIMMYT's most important breeding criteria. Table 2 lists the average yields of nine varieties from the 23rd International Spring Wheat Yield Nursery (ISWYN) (Rajaram et al. 1989) involving 10 tropical and near tropical environments. The yields ranged from 2679 kg/ha for HUW 206 (an Indian selection from Veery 7) to 2420 kg/ha for Pavon 76. The yield performances of these varieties were statistically the same; however, their stability performances (Table 2) are different, as determined by regression parameters. The varieties HUW 206, Genaro 81, Ocepar 7, and Ures 81 were found to be less than 1 and hence more adapted to warmer areas.

Table 2. Average yield (kg/ha) and stability parameters of nine varieties over 10 high temperature environments[a]; results of 23rd ISWYN.

Variety	Average yield	Correlation coefficient (r)	Regression coefficient (b)
HUW 206	2679	0.938	0.970
SERI 82	2612	0.907	1.138
GENARO 81	2586	0.856	0.807
NS51. 28	2576	0.948	1.099
OCEPAR 7	2566	0.941	0.911
URES 81	2515	0.900	0.937
WL2265	2508	0.895	1.036
PJB 81	2489	0.838	1.098
PAVON 76	2420	0.940	1.090

[a] Locations and latitudes: Gezira, Sudan (14°24'N); Joydebpur, Bangladesh (23°46'N); Sagaing, Myanmar (22°2'N); Bhairahawa, Nepal (27°6'N); Taichung, Taiwan (26°57'N); Chiang Mai, Thailand (19°57'N); Riyadh, Saudi Arabia (24°20'N); Brasilia, Brazil (15°35'S); Campinas, Brazil (22°53'S); and Itapua, Paraguay (27°17'S).

It would be interesting to study the physiological basis of these varieties to find their mechanism for heat tolerance. The Veery class of varieties (HUW 206, Genaro 81, Ures 81, Seri 92) has been recommended in tropical areas of the world including Myanmar, Bangladesh, Paraguay, eastern India, southern Pakistan, and Guatemala. This adaptability pattern is presumably a factor in the stability of these varieties under high temperatures.

Heat tolerance is an essential characteristic of wheats grown in certain areas of West Asia and North Africa. In selecting and testing for this characteristic, the CIMMYT/ICARDA spring bread wheat breeding program at ICARDA in Aleppo, Syria, uses multilocation testing as a basic methodology. The hub of this screening program is Tel Hadya, Syria, where planting of heat-tolerant nurseries is advanced or delayed to allow high temperature stresses to affect the germplasm during different critical stages of development.

The long-term (1980-89) average maximum and minimum monthly temperatures at Tel Hadya are also shown in Table 1. Traditionally, wheat is planted in this area during November and harvested in May. Screening for heat tolerance is done at two stages:

- Terminal heat stress (THS), where the planting date is delayed until early April. This exposes the germplasm to high temperatures during the reproductive phase.

- Early heat stress (EHS), where planting is done in the summer. This exposes the germplasm to heat stress during the vegetative and part of the reproductive stages.

In both stages of screening, supplementary irrigation and optimum fertilization are used in order to minimize the effect of drought or soil fertility. Table 1 also presents the long-term maximum and minimum temperatures during the wheat growing season of Wad Medani, Sudan, a location at 14°N latitude where heat stress during the season causes substantial yield losses. Using three years' average data for days to heading and days to maturity from yield trials at Wad Medani and Tel Hadya, the crop duration in both cycles is found to be similar. Using these techniques, lines combining THS and EHS have been identified and distributed to high-temperature environments of the region where these characteristics are needed (Tables 3 and 4). A reasonable number of lines have been selected by national programs based on their yield superiority over the national check varieties (Table 3). This is a strong selection pressure considering that the national check is usually a widely grown improved variety at each specific location.

It is interesting to note the rather similar site grain yields between Tel Hadya-late, Sids-Egypt, Tel Hadya-Summer, and Wad Medani-Sudan (Table 4). Selecting under severe heat stress has allowed the program to discard highly vernalization-sensitive genotypes that cannot perform well under high temperature environments.

Table 5 shows four selection environments used by the CIMMYT/ICARDA breeding program. These environments are highly variable in terms of temperature and daylength. By shifting segregating generations and selecting germplasm under this range of environments, the program has identified germplasm with low sensitivity to vernalization and photoperiod. Recent studies on vernalization and photoperiod carried out by the program have confirmed these results (Ortiz Ferrara et al. 1993).

Table 3. Mean yield (kg/ha) of the top yielding entry (TYE) in comparison to the national check (NC) varieties in 10 high-temperature environments, RWYT-MRA 1989-90.

Location/Country	TYE	NC	%>NC	SEL	Lat.
Doha, Qatar	6153	5300	116	3	25°N
Riyadh, S. Arabia	4622	3840	120	12	24°N
T. Hadya-late, Syria	2860	1880	152	7	36°N
Al-Ain, U.A.E.	5667	5044	112	9	24°N
Shandaweel, Egypt	7378	6200	119	5	26°N
Mataana, Egypt	6222	5056	123	9	24°N
Dinajpur, Bangladesh	4361	4306	101	2	25°N
Pantnagar, India	6867	5967	115	7	29°N
Wad Medani, Sudan	1775	1250	142	3	14°N
Hudeiba, Sudan	5133	4778	107	2	17°N
Mean	5103	4362	120	6	

SEL = No. of entries higher yielding (P=0.05, 1-sided test) than the national check.

Selection Criteria for Heat Stress Tolerance

Extensive literature supports the use of the empirical (final grain yield) and/or the analytical (morphophysiological yield-related traits) criteria when breeding for heat and other abiotic stresses.

Empirical selection

It is absolutely clear that high temperature stress indirectly reduces yield by directly affecting various yield components. Hence, grain yield as a selection criterion for heat stress remains the most reliable yardstick. However, at the segregating population level, yield cannot be deployed as a salient criterion because it would involve harvesting, threshing, and weighing a large, unmanageable number of lines. It is desirable to use those components and characters that collectively are expected to impart heat tolerance. Based on the experience of the CIMMYT and the CIMMYT/ICARDA Wheat Programs, it is suggested that a combination of empirical observations and quantitative measurements might be the best route for selecting bread wheats that are tolerant to heat stress. When thousands of lines are deployed in segregating populations, an experienced plant breeder can make relatively subjective judgements on biomass, number of spikes, tillering capacity, stand establishment, leaf senescence, and grain-filling period. This involves using a standard check variety for comparison within the framework of an efficient experimental design. This empirical judgement should be supported by properly analyzed yield trials and quantitative measurements to support the associations of characters involved in heat stress tolerance.

Table 4. Mean grain yield of 24 bread wheat genotypes in eight heat-stressed environments. Regional Heat Tolerance Yield Trial (RHTYT) 1991-92.

Environments	Yield (kg/ha)	Latitude	Coolest month mean temp. (°C)
Riyadh, S. Arabia	6543 a	24°N	15.0 W
Shandaweel, Egypt	5283 b	26°N	14.2 W
Mataana, Egypt	4550 c	24°N	15.2 W
Shendi, Sudan	3987 c	16°N	19.4 H
TH-Late, Syria	2600 d	36°N	16.8 W
Sids, Egypt	2321 d	29°N	14.0 W
TH-Summer, Syria	2142 d	36°N	25.5 VH
Wad Medani, Sudan	2077 d	14°N	24.6 VH
Mean	3687		

W = warm, H = hot, VH = very hot (Fischer, 1985); TH = Tel Hadya.

It is obvious that yield components and many morphological and physiological characters are affected when exposed to high temperatures, nonetheless, the overall effects can be measured by quantifying yield reduction.

This approach is currently used by some national (Tandon 1985), and international (Villareal et al. 1985, Ortiz Ferrara et al. 1989) breeding programs in the world. As mentioned before, Table 1 describes the current field techniques used by the national breeding program of Sudan and in the CIMMYT and the CIMMYT/ICARDA breeding programs to identify heat tolerant germplasm. By delaying planting dates, the crop is exposed to high temperatures during critical stages of plant development. The results of testing under such a technique at CIMMYT are presented in Table 6. These varieties were planted in the Yaqui Valley of northwestern Mexico at the optimum time (November) and late (January). Planting in November results in a crop growth period of 5 months with flowering occurring in early February when temperatures are still cool. The late planting after January 20 results in flowering during late March when temperatures are hot. The November-planted wheats mature in mid-April, while the January-planted crops reach physiological maturity in mid-May. In general, late-planted wheats in the Yaqui Valley have continuous exposure to high temperatures, especially at the critical stages of flowering and grain-filling.

Table 5. Long-term (1980-1989) mean maximum and minimum temperatures (°C), and day length in four different selection environments in Syria and Sudan.

Environment	Planting date	Day length (hrs)	Temperature Max.	Min.
TH-Summer	15/06	15.5	33.9	17.1
TH-Late	1/04	14.0	24.8	8.8
TH-Normal	15/11	11.1	18.8	6.5
Wad Medani (Sudan)	25/10	12.2	37.3	19.7

TH = Tel Hadya, Syria.

Because of these temperature variations, experiments can be designed to measure the yield reduction from early to late planting. The reduction is mainly due to high temperatures, especially if diseases are controlled and other agronomic inputs are the same. The results in Table 6 clearly establish that some genotypes are more superior under high temperature environments than others.

Analytical selection

The utility of particular traits as selection criteria in a breeding program will depend upon the ease and cost of screening as well as upon the amount of genetic variability available for that trait. During the search for traits, it is important to study as many genotypes as possible.The use of at least 12 genotypes, or more if possible, has been suggested to address the expected genetic variation for that trait, since empirical studies with two or three genotypes quite often lead to erroneous conclusions.

In their work on tolerance to high temperatures, CIMMYT breeders utilize data of the following characters: enhanced stand establishment, good tillering, delayed leaf senescence, grain plumpness/high test weight, good spike fertility, medium maturity, accelerated grain-filling period, and high biomass. Both genetic variability and empirical selection procedures are available for these characters.

To maintain tillering and biomass and to alleviate the negative effects of high temperature, it is necessary to seek mechanisms that reduce the acceleration of the plant's development (Fischer 1989). Midmore et al. (1982) pointed out that moderate vernalization and photoperiod sensitivity would achieve this. This led to more biomass at anthesis in their studies, but no more grain/m² because partitioning to the spikes was poor and anthesis occurred under hot conditions (Midmore et al. 1982). There is evidence that high temperature before anthesis reduces floret fertility and that varieties differ substantially in this response; many varieties have good fertility at high temperatures. CIMMYT's experience is very notable in this regard. Remarkable variability in spike fertility has been observed in segregating populations.

In general, leaf senescence is also accelerated by high temperature. The lines derived from spring x winter are very notable in this variability.

The senior author of this paper conducted an experiment to study the association of 11 morphophysiological traits with grain yield under heat-stressed field conditions. Table 7 shows the correlation coefficients for each of these traits. Erect growth habit, low-medium seedling vigor, increased leaf rolling, delayed senescence, medium to tall plants, early maturity, and 1000-grain weight play an important role under heat stress.

Table 7 also shows the amount of genetic variability for the 11 traits tested under heat stress. Sufficient variability exists for all these traits to warrant selection in both advanced and early segregating generations.

Conclusions

High temperature stress indirectly reduces yield by directly affecting various yield components. Hence, yield as a criterion to select against heat stress, especially in yield trials, remains the most reliable criterion. It is desirable to use those components and traits that collectively are expected to impart heat tolerance. Based on the experience of the CIMMYT and CIMMYT/ICARDA wheat programs, it is suggested that a combination of empirical observations and quantitative measurements might be the best route for selecting wheats that are tolerant to heat stress.

Table 6. List of varieties and advanced lines and their relative yield responses (kg/ha) when tested in Yaqui Valley, Sonora, Mexico, in 1989 after optimum (November) and late (January) planting.

Variety	Optimum planting	Late planting (high temperature)	Percent reduction in yield
FALKE	6264	3658	42
CNO79*2/PRL	6115	2980	52
URES*2/PRL	5672	3816	33
PFAU'S'/VEE5'S'	5502	4158	25
JUP/BJY	5031	4820	5
KAUZ	6179	4050	35
SERI 82	5531	3206	43

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Table 7. Genetic variability and correlation coefficients between grain yield and 11 agronomic traits under heat stress.

Trait	Correlation Coefficient	Mean (Range)	S.E.
Growth habit	-0.60**	2.79 (1.0-5.0)	0.90
Seedling vigor	-0.38**	3.01 (1.0-4.0)	0.61
Leaf rolling	0.34**	2.79 (1.5-5.0)	0.86
Leaf temperature	-0.04	29.4 (27-32.4)	1.43
Leaf senescence	-0.53**	2.68 (1.0-5.0)	0.82
Peduncle length	0.21	18.7 (13-25.5)	2.71
Plant height	0.36**	51.3 (42.5-60)	4.12
Tiller number	0.15	168 (118-218)	22.90
1000-kernel weight	0.53**	24.5 (19.2-32)	2.42
Days to heading	-0.55**	53.9 (29-64)	4.24
Days to maturity	-0.65**	85.0 (76-91)	3.06
Grain yield	1.00	1308 (521-2083)	398.00

N = 84; ** = P<0.01; S.E. = Standard error.

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Questions/Discussion

Dr. Ortiz Ferrara was asked if different locations could be used to test for heat stress rather than different sowing dates. He agreed with this idea provided the different environments offered the heat stress at the particular growth period(s) required and had contrasting day lengths. A question was raised in relation to satisfying a vernalization requirement in Sudan where the minimum temperatures rarely go below 12°C in the coolest month. Dr. Ortiz Ferrara commented that it is well documented in the literature that temperatures of 13°C can vernalize true spring-type wheats although the optimum temperatures for vernalization are between 2-8°C.

There was a comment that all the data shown involved advanced lines and no heat tolerance testing appeared to be conducted on segregating lines. Dr. Ortiz Ferrara explained that the CIMMYT/ICARDA program had been exposing early generations to various heat stresses for the last seven-eight years.

Breeding Strategy for Developing Heat-Tolerant Wheat Varieties Adapted to Upper Egypt and Sudan

A.M. AbdElShafi Ali
Wheat Research Department, ARC, Giza, Egypt
O.A.A. Ageeb
ARC, Wad Medani, Sudan

Abstract

Following multilocational testing over the years, the Wheat Research Department released two bread wheat varieties (Giza 160 and 164) tolerant to heat stress. The results of 27 micro- and macro-yield trials indicated that the new variety Giza 160 had an average yield superiority of 4 and 11% over recommended varieties Giza 155 and Giza 157, respectively. Giza 164 outyielded the check variety Sakha 69 by 6% in 85 micro- and macro-trials in Upper Egypt. A field screening technique (based on different planting times at different locations) of durum and bread wheat germplasm has been designed for the identification of heat tolerant lines. Regression analysis, as well as grain yield per se, indicated that Giza 164 is the best adapted genotype for heat stress conditions in Upper Egypt. Introduced materials from CIMMYT were tested at Mataana Research Station in 1991-92; Debeira, Bacanora 88, Genaro 81, Fang 60, and Pavon 76 produced the highest grain yield. The reported studies indicated that multilocation testing, creating heat stress environments by using different planting times and continuous regional activities between countries having similar environments are an efficient screening for heat stress.

Introduction

High temperature, especially during grain-filling, is considered the major environmental factor drastically reducing wheat production in Upper Egypt, where about 17-25% of the total wheat area in Egypt (760,000 ha) is grown. A further constraint facing wheat production over the last five years is the expansion of wheat area (66,000 ha) into marginal conditions of low soil fertility and desert climate.

In central Sudan, the delay of wheat sowing by up to one month is common due to the difficulties in cultivation of the large area (252,000 ha) by contract machinery (Ishag and Taha 1991). Consequently, much of this area suffers from late heat stress resulting in yield reductions. Therefore, developing high yielding wheat varieties tolerant to heat stress is a very important objective to increase wheat productivity, especially in the Upper Egypt region and Sudan. High yielding ability under heat stress could result from escape by selection for early maturing crops (Sullivan and Jordan 1991). Fischer (1984) proposed that, to avoid high temperature at critical stages such as grain-filling, one should select seeding dates that ensure flowering at the coolest time during the growth cycle. Further, Nachit and Ketata (1986, 1991) and Ortiz Ferrara et al. (1989, 1991) conducted field research based on different planting times, which proved to be an efficient tool for evaluation of large number of lines or families under heat stress and a complement to multilocational testing.

The purpose of this study is to present our breeding strategies of the last decade to release wheat lines and varieties tolerant to late heat stress, and to measure growth, development, yield response, and stability of some wheat genotypes from the national programs of Egypt and Sudan and from international nurseries (CIMMYT) under different environmental conditions.

Hybridization and Selection

Giza 160 was selected from the local cross Chenab 70/Giza 155, made at the Giza Research Station in 1973-74. Chenab 70 was introduced from Pakistan, while Giza 155 is an Egyptian cultivar. The selection of the new cultivar was made through the pedigree method. In 1978-79, this variety entered evaluation for yielding ability in both micro (A+B) and macro (D) yield trials in the Research Stations and farmers' fields. Twenty-seven yield trials were conducted in Upper Egypt to compare Giza 160 with commercial varieties from 1978-79 to 1981-82. To release the new variety Giza 164 (Veery'S'), about 85 micro- and macro-yield trials were conducted in Upper Egypt from 1979-80 to 1986-87. As testing proceeded from micro- to macro-levels, the number of entries tested was reduced, while plot size and number of experiments increased to ensure selecting the most promising material and obtaining accurate data. This program is orientated towards overcoming the yield-limiting factors occurring in the Upper Egypt region.

In general, Giza 160 exceeded Giza 155 and Giza 157 in Upper Egypt in grain yield (average of 27 experiments) by 4 and 11%, respectively (Table 1). Some of the macro-yield trials (D) were tested at New Valley for heat tolerance evaluation over three seasons. It is medium in maturity and tolerant to rust with adaptability to growing conditions in the Upper Egypt region (Aswan, Qena, and New Valley Governorates). Table 2 shows the yield performance of the new variety Giza 164 (released in 1988) compared to the commercial wheat variety Sakha 69 in Upper Egypt. The results of 85 micro- and macro-yield trials from the 1979-80 through 1986-87 seasons indicated that Giza 164 outyielded Sakha 69 by about 6%. The results (Gomaa et al. 1988) indicated that Giza 164 is tolerant to the unfavorable conditions of Upper Egypt. Last year, Giza 164 and Giza 160 covered about 60% of the wheat growing area in Upper Egypt.

Table 1. Average grain yield (t/ha) of the new variety Giza 160 as compared with Giza 155 and Giza 157 in micro- (A and B) and macro- (D) yield trials in Upper Egypt in the 1978-79 through 1981-82 seasons (pooled from Gomaa et al. 1984).

Variety	A-yield trial	B-yield trial	D-yield trial
Giza 160	5.88 ab	5.25 b	5.79 b
Giza 155	5.46 b	5.38 b	5.30 c
Giza 157	5.51 a	4.54 c	5.04 c

Table 2. Yield performance (t/ha) of new variety Giza 164 and its yield percentage of Sakha 69 in Upper Egypt during the 1979-80 through 1986-87 seasons (pooled from Gomaa et al. 1988).

Yield Trial	N	Sakha 69 $\bar{X}$	Sakha 69 %	Giza 164 $\bar{X}$	Giza 164 %
A-yield trial	9	6.34	100	5.84	92
B-yield trial	21	5.45	100	5.80	106
D-yield trial	49	5.56	100	6.18	111
E-yield trial	6	5.29	100	5.69	107
Overall mean	85	5.60	100	5.94	106

Planting Date Testing

The use of different dates of planting allowed us to subject some promising wheat cultivars to late heat stress. Six wheat genotypes (Giza 160, Giza 164, and Sohag 3 from Egypt and Debeira, Condor, and El Nelain from Sudan) were tested at Shandaweel, Mataana, and Kom Ombo Research Stations, sown on 20 November and 25 December 1991. The same genotypes but including Sohag 1 were sown in Sudan (Shendi and Gezira Research Stations) on 23 November 1991. In this case, we considered the optimum sowing date in Sudan (23 November) as late planting for Upper Egypt.

A third experiment with 16 bread wheat genotypes from CIMMYT was sown at Mataana (25 December 1991) in Egypt and at Gezira Research Stations (23 November 1991) in Sudan. Data included yield, yield components, and some physiological and morphological characters.

The mean temperatures for the coolest month (January) were 11.4, 15.2, and 21.4°C for Assiut, Aswan, and Shendi, respectively, and 17.3, 20.6 and 27.3°C in March 1992 at the same locations. In May 1992, which is considered a very hot month in normal weather conditions in Upper Egypt, the average temperatures were mild with 26.6 and 30.7°C for both Assuit and Aswan Governorates, respectively. The difference between Aswan (Egypt) average temperature and Shendi (Sudan) was about +6.2 and +6.7°C in January and March, respectively. The data also showed that the average maximum and minimum temperatures during the 1991-92 season were lower than normal. This resulted in a relatively long winter season in both countries with the highest recorded average grain yield (5.64 t/ha) in Egypt and the highest total wheat production (0.87 million tons) in Sudan (AbdElShafi et al. 1992).

Late planting reduced grain yield on average by 1.2 t/ha or 19% in Upper Egypt experiments as compared with the optimum sowing date (Table 3). The greatest

Table 3. Grain yield (t/ha) at eight sites in Egypt and Sudan, 1991-92.

	Egypt									Sudan	
Variety	Shand. D_1	Mat. D_1	Kom Ombo D_1	$\bar{X}$ D_1	Shand. D_2	Mat. D_2	Kom Ombo D_2	$\bar{X}$ D_2	D_1-D_2 (%)	Gezira	Shendi
Giza 160	7.5	6.8	5.8	6.7	3.8	5.5	5.7	5.0	-25	5.1	3.5
Giza 164	6.8	6.9	5.2	6.3	4.9	5.8	5.2	5.3	-15	4.5	3.9
Sohag 3	6.3	7.7	5.3	6.5	5.2	6.3	4.7	5.4	-17	4.5	4.0
Debeira	7.7	6.9	5.2	6.6	3.6	6.3	5.3	5.1	-23	5.0	3.3
Condor	6.6	5.9	5.5	6.0	4.4	5.4	5.3	5.1	-16	4.7	3.6
El Nelain	7.4	6.7	4.6	6.2	4.0	6.8	5.7	5.5	11	4.9	3.6
Mean	7.1	6.8	5.3	6.4	4.3	6.0	5.3	5.2	-18.7	4.8	3.7
Se	0.7	0.5	0.4		0.5	0.9	0.6			0.7	0.8
CV %	10.3	8.0	8.4		11.6	14.9	10.4			14.5	22.6
LSD, 5%	1.1	0.8	0.7		0.8	1.4	0.8				

D_1 and D_2 were optimum and late plantings, 25 Nov. and 20 Dec.
Shand. = Shandaweel; Mat. = Mataana.

reduction was observed at Shandaweel, while it was least at Mataana Station. The reduction in grain yield by delayed sowing resulted from decreased duration of grain-filling particularly for late heading varieties (Debeira and Giza 160).

Stability parameters were also calculated to determine genotypes tolerant to heat stress. These stability parameters and mean grain yields of the six genotypes in eight environments (Table 4) indicate that El Nelain, Giza 160, and Giza 164 were the best adapted genotypes for heat stress conditions in Upper Egypt and north and central areas of Sudan. They possessed the most desirable combination of stability characteristics having almost the highest mean yields over all environments, regression coefficients equal to unity, and nonsignificant deviations from the regression (Eberhart and Russel 1966). Debeira responds to more favorable conditions and fertile soil, while Condor may tolerate late sowing and harsh conditions.

Research results from many sources indicate that no single criterion is adequate to predict plant response to heat stress.

Table 4. Mean grain yield and stability parameters of eight heat tolerance experiments including six genotypes at Shandaweel, Mataana, Kom Ombo, Gezira, and Shendi Research Stations, 1991-92 season.

Variety	Mean (t/ha)	Stability Parameters		
		b	S^2d	CD
Giza 160	5.46	1.10	0.08	0.91
Giza 164	5.39	0.86	-0.03	0.94
Sohag 3	5.49	0.89	0.32**	0.75
Debeira	5.42	1.28*	-0.03	0.97
Condor	5.18	0.74*	-0.04	0.92
El Nelain	5.47	1.13	0.10	0.90
Mean	5.40	1.00		

However, selection for genotypic improvement in stress resistance may be possible through the use of physiological, morphological, and phenological characters. Some measured parameters are shown in Table 5 as the mean values across three sites in Upper Egypt.

Late sowing significantly decreased the 1000-kernel weight of all varieties. Sohag 3 and Debeira exhibited the greatest stability in this character. El Nelain, at the opposite extreme, decreased in 1000-kernel weight by 18%.

Although the effect of late planting on spike population was not significant, there was a significant date x variety interaction. Debeira behaved totally different from the other varieties and increased the spike population at the late date by 12%.

Overall, late planting date did not significantly affect plant height, although the data show quite large differences. El Nelain increased plant height by 3% contrasting with Condor, which decreased 8%.

All six varieties behaved similarly with regard to the time from emergence to heading, reducing the period by approximately 11%.

Although differences were observed in these variables, they do not appear closely related to yield at the optimum date, yield at the late planting or the percent yield reductions (Table 3).

International Collaboration

An important development in the work to identify tolerance or resistance to heat stress has been the close cooperation of wheat breeders in the region and the international centers such as CIMMYT and ICARDA.

Through that cooperation, the national programs working towards the development of stress-tolerant cultivars will have access to genotypes that show clear differences in response to well defined environmental stresses.

The results from Egypt and Sudan of the Second International Heat Stress Genotype Experiment (IHSGE) are shown in Table 6. The highest yield in the Egypt experiment, sown at Mataana Research Station on 25 December, was attained by Debeira, Bacanora 88, Genaro 81, Pavon 76, and Fang 60, which outyielded the check variety Anza by 23 to 32%. However, at the Gezira experiment in Sudan, Debeira was the only genotype of the above group that was among the top yielders, along with Seri 82, Glennson, Nesser, and Anza. Grain yield at Gezira was about 33% less than in the Egypt. The period from emergence to heading was about 29 days longer at the Egyptian site with Sonora 64 the earliest and Bacanora 88 the latest heading line in both sites. Grain size differed little between the two countries.

The results at Mataana indicated that straw yield, plant height, plant population, and number of grains per spike may be useful selection parameters for terminal heat stress. The length of the period from emergence to heading, dry weight at anthesis, and percentage of groundcover at anthesis appear to be valuable selection criteria for early heat stress (Gezira experiment). Ortiz Ferrara et al. (1989, 1991) found similar results when screening genotypes under early and terminal heat stresses.

Conclusions and Recommendations

This paper summarizes field screening techniques that have been employed to develop and identify genotypes tolerant to late heat stress. The interactions between genotype and planting time were significant, indicating that the genotypes performed differently in the two environments generated by differential planting time or planting under different environmental conditions prevailing in the Nile Valley Region, suggesting that late

Table 5. The mean values across three sites in Upper Egypt for selected paramenters.

	Thousand kernel weight			Spikes/m²			Plant height (cm)			Heading date (days)			Mean Yield (t/ha)
	D_1	D_2	Change[a] (-%)	D_1	D_2	Change (-%)	D_1	D_2	Change (-%)	D_1	D_2	Change (-%)	D_1
Giza 160	42.3	35.6	15.8	627	575	8.3	104	104	0.0	102	91	10.7	6.7
Giza 164	42.6	36.9	13.4	535	536	0.0	113	112	1.4	110	97	11.8	6.3
Sohag 3	47.6	45.1	5.2	482	464	3.7	101	96	5.4	106	94	11.3	6.5
Debeira	39.2	36.8	6.2	506	568	+12.3	115	107	7.0	107	95	11.2	6.6
Condor	37.3	33.3	10.8	592	559	5.6	105	96	8.0	108	96	11.1	6.0
El Nelain	44.8	36.7	18.1	598	546	8.7	110	114	+3.3	102	90	11.8	6.2
Mean	42.3	37.4	11.6	556	541	2.7	108	105	2.8	106	94	11.3	
LSD 5%													
Date		0.9		NS			NS			1			
Variety		1.5		27			5.4			1			
Date x Variety		2.1		38			NS			NS			

[a] Change: $[(D_1-D_2)/D_1] \times 100$.

planting offers a means to select for terminal heat tolerance more efficiently than normal planting. Also, the techniques proved to be useful in identifying easily measurable traits associated with yield under heat stress. These traits could help the breeders in the selection process. Further, the results indicate that yield potential, stress tolerance, and yield stability can be successfully combined. Using these techniques, we are able to select varieties tolerant to heat stress in both countries, e.g., El Nelain, Giza 160, Giza 164, and Debeira. Therefore, we would encourage the network activities in heat stress to benefit from the different environmental conditions prevailing along the Nile Valley region and more close cooperation between wheat breeders in both countries and CIMMYT and ICARDA.

An additional future project should be to investigate wheat genotypes under conserved soil moisture surrounding Nasser Lake on the Egypt-Sudan border where high temperature and drought stress are associated.

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Table 6. Grain yield, 1000-Kwt, days to heading, and plant height in the 2nd International Heat Stress Genotype Experiment at Mataana in Egypt and Wad Medani in Sudan, 1991-92 season.

	Grain yield (t/ha)			1000-Kernel weight (g)			Heading (days)			Plant height (cm)		
Variety	Egypt	Sudan	x̄	Egypt	Sudan	x̄	Egypt	Sudan	x̄	Egypt	Sudan	x̄
Anza	6.9	5.3	6.1	33.6	34.9	34.2	91	57	74	90	74	82
Bacanora	8.8	4.8	6.8	40.4	39.0	39.7	92	67	79	96	77	86
Ciano 79	7.5	5.1	6.3	31.5	34.4	33.0	89	57	73	93	74	84
Debeira	9.1	5.5	7.3	39.0	39.6	39.3	86	66	76	97	85	91
Fang 60	8.5	4.6	6.6	39.6	38.9	39.3	85	55	70	111	88	100
Genaro 81	8.7	4.9	6.8	34.3	36.6	35.4	91	67	79	94	77	86
Glennson	7.1	5.6	6.3	35.2	39.3	37.3	94	63	78	105	84	95
IP4	3.9	3.7	3.8	40.4	39.3	39.8	85	57	71	107	91	99
Kanchan	5.6	4.2	4.9	45.1	42.5	43.8	91	56	69	108	84	96
Nacozari 76	7.1	4.5	5.8	34.8	236.8	35.8	84	52	68	96	77	86
Nesser	7.0	5.5	6.3	32.0	34.5	33.2	83	56	70	86	71	79
Pavon 76	8.5	5.1	6.8	35.6	39.2	37.4	89	62	76	104	83	93
Seri 82	6.7	5.7	6.2	36.3	40.2	38.2	91	62	76	94	82	88
Siete Cerros 66	7.1	4.5	5.8	35.2	37.0	36.1	89	54	72	105	79	92
Sonora 64	7.6	2.9	5.3	34.6	33.6	34.1	79	52	65	90	70	80
Trigo 3	1.4	2.9	2.2	36.6	33.5	35.1	82	43	68	130	109	119
Mean	7.0	4.7	5.8	36.5	37.4	37.0	87	58	73	100	82	91
S.E.	1.0	0.4	0.8	1.5	1.0	1.3	3	2	3	3	3	3
CV%	14.7	8.1	13.2	4.1	2.7	3.4	4	6	3	3	4	4
LSD 5%	1.7	0.6	0.9	2.5	1.7	1.5	5	3	3	6	6	4

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Questions/Discussion

In answer to a question regarding higher yield potentials in Egypt than Sudan, Dr. AbdElShafi explained the major differences between the two countries are in number of fertile spikes produced, number of grains per spike, and plant height.

Seven Years of Hot Climate Wheat Screening Nurseries: 1985-91

C.E. Mann
CIMMYT Southeast Asia Program, Bangkok, Thailand

Abstract

For seven years the Hot Climate Wheat Screening Nursery served as a supplement to CIMMYT international nurseries for exchange of wheat germplasm between breeders in hot environments. Even though testing was not the original objective, yields and frequencies of selected entries have identified suitable germplasm, useful countries of origin, and aspects for further development of heat-tolerant material.

Introduction

During a regional meeting of wheat breeders from Southeast Asia in 1984, it was felt that there was insufficient germplasm available adapted to hot climates. Breeding efforts for this mega-environment at CIMMYT were still at an early stage and selection methodologies for heat adaptation were not well developed at that time. The idea arose to complement CIMMYT's nurseries, which are backed by a strong breeding program, with a screening nursery that included superior varieties and lines from the (usually) small breeding programs in areas considered marginal for production due to heat. The CIMMYT regional wheat office for Southeast Asia was asked to collect suitable material worldwide, multiply seed, and assemble it into sets for distribution. Ben Ona from the University of the Philippines at Los Baños suggested the name "Hot Climate Wheat Screening Nursery" (HCWSN).

Letters requesting seed for multiplication went to breeders in hot environments who were known to receive CIMMYT international nurseries and some others. For all seven nurseries, there was an attempt to apply two conditions:

- There would be no selection during multiplication.
- In order to avoid duplication of original CIMMYT nurseries, submitted lines should be either non-CIMMYT crosses or selections from introduced segregating populations.

As such, the nursery was considered a platform for exchange rather than a means for testing germplasm. Its success depended completely on the inputs coming from the cooperators themselves. Nevertheless, data return was requested as a feedback for measuring the usefulness of the nursery. This paper extracts some of the useful information that came as a bonus to germplasm exchange, by looking at reports for the characters "yield" and "selected entries".

Germplasm and Data Return

Seed to be multiplied for the seven nurseries came from 20 different countries (Table 1). A number of entries were not submitted by a breeding institution in the country of origin; rather they were selected by the CIMMYT-Bangkok office for their potential

usefulness. The number of total entries varied over the years from 37 to 99 excluding recurrent checks.

Instead of looking at submitting countries, it is more interesting to look at where the respective crosses were made. Table 2 separates (to the best of our knowledge) the submitted entries into the following categories : 1) unknown, 2) CIMMYT advanced line, 3) CIMMYT F2 population, and 4) other origins. Ignoring the 1st HCWSN due to its quick start, 58 to 82% of the entries of the 2nd through 7th HCWSNs were in desired categories non-CIMMYT or introduced CIMMYT F2 for which the nursery was created. If duplications over the years are taken out, the average percentage of "desired" lines in HCWSNs 1 to 7 was 67 or just above two thirds.

Table 1. Number of submitted entries for 1st to 7th HCWSNs by country.

	HCWSN No.							
Country	1	2	3	4	5	6	7	Total
Argentina				1				1
Bangladesh	12	3	3	5		5		28
Bolivia					13		10	23
Brazil			8	3				11
China			7	6	2	4	6	25
Colombia							6	6
Guatemala							5	5
India		17		13			10	40
Indonesia					10			10
Madagascar				9	10		5	24
Mexico	2	20						22
Nepal			5	10	10			25
Pakistan	38	23	10	10	10			91
Philippines	1	10	5	16	3	3		38
Syria							1	1
Thailand	10	25	11	7	9	20	14	96
Vietnam							2	2
Yemen			4					4
Zambia			5	5	6			16
Zimbabwe				14		5		19
Total	63	98	58	99	73	37	59	487

Table 3 provides details of the other origins category, i.e., crosses made outside Mexico, by nursery. Table 4 summarizes the cross origins after duplications are removed.

Table 5 lists the number of sets shipped to cooperators and reports returned as well as the number of characters that were recorded on average in each HCWSN and the number of locations reporting yield and selected entries.

Methods

Cooperators were asked to provide optimum management for these nurseries. From casual observation and reports, it is clear that this did not always happen so that results reflect probably a cross section of stresses that occur in hot environments. Plot sizes varied around the recommended size of 1.25 m^2.

Table 6 lists stations reporting yield and selected entries and classifies them according to temperature and water pressure deficit in the coolest month following Fischer (1985). Most of this information was obtained from the CIAT Meteorological Database; some came directly from the stations.

Table 2. Origin of entries in the 1st to 7th HCWSNs.

	1	2	3	4	5	6	7	Total
Total	63	98	58	99	73	37	59	487
Unknown origin	4	8	7	3	13	2	12	49
CIMMYT line	38	38	9	28	17	7	17	154
CIMMYT F2 pop.	1	20	16	26	25	13	5	106
Other origin	20	32	26	42	18	15	25	178
% "desired" entries[a]	36	58	82	71	72	80	64	

[a] "CIMMYT F2 population" plus "Other origin" as % of "Total" minus "Unknown origin".

Table 3. Origin of non-CIMMYT crosses in 1st to 7th HCWSNs by nursery and country.

HCWSN No.													
1		2		3		4		5		6		7	
PAK	16	PAK	8	CHI	7	IND	12	BRA	5	ZIM	5	IND	9
IND	3	PHI	7	BRA	5	PAK	8	PAK	3	CHI	4	CHI	6
LEB	1	IND	3	PAK	5	CHI	6	IND	3	BAN	4	THA	4
		BRA	1	THA	4	ZIM	5	ZAM	3	PHI	1	VIE	2
				PHI	3	ZAM	4	CHI	2	THA	1	COL	2
				ZAM	1	PHI	3	PHI	1			PAK	1
				USA	1	NEP	3	ISR	1			SYR	1
						ARG	1						
Total	20		19		26		42		18		15		25

Country abbreviations:

ARG	Argentina	IND	India	SYR	Syria
BAN	Bangladesh	ISR	Israel	THA	Thailand
BRA	Brazil	LEB	Lebanon	USA	United States
CHI	China	NEP	Nepal	VIE	Vietnam
COL	Colombia	PAK	Pakistan	ZAM	Zambia
		PHI	Philippines	ZIM	Zimbabwe

Table 4. Summary of cross origins of 1st to 7th HCWSNs after removal of duplications.

Pakistan	31	Zimbabwe	10	Colombia	2	Unknown origin	57
India	25	Thailand	8	Argentina	1	CIMMYT line	122
China	25	Zambia	8	USA	1	CIMMYT F2 population	100
Phil-		Bangladesh	4	Syria	1	Other origin[a]	147
ippines	13	Nepal	3	Lebanon	1	Total	426
Brazil	11	Vietnam	2	Israel	1	% "desired" entries[b]	67

[a] Sum of columns 2, 4, and 6 of this table.
[b] See note Table 2.

Table 5. Distribution of 1st to 7th HCWSNs and data returned from cooperators.

HCWSN #	Sets shipped	Reports received	Mean number of recorded characters	Number of sites reporting		
				Yield	Selected entries	Both
1	?	6	5.5	5	4	4
2	?	16	5.6	9	12	5
3	36	24	5.5	13	17	9
4	46	22	5.8	15	14	9
5	44	25	7.0	16	18	9
6	40	17	6.3	9	15	7
7	36	9*	6.1	2	6	0
Total	202	119		69	86	43
Mean	40	17	6.0			

* Data return not complete.

Table 6. Locations reporting yield and selected entries in 1st to 7th HCWSNs.

Location			Class[a]	Reported HCWSN No.	Latitude	Longitude	Elev. (m)
Angola	Huambo	Chianga	W D	4 5 6	12 44 S	15 50 E	1700
Kenya	Rift Valley	Kajiado	H D	7			1650
Madagascar	Antsirabe	Fifamanor	W H	3 4 5	19 52 S	47 00 E	1650
Malawi	Lilongwe	Chitedze	W D	3 4 5	13 59 S	33 38 E	1097
Sudan	Gezira	Wad Medani	VH D	3 4 5 6	14 24 N	33 29 E	411
Uganda	Mbale	Buginyanya	H H	5	01 16 N	34 20 E	1875
Zaire	Butembo	Luofu	W H	5 7	00 37 S	29 06 E	1400
Zambia	Chilanga	Mt. Makulu	W D	3	15 32 S	28 15 E	1213
Zimbabwe	Harare	Causeway	W D	3	17 45 S	31 05 E	1506
Bangladesh	Chittagong	Hathazari	H D	2 3 5	22 30 N	91 47 E	13
Bangladesh	Pabna	Ishurdi	H D	2	24 00 N	89 16 E	2
Bangladesh	Jessore	Jessore	H D	1 5 6 7	23 11 N	89 14 E	7
Bangladesh	Dhaka	Joydebpur	H D	1 3 4 5 6	24 00 N	90 25 E	8
Bangladesh	Dinajpur	Nashipur	H D	6	25 38 N	88 41 E	39
Bangladesh	Dinajpur	Rajabari	H D	1 2 5	48 N	86 40 E	15
China	Yunnan	Dehong	W D	4 6	24 26 N	98 35 E	914
China	Guangdong	Guangzhou	W H	4 5	23 08 N	113 09 E	6
China	Guangxi	Nanning	W H	6	22 48 N	108 11 E	92
India	Karnataka	Dharwad	VH D	3 5	15 26 N	75 07 E	678
India	Madhya Pradesh	Indore	H D	5	22 37 N	75 50 E	557
India	Punjab	Ludhiana	W D	2	30 56 N	75 52 E	247
India	Karnataka	Ugar Sugar M.	VH D	2	15 26 N	75 07 E	570
Indonesia	West-Sumatra	Rambattan	H D	5	00 29 S	100 34 E	500
Indonesia	West-Sumatra	Sukarami	H H	2 4	00 55 S	100 35 E	930
Myanmar	Sagaing	Ye-U	H D	2	22 40 N	95 15 E	90
Myanmar	Sagaing	Zaloke	H D	2 3 5 6	22 O2 N	95 02 E	73
Nepal	Banke	Khajura	W D	2	28 05 N	81 38 W	100
Nepal	Rupandehi	Bairawa	W D	2 3 4 5 6 7	27 06 N	83 04 E	105
Pakistan	Punjab	Islamabad	C D	2 7	33 42 N	73 08 E	683
Pakistan	Sind	Tandojam	H D	2	25 02 N	63 38 E	19
Philippines	Ilocos Norte	Batac	VH H	4	18 03 N	120 53 E	4
Philippines	Ilocos Norte	Dingras	VH H	3 5 7	18 11 N	120 32 E	73
Philippines	Laguna	Los Baños	VH H	2 4	14 13 N	121 15 E	23
Thailand	Chiang Mai	Chiang Mai	H D	1	18 47 N	98 58 E	314
Thailand	Lampang	Lampang	H D	3 4 5	18 21 N	99 36 E	275
Thailand	Chiang Mai	Samoeng	W D	3 4 5 6	18 17 N	98 36 E	820
Thailand	Surin	Surin	VH H	3	14 52 N	103 28 E	123
Vietnam	Hau Giang	Can Tho	VH H	4	10 02 N	105 50 E	8
Vietnam	Hanoi	Dan Phuong	W H	6 7	21 05 N	105 38 E	10
Vietnam	Hanoi	Van Dien	W H	3	21 01 N	105 48 E	5
Yugoslavia	Croatia	Botinec	C ?	4	45 46 N	15 56 E	116
Qatar	Doha	Rawdat	W D	4 5 7	25 48 N	51 18 E	50
Syria	Aleppo	Tel Hadya	C D	5 6	36 05 N	36 55 E	284
Yemen	Taiz	Auseifera	?	4	13 36 N	43 55 E	1350
Yemen	Hadramout	Seiyun	?	3	16 N	52 E	600
Yemen	Tihama	Zabeed	VH D	3	14 24 N	44 23 E	250
Mexico	Sonora	Cd. Obregon	W D	2 3 4 6	27 20 N	109 54 W	38
Mexico	Edo. de Mexico	El Batan	W H	2	19 31 N	098 50 W	2249
Bolivia	Sta. Cruz	Saavedra	H D	3 4 5 6	17 14 S	63 10 W	320
Brazil	Sao Paulo	Campinas	W D	3 4	22 52 S	47 04 W	563
Brazil	Parana	Londrina	W H	1 3 4 5 6	23 22 S	51 10 W	585
Brazil	Parana	Palotina	W H	3 4	24 17 S	53 54 W	310
Ecuador	Pichincha	Sta. Catalina	W H	2 5 6 7	00 22 S	78 33 W	3050
Paraguay	Cordillera	Caacupe	W H	2 3 5 6	25 24 S	57 06 W	228
Paraguay	Itapua	Cap. Miranda	W H	5	27 17 S	55 49 W	105

[a] Classification according to Fischer (1985): C = Cool, D = Dry, H = Hot (first letter) or humid (second letter), VH = Very hot, W = Warm.

Analysis of variance was performed with yield data using each location as one replication. Analysis of variance was also performed separately for two subgroups of environments if at least three replications were available for each group (3rd through 6th HCWSNs). Subgroup one includes sites classified as hot or very hot; subgroup two includes sites classified as warm or cool.

To analyze selected entries, we counted how often each entry of an HCWSN was selected. Entries within HCWSNs were then grouped into three selection history types: 1) CIMMYT advanced line, 2) CIMMYT F2, and 3) others. Entries of unknown selection history were removed from this analysis. A chi-square test was performed to compare the selection frequency of each type based on its proportion of the total number of entries in the respective HCWSN with the actual count of hot plus very hot or warm plus cool locations. To be meaningful, only the 2nd, 4th and 5th HCWSNs were used where at least 10 entries of each selection history type were included and at least four sites for each environment type were reported.

Results and Discussion

Yield

There were significant differences between entries in the 3rd HCWSN and highly significant differences in all other HCWSNs. These are tabulated in Table 7 together with significances in the analyses of very hot plus hot and warm plus cool sites. The respective coefficients of variation are high in terms of normal yield trials ranging from 25 to 40%. However, this is no surprise when considering the plot size of the screening nursery and the differences between replications that are, in fact, differences between sites. Consequently, multiple range tests are of little help. For each HCWSN, mean ranks are presented over environments of the seven top yielding entries of each HCWSN with additional columns for their ranking in the separate analysis of very hot plus hot and warm plus cool environments where appropriate (Table 8). Comparing the ranks within rows helps to identify specific adaptation to heat as well as broad adaptation, which includes heat tolerance.

Table 8 shows the selection history and country of origin of the crosses. Overall, selection histories identified as "Others" and "CIMMYT F2" are represented about equally among the top yielding seven of the nurseries as are CIMMYT lines, which are generally known for broad adaptation. This is confirmed through results discussed later.

Crosses originating in Pakistan, Brazil, and Zambia appear more frequently in the upper third of entries than might be expected from their contributions of lines to the whole nursery over several years. The same is true for CIMMYT F2 populations that underwent selection in Nepal and Thailand. It might be useful to consider these countries as future sources of heat-tolerant germplasm.

Table 7. ANOVA results of 1st to 7th HCWSNs overall and separately for hot and very hot as well as warm and cool locations.

HCWSN #	Probability of F-test Overall	CV %	Probability of F-test Hot and very hot	Probability of F-test Warm and cool
1	0.00	32		
2	0.00	31		
3	0.05	40	0.18	0.10
4	0.00	32	0.01	0.01
5	0.00	40	0.00	0.26
6	0.00	32	0.01	0.01
7	0.01	25		

Table 8. Ranking and origin of five top yielding entries of 1st to 7th HCWSNs over all environments and in hot and warm environments.

HCWSN No.	Entry No.	Variety name	Cross origin[b]	Yield rank: Overall	Yield rank: Hot & v.hot	Yield rank: Warm & Cool
1	35	PUNJAB81	PAK	1		
	33	**MANT13**[a]	C	2		
	32	LYALLPUR73	CF2	3		
	20	MEISE	C	4		
	8	AZ//KAL/BB	C	5		
	46	M154	PAK	6		
	19	#1015	PAK	7		
2	70	THB	BRA	1		
	1	CMU10	C	2		
	69	IAS/ALD	C	3		
	2	KUHR7	C	4		
	11	SW29	C	5		
	9	#1015	PAK	6		
	74	PG780998	IND	7		
3	41	NR86III	C	1	29	3
	27	SW59	C	2	17	4
	42	NR86V	C	3	18	6
	21	FNBW74013-52	THA	4	2	23
	26	KUHR7	C	5	23	10
	29	BAW60	CF2	6	45	2
	1	B59	BRA	7	3	13
4	104	WSM287	IND	1	28	1
	11	SC84072-1H-1C	CF2	2	2	3
	63	SW57	C	3	4	9
	31	OC853	CF2	4	16	8
	20	Local Check		5	3	12
	13	SC84083-3H-1C	CF2	6	5	13
	98	NI5439	IND	7	1	35
5	21	KVZ/K4500.L..	C	1	9	1
	49	K7	ZAM	2	7	3
	46	H37	CF2	3	5	4
	20	Local Check		4	2	6
	14	CEP7593/CEP..	BRA	5	10	7
	68	CMU245	C	6	8	9
	47	H41	?	7	3	13
6	3	S85134-1H-0H..	ZIM	1	3	2
	17	KUHR6	C	2	5	3
	11	SMGBWS86706	CF2	3	1	11
	19	KUHR7	C	4	4	9
	20	Local Check		5	6	10
	27	C834-2	PHI	6	9	5
	12	SMGBWS86707	CF2	7	10	7
7	20	Local Check		1		
	22	ICTA MERINO	?	2		
	29	GLEN	C	3		
	2	BARKAT//BUC..	CF2	4		
	19	ICTA L129	?	5		
	42	SW114	?	6		
	18	ICTA L123	?	7		

Explanations:

[a] Bold face indicates selected in more than 30% of sites.

[b] Cross origins: ? = Unknown, BRA = Brazil, C = CIMMYT, CF2 = CIMMYT F2, IND = India, PAK = Pakistan, PHI = Philippines, ZAM = Zambia, ZIM = Zimbabwe.

Selected entries

As can be seen from Table 5, only 38% of the sites report both yield for all entries (not only the retained ones which were harvested) and "selected entries". Entries selected in 30% of the reporting sites or more are highlighted in bold faced in Table 8. A majority of these are also among the top yielding third of each HCWSN. All of these lines merit further consideration in hot climate wheat breeding programs.

It was hypothesized that warm and cool environments would select the same or a higher proportion of CIMMYT lines than their share in the total number of entries of this selection history type because this generation of CIMMYT material was not developed for heat tolerance. Vice versa, it was expected that an overproportional amount of CIMMYT F2s and other crosses would be selected in very hot and hot sites where most of them were developed. Observed and expected values (Table 9) followed this trend with two nonsignificant exceptions in the chi-square test. Two of the tests were highly significant. This weak confirmation of the hypothesis is attributed to the fact that 1) even CIMMYT lines were preselected for heat tolerance when they were submitted by cooperators, and 2) CIMMYT F2s and local crosses of cooperators are likely to have specific adaptation, which would hinder superiority in other environments.

Conclusions

The Hot Climate Wheat Screening Nurseries served the purpose of exchange of germplasm between breeders in marginal warm and hot areas as evidenced by the fact that many lines were retained by recipients.

Table 9. Chi-square tests for selected versus expected times of selections of entries with different selection history.

HCWSN No.		Total			V.hot & hot			Warm & cool		
		Oth.	CF2	C	Oth.	CF2	C	Oth.	CF2	C
2	Number of entries	32	20	38						
	Actual selections				14	16	30	27	23	63
	Expected selections				21	13	25	40	25	48
	Chi-square value				3.9	ns		9.4	**	
	Expected shift				no			yes		
4	Number of entries	42	26	28						
	Actual selections				22	25	8	88	44	48
	Expected selections				24	15	16	79	49	52
	Chi-square value				11.1	**		1.9	ns	
	Expected shift				yes			no		
5	Number of entries	18	25	17						
	Actual selections				26	25	16	35	56	39
	Expected selections				20	28	19	39	54	37
	Chi-square value				2.5	ns		0.6	ns	
	Expected shift				yes			yes		

Oth. = other crosses; CF2 = CIMMYT F2- derived line; C = CIMMYT cross.

Lines with heat adaptation over many sites have been identified and are listed for further use in crosses for heat tolerance.

There are indications that breeding for hot environments is more successful if conducted in target areas. Many of the suitable lines fall through the CIMMYT screen if handled in the traditional international nursery assembly and multiplication procedures in Mexico.

Reference

Fischer, R.A. 1985. Physiological limitations to producing wheat in semitropical and tropical environments and possible selection criteria. In pages 209-230, Wheats for More Tropical Environments. Mexico D.F.: CIMMYT.

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Development of Wheat Germplasm Tolerant to Heat Stress in Sudan

A.B. Elahmadi
Agricultural Research Corporation, Wad Medani, Sudan

Abstract

The majority of the area under wheat in Sudan is found in the central irrigated plains between 14-16°N. Heat stress is one of the main constraints of wheat production caused by high temperatures (monthly average of more than 25°C) at the beginning (Nov.) and end of the season (Feb.-March). Heat adversely affects spike and grain formation. The work reported here was directed towards early-season heat stress. The germplasm tested originated from visually selected (90-120) lines from introduced heat tolerance nurseries from ICARDA and CIMMYT and from advanced locally bred lines.

Heat stress is known to cause stunted plant growth, reduced tillering, and accelerated development and to lead to small heads, shrivelled grains, and low yields. By using some of these responses (days to heading and maturity, plant height, grain yield), we are attempting to find an easily observable character to help in screening for heat tolerance. The approach used was planting the germplasm under test with three to four check cultivars of known performance with respect to heat from two sowing dates. The results indicated large variation among lines. The performance of the checks was consistent in spite of different results obtained in different seasons. Days to heading seems to be the simplest character that holds promise to aid in screening for heat tolerance.

Introduction

Wheat (*Triticum aestivum* L.), although a temperate region crop, has been grown in Sudan from early times. It has been restricted to the banks of the Nile north of Khartoum and grown during the short cool season (Nov.-March). Baladi, the variety grown by farmers, was a mixture of cultivars. The sources of the components of the mixture are unknown, but they were probably introduced from Egypt at different times.

Introduction of wheat to other parts of the Sudan was first attempted in 1918 at Gezira. Due to low yields, it was soon abandoned as a crop there. Interest in wheat and wheat research resumed after World War II due to food shortages. Early breeding programs consisted of mass selection from within Baladi wheat and introductions. Early reports indicated that the introduced varieties were inferior to Baladi. By 1943, numerous variety trials had been summarized and the variety Hindi 62 from Egypt emerged as being superior to Baladi and recommended for distribution (Khalifa 1974). There was more emphasis on mass selection from the local varieties prior to 1958. After that, more weight was given to introductions, especially from international agencies (George 1958). Some of these introductions were included in trials during the 1958-59 season. From 1960 onwards, testing sites included locations in Gezira, Blue Nile Province, and even under rainfed conditions at Tozi. At Khashm El Girba, the wheat program was not initiated until 1963-64.

Increased production of wheat has been necessary for the following reasons:

- Food shortages became common after World War II;
- Emergence of food crops as strategic weapons in world politics;
- Growth of towns and cities;
- Food habit changes of a large sector of the population;
- Recent increases of wheat prices in world markets;
- Recent rise in the expense (fuel costs) of baking traditional sorghum bread (Kisra) at home compared to cheaper wheat bread from the bakeries.

Such factors made a wheat breeding program a necessity to maximize yield and to introduce wheat into new territories. The new areas that lie at hotter, lower latitudes brought breeding for heat tolerance to prominence among other objectives. This paper presents the efforts and approaches that may hold promise in breeding superior wheat cultivars for high-temperature regions.

The Environment

Defining the environment is important because it effects changes with the developmental phases of the plant. Fischer and Maurer (1976) found that the development of wheat was hastened by heat. Kirby (1974) stressed the synchronization effect of the terminal primordia on the development of the later-formed florets; thus hastening the development of the terminal primordia shortens time for the development of the later-formed ones. Fischer (1985) emphasized the effect of solar radiation and temperature on growth before anthesis. Rawson and Bagga (1979) found that there was progressive reduction in grain number for every day that the plants of two wheat cultivars remained at a higher temperature compared to a lower one.

About 85% of the wheat area in Sudan is found in the central irrigated plains (14-16°N). The soils are mostly black clay vertisols. The crop is adequately irrigated and fertilized. Relative humidity is generally low during the growing season. The crop is sown during November and harvested during March. The maximum and minimum temperatures for those months are shown in Table 1. Higher temperatures are experienced during the beginning and end of the season, coinciding with spike formation and grain-filling. The coolest months are December and January.

Selection Criteria

McWilliam (1980) stated that it is difficult to provide an adequate definition of heat stress in plants since their response depends on many factors including the species, duration of exposure to high temperature, and the growth stage. Fischer (1985) showed that it is difficult to separate the effect of heat stress from those imposed by moisture stress since both are confounded at elevated temperatures. Thus the situation seems to be very complex, but we neglect the effect of moisture stress assuming our plants are well watered and the whole response is caused by high temperature.

Table 1. Average monthly winter temperatures (°C) at Wad Medani, Sudan.

	1989-90		1990-91		1991-92	
	Min.	Max.	Min.	Max.	Min.	Max.
Oct.	22.7	38.6	23.3	39.6	13.3	34.4
Nov.	19.3	37.5	20.8	38.8	13.0	37.1
Dec.	14.4	32.2	19.2	37.4	13.3	32.5
Jan.	15.2	33.4	13.7	32.1	12.1	30.7
Feb.	14.3	31.1	15.6	35.7	11.8	30.4
Mar.	15.3	35.7	17.9	37.9	18.4	38.0

Many characters have been suggested as selection criteria for heat tolerance or avoidance, including morphological and chemical ones. Ehleringer (1980) gave an example of leaf pubescence and Mooney (1980) referred to high angled leaves as characters that reduce the adverse effect of heat stress. Teeri (1980) reported the effect of high temperature on some enzymes and Raison et al. (1980) suggested the disturbance of the membrane structure and function by heat. For the breeder who has to screen large populations visually, easily recognizable characters would be the best tools for selection. However, the correlations of such characters with a complex one like heat tolerance vary from one experiment to the other and hence are sometimes misleading.

As mentioned before, the Sudanese wheat season is very short and the crop has a duration of about 110 days between sowing and maturity. High temperatures are experienced at the beginning of the season (November) and at the end (February). Thus, breeding for earliness is a general requirement, but from experience, very early genotypes usually give low yields. Hence, breeding for heat tolerance at both extremes of plant development should allow extending the season for longer periods and increase the ceiling imposed on yield by the short season.

Sensitive cultivars when exposed to high temperatures exhibit stunted plant growth, low tillering, hastened developmental phases (heading and maturity), smaller heads (low number of grains/head), smaller grain size (shrivelling), and low grain yield.

In our breeding material and introductions, we have observed very large variability in the degree of response to heat stress with respect to each of the above characters. We acknowledge that there are some correlations among those characters and selecting for individual traits could be misleading. Again variations in temperature with season and their effect on the plant depending on its phase of growth make it more difficult to select for heat tolerance. In handling our breeding material, we usually select visually for desirable agronomic characters, which is an indirect way of screening for heat tolerance. However, yield performance determined by testing in comparative yield trials is the most reliable screening criterion.

Appropriate Germplasm

Screening for a character like heat tolerance in a species indigenous to temperate regions requires assembling of germplasm with a broad genetic base. CIMMYT and ICARDA have prepared nurseries targeted for this purpose for the last six years. Each year, we have received 200 to 250 accessions from the two Centers. These have been grown under normal season conditions at Gezira Research Farm and observations on some agronomic and yield data have been taken. On the basis of these data and visual appraisal, some lines have been selected for further evaluation.

The hybridization program emphasizes the use of the appropriate parents for heat stress tolerance. Adapted cultivars (released varieties) as well as genotypes known for their heat tolerance like Hindi 62 and Baladi are included in the crossing block. The segregants are handled using the pedigree and (sometimes) the modified bulk methods. The selected advanced lines are subjected for further evaluation.

Screening Approach

Johnson (1980) recognized the fact that breeders have to assess plant performance at the critical developmental phase, use small quantities of plant material, and screen large populations in a time-efficient manner. He

also regarded field performance as the standard to assess plant response under stress. Although field methods are prone to inconsistencies and are sometimes laborious, they are more accessible to us compared to controlled environment chambers or other physical or chemical analyses of the plant tissues.

Our efforts are directed towards the development of cultivars that tolerate early-season heat stress. Thus, planting in early November enables us to make use of the large supplies of available water and to plant the large areas with the available machinery in time.

The number of entries screened for heat tolerance in this manner varied from year to year (90 to 120). They comprised introductions and advanced lines as mentioned above. The lines were arranged in an augmented design with three or four checks. Plot size was two rows 5 m long and 20 cm apart. The experiment was planted on the first and third weeks of November. The two sowings were on adjacent plots and received similar cultural treatments. The first sowing date was exposed to greater early-season heat stress. Late-season temperatures were not considered. Observations on days to heading and maturity, plant height, and grain yield were taken.

Complete data (i.e., days to heading, plant height, and grain yield) were available for the 1989-90 and 1990-91 seasons. For the 1991-92 season, only days to heading and grain yield were available. Tables 2-4 present data from some representative lines showing the variability of the responses between the first sowing date (warmer) and the second one (cooler).

Table 2. The effect of early season heat stress on a selection of entries from the Heat Tolerance Experiment, Wad Medani, Sudan, 1989-90.

Genotype	Change in plant height (cm)	Change in days to heading	% change in yield
Ures'S'/Prl'S'	-10	-	-29
H37 = Pf7339/Hahn'S'	NA	-	+2
F5 WM 88-89 L3945	-	+7	-62
F5 WM 88-89 L3979	+5	-1	-52
F5 irrig. BW88-89 L4026	-	-1	-2
F5 irrig. BW88-89 L4064	-5	-2	+44
F6 WM 88-89 L4076	-	-4	+9
F8 WM 88-89 L4151	-	-2	-34
F6 Sudan 88-89 L4223	+5	-5	+64
F6 Sudan 88-89 L4235	+10	+1	+34
F6 Sudan 88-89 L4315	-10	-7	-75
F6 Sudan 88-89 L4326	-5	-13	-68
F6 Sudan 88-89 L4358	-5	-3	-74
F6 Sudan 88-89 L4374	-5	+1	-52
F6 Sudan 88-89 L4471	-5	-4	-25
F6 Sudan 88-89 L4540	-5	-1	+33
F6 Sudan 88-89 L4726	-	-	+50
Condor (check)	-1	-5	-13
Debeira (check)	-2	-3	-18
Giza 155 (check)	+6	-	+18

Results and Discussion

The temperature records for the three seasons were quite different, especially during the early season period under investigation (Table 1). The 1989-90 season could be considered as normal, while the 1990-91 season was warmer during the same period by 3-4°C and the 1991-92 season was cooler than normal by more than 5°C (compared to the long-term averages). These different conditions were reflected in the results.

In the 1989-90 season, more lines showed reduction in the early sowing for the three characters than those that benefitted from it (Table 2). In the 1990-91 season, there was a reduction in days to heading in early seeding in all the entries in this group of genotypes for this abnormally warm season (Table 3), although many lines increased in yield. For the abnormally cooler 1991-92 season (Table 4), the response to early planting was positive in almost all selected genotypes. There was an increase in days to heading and grain yield.

Over the years, the relative ranking of the three checks with respect to days to heading was consistent, irrespective of the direction and degree of change, the cultivar Giza always showing more tolerance, Debeira being intermediate while Condor was always the most sensitive to early planting.

Table 3. The effect of early season heat stress on a selection of entries from the Heat Tolerance Experiment, Wad Medani, Sudan, 1990-91.

	Change in plant Height (cm)	Change in days to heading	% change in yield
Buc'S'/Bjy'S'	-	-4	-30
Kauz'S'	-5	-13	-9
Kauz'S'	-10	-5	-61
Ures*2/Pr1'S'	-10	-14	+36
Genaro 81	-10	-14	+1
Tob'S'/8156//Y50/Kal*3/3/8311	-30	-18	-41
Son64/HO4//Rex/3/Edel/Mex	-15	-19	+292
K2-Psi 73280/ATR71/T3pp	+5	-12	+4
H37 = PF7339/Hahn'S'	+5	-9	+5
F5 WM 88-89 L3934	-5	-7	+2
F5 WM 88-89 L3972	-	-6	+33
F5 WM 88-89 L3974	+10	-9	+43
F5 WM 88-89 L3977	-15	-11	-52
F6 irrig. 88-89 L4025	-15	-11	-41
F6 irrig. 88-89 L4026	-5	-7	-50
F6 irrig. 88-89 L4151	+5	-1	+25
F8 dry 88-89 L4206	-20	-1	+143
H41	-	-13	+25
K12=Kvz//HD2009/3/Tob/Cno	-5	-8	-21
Condor (check)	-15	-13	-30
Debeira (check)	-13	-11	-19
Giza 155 (check)	-	-5	+15

The response to the early-season heat stress seems highly variable. The variations between seasons complicated the whole picture and of course affected the direction and degree of response. Since we collected data on different sets of genotypes for each season except the checks, we could not study the changes in the relative ranking of those genotypes by season.

Conclusion

It is important for the breeder to find an easily measurable character to be able to screen a large number of genotypes for a complex character like heat tolerance. The two simple characters, i.e., days to heading and plant height seem to hold promise, especially the first one. This character could be further refined or strengthened by laboratory growth analysis. If we are able to use such characters and approaches to screen for heat tolerance per se, the yield potential of the selected lines can be assessed by the comparative yield trials. Some of those lines might be recycled in the hybridization program if they showed heat tolerance, but low yield potential.

Table 4. The effect of early heat stress on a selection of entries from the Heat Tolerance Experiment, Wad Medani, Sudan, 1991-92.

Genotype	Change in days to heading	% change in grain yield
SMGBWS86702 = Amd'S'	-8	-9
SMGBWS86703 = Spn//...	-5	-20
Dove'S'/Inia/4/477(2)//...	-1	+33
Kasyon/Glen 81	+8	+50
Fet'S'/3/Gov/Az//Mus'S'	+3	+20
Vee'S'/Pjn'S'	+5	+114
Pf 72640/Pf7326//Pf7065...	+2	+4
Lira'S'//Au/Up 301	+6	+67
Gim'S'/Mr.Jail(17-08)-1Y-0B	+6	+25
Gim'S'/Mr.Jail(17-08)-3M-0Y	+9	+2
IAS58/4/Kal/BB//Cj...	+5	+84
Ald'S'/Cep 75630//Cep 75...	-	+118
F4 90-91 L2254	+2	+85
F6 90-91 L2639	+12	+400
F6 90-91 L2644	+13	+236
F6 90i-91 L2660	+14	+219
Condor (check)	-	+18
Debeira (check)	+4	+35
Giza 155 (check)	+14	+51

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Experience of the Sasakawa-Global 2000 Agricultural Project in Supporting Sudan's Wheat Production

J.A. Valencia
Sasakawa-Global 2000, Kano, Nigeria
N.C. Russell
International Center for Tropical Agriculture, Cali, Colombia
C.R. Dowswell
Sasakawa-Global 2000, Tepetlaoxtoc, Mexico

Abstract

This paper offers an account of the experience and accomplishments of the Sasakawa-Global 2000 Agricultural Project in Sudan. Between 1986 and 1992, project staff worked closely with the country's extension service within the Ministry of Agriculture to explore the possibilities for improving wheat production. The Program succeeded overwhelmingly in demonstrating the potential of extension officers for serving as agents of change in food production. It did so primarily by training and supporting them in the use of an effective tool for technology demonstration (i.e., the production test plot program). This experience, in turn, underscored the importance of establishing closer links between extension and research to ensure that innovations emerging from the agricultural sciences reach their intended beneficiaries in the countryside.

Introduction

The Sasakawa-Global 2000 Agricultural Project in Sudan is one of a half dozen such efforts in seven countries, established jointly by the Sasakawa Africa Association (SAA) and Global 2000, Inc. SAA was set up in 1986 by Ryoichi Sasakawa, Japanese philanthropist and chairman of the Sasakawa Foundation, and Global 2000 was created in the same year by Jimmy Carter, former president of the USA. Most of the funding for the projects has been provided by the Sasakawa Foundation. In Sudan, funds for an extension (from 1990 to 1992) were received from the Carter Center in Atlanta (where Global 2000 is based) and from the governments of Norway and Sweden.

The central aim of this and the other projects is to demonstrate the possibilities for improving food security in sub-Saharan Africa. In working toward this goal, these projects are under the overall guidance of Norman E. Borlaug, who received the 1970 Nobel Peace Prize for his pathfinding work in helping to revolutionize wheat production in Asia and Latin America.

The Choice of Sudan

Along with many other countries in sub-Saharan Africa, Sudan suffered from a severe famine during 1984, which across the region threatened some 20 million people with starvation. In Sudan alone thousands died, and many more crossed international borders and crowded into refugee camps in search of food, water, and shelter.

Although drought was the immediate cause of this calamity, the inability of African nations and international aid agencies to avert the consequences had less to do with natural disasters than with human failures. For years, Sudan and other countries in the region had neglected agriculture, investing relatively little in research, production inputs, rural infrastructure, and so forth and pursuing economic policies that were detrimental to the producers of food and export commodities. In Sudan, the government dealt with its growing food deficit largely by importing wheat, whose price to the consumer was kept low through a combination of food aid, overvalued currency, and direct subsidies. These factors, together with rapid urbanization, led to sharp growth in wheat consumption and a need for ever increasing imports to satisfy demand.

The short-sighted strategy of relying on wheat imports became difficult to maintain as Sudan's economic situation deteriorated throughout the 1980s. Much of its food aid dried up; inflation increased rapidly; and the country's external debt rose to about US$13 billion (163% of gross national product) by 1989. Efforts to deal with overall economic problems and with the worsening food situation were complicated by internal problems in the southern part of the country.

Even by 1986, it had become apparent that Sudan was badly in need of a demonstration that the key to alleviating its immediate problems with food security and eventually improving its economic performance lay to a large extent in greater support of agriculture, particularly food production.

What encouraged Global 2000 to go ahead with an agricultural project in this country was the ample evidence of its potential for producing enough food to satisfy domestic needs and regularly export substantial quantities to North Africa and the Middle East. The unfortunate thing, though, is that Sudan's high food production potential is not shared evenly throughout the country. A large proportion of the area cropped is arid or semiarid, and yields in rainfed production are kept at subsistence levels by inadequate moisture and other constraints that cannot readily be overcome with the technology available. The real hope for substantial improvement in food production lies in the limited, but densely populated zones where irrigation is available. There, technology has already been developed that could greatly increase the efficiency with which water, fertilizer, and other inputs are used.

The choice of Sudan then was based on the severity of its food situation, but also on its prospects for choosing a strategy, based largely on domestic food production, that could lead the country out of this crisis and ultimately contribute to the alleviation of poverty and to economic growth. In helping the country explore these prospects, we focused originally on sorghum and millet production in western Sudan, but later shifted our attention to the irrigated areas. Although Global 2000 dealt with both sorghum and wheat in those areas, this paper concentrates on the experience with wheat production.

The Project's Approach

The Project was launched in April 1986 upon the signing of a memorandum of understanding with the Sudanese government.

Objectives and expectations

The central aim was to demonstrate the technical feasibility of improving food production. In doing so, Global 2000 also

hoped to underscore the validity of a number of related points, which are summarized below.

Even though Sudan still has a long way to go toward providing its agriculture with an adequate knowledge and technology base, the country's Agricultural Research Corporation (ARC) has succeeded in developing a wide range of appropriate improved practices. In some areas, these can enable farmers to increase their output of food crops substantially over the yields obtained under traditional modes of cultivation.

In general, the new technology consists of a combination of improved varieties and accompanying management practices, including the use of modest amounts of chemical fertilizers. Although not perfect, much of this technology is acceptable to small-scale farmers and can be quite effective under their management.

National extension systems can disseminate the new technology more widely among farmers if a few reasonable conditions are fulfilled. First, extension must have better links with research to ensure that extension agents are familiar with the recommended technology and that researchers receive feedback about its performance on-farm. Second, extension needs a dynamic program for demonstrating this technology in farmers' fields and for convincing them of its potential value. To carry out such a program, extension obviously must have adequate management, training, transportation, and operating funds.

Eliminating bottlenecks in the supply of inputs is arguably a more complex challenge than that of mobilizing extension, but not one that is beyond the resources and managerial ability available in African countries. In large-scale irrigated schemes, like those in Sudan, the task is considerably less difficult than in the region's vast rainfed areas.

To summarize, the project's objectives in the technical arena were to show that 1) useful technology is available, 2) many farmers are willing to adopt it, 3) extension can transfer the new practices effectively, and 4) there is an urgent need to make modern inputs more widely available among smallholders.

In demonstrating these points, Global 2000 intended for the first recipients of the message to be small-scale farmers, extension agents, and researchers. The degree to which they can bring about lasting change, is determined to a large extent by government decisions and actions on a number of issues. For that reason, it was planned from the start to gain the attention of Sudan's agricultural policy makers. Contacts with them consisted primarily of supplying information derived from the project's field activities, international workshops focusing on issues related to this work, and the personal intervention of Mr. Carter, on occasion, to pursue specific points.

A dynamic program of technology demonstration

The primary tool for convincing farmers to accept new technology and for mobilizing extension to deliver it was the production test plot (PTP), with which farmers apply the recommended practices. In doing so, they receive practical instruction and assistance from extension officers.

On the face of it, this approach may seem no different from demonstration programs promoted by other organizations that support agricultural extension. But, in fact, the PTPs deviate from other such tools in a number of ways. In the first place, Global 2000 demonstrations are much larger,

measuring 1 or 2 ha in Sudan (depending on the method of land preparation), compared to only 0.1-0.2 in most other projects. Larger plots are preferred because they permit a more realistic demonstration of the improved technology, which gives farmers the chance to assess its resource requirements and rewards on a commercial scale.

A second distinctive aspect of the PTP approach is that each participating farmer is provided with all the necessary inputs (on a loan basis) by extension staff. In most countries where the Global 2000 Projects are underway, this is not a normal part of their responsibilities, and we must make a special effort to mobilize extension staff for input delivery. In doing so, the intention is not to make the project or extension serve as a remedy for faulty systems of input supply. The purpose rather is to ensure that farmers have an opportunity to test new technology on a fairly large scale.

Sudan's irrigated areas represent an uncommon exception to the usual pattern. There, the extension service (of the Gezira Scheme, for example) already has responsibility for providing farmers with seed, fertilizer, and land preparation services on a loan basis.

A third feature of the PTPs is that farmers are always actively involved in the demonstration. They implement the technology themselves under the guidance of extension staff rather than simply observing passively what others have done.

Apart from its effects on the thinking and behavior of the individual cooperating farmer, the PTP has potential for influencing many others. For that reason, we used the demonstrations quite heavily as venues for farmer field days and frequently involved political leaders in these events.

Organization and staffing

A program of the sort outlined above can be implemented with a minimum number of expatriates, but requires that they develop extensive contacts with national institutions.

The Global 2000 Project in Sudan was staffed by a total of three Mexican scientists, all of whom had extensive experience in research on wheat and other crops that can be grown in hot environments such as those found in Sudan. These staff members were: Ignacio Narváez, country director (1986-1990); Marco Quiñones, senior scientist (1986-1988); José Antonio Valencia, senior scientist (1987-1989) and country director (1990-1992). These persons worked primarily with the Extension Directorate of the Ministry of Agriculture and Natural Resources (MANR) as well as with the Extension Departments of various irrigation schemes, mainly those managed by the Sudan Gezira Board, the Rahad Scheme, and the Blue and White Nile Corporations. In doing so, they were supported by seven project staff hired locally and by dozens of extension officers in the areas where the demonstration program took place. Project funds were used mainly to cover the expenses of this work, including vehicles and operating funds for the extension services and until 1989 inputs for cooperating farmers.

In addition, close ties were maintained with ARC, which developed the technology demonstrated in the PTPs. In doing so, ARC had been receiving various forms of support (including experimental germplasm, training, and technical consultation) from various international research centers, namely CIMMYT (International Maize and Wheat Improvement Center, Mexico), ICARDA (International Center for Agricultural Research in the Dry Areas, Syria), and ICRISAT (International Crops Research Institute for the Semi-Arid Tropics, India).

In cooperation with ARC scientists, Global 2000 staff conducted some adaptive research designed to tailor the recommended practices more closely to environments in which they were demonstrated. For that purpose, ARC received modest amounts of funds to carry out technology verification trials.

All of the project's activities were under the overall guidance of a Management Coordinating Unit (MCU), which was chaired by the undersecretary of MANR and included representatives of a half dozen or so institutions concerned with food production in Sudan. Each year the MCU reviewed and amended, as necessary, work plans developed by Global 2000 staff in consultation with the country's regional directors of extension and research. At the end of each cropping season, field results were analyzed and the results used in preparing work plans for the next year.

The Project's Experience

As in many neighboring countries, rapid urbanization has led to rising demand for wheat since the 1970s, a trend encouraged by government policies. Simultaneously, the country has tried to create a domestic capacity for wheat production that would keep pace with growth in consumption. The failure of early efforts to achieve this end has required that sizable amounts of foreign exchange be spent to purchase ever larger quantities of imported wheat.

Though for a number of years the financial burden was more or less tolerable, by the early 1980s this had ceased to be the case. Because of reduced food aid, a severe shortage of foreign exchange, and large budgetary deficits, together with continued rapid growth in per capita consumption (at an annual rate of 2.7%), the wheat problem quickly got out of hand.

At that time, the government was close to giving up any remaining hope that the burden of wheat imports might be lifted through domestic production. In 1984-85, the Gezira Scheme grew no wheat at all because widespread drought had greatly reduced the amount of water available for irrigation. Even though by the next year the area planted was back to almost normal levels, the scheme's management was seriously contemplating permanent removal of wheat from its four-year crop rotation to provide more land and resources for cotton and other crops. Given low wheat yields in Gezira, this thinking made good sense.

But what if average yields could be more than doubled? Would it then be worth the effort to strive for greater self-sufficiency in wheat? In an unexpected but worthwhile departure from the original plan of the Global 2000 Project in Sudan, this question was posed in the following year of operations and a considerable effort was made to examine its technical dimensions.

Demonstrating the possibilities

In the mid-1980s, the prevailing attitude about wheat among pro-cotton administrators of Sudan's irrigated schemes was that the less hospitable climate of the country's central region makes it impossible to obtain wheat yields comparable to those in the cooler areas further north. Without question, climate does place limits on the potential productivity of a given crop in a particular environment. But to establish what those limits are, one must reduce other production constraints that are more amenable to a technical solution. In Sudan low wheat yields can be attributed to various factors that are unrelated to climate, including:

- Inadequate seedbed preparation resulting in poor stands;

- Low, inappropriate, and unbalanced use of chemical fertilizers;
- Failure to take advantage of the best varieties available;
- Shortcomings in other aspects of crop husbandry; and
- Inefficient use of irrigation water.

1986-87—During the 1986-87 season, 19 farmers successfully established wheat PTPs in three groups of the Gezira Scheme and 11 farmers in the Kosti area of the White Nile Corporation. The technology package demonstrated in these plots consisted of the following elements:

- The improved variety Condor;
- Fertilizer application before planting, including nitrogen in the form of urea at 90 kg/ha and phosphorus as triple superphosphate at 45 kg P/ha (on half of some plots farmers were asked to apply an additional 44 kg N/ha prior to the second irrigation);
- A seeding rate of about 150 kg/ha;
- Optimum sowing date (the first half of November); and
- Irrigation every 14 days.

The best results were obtained in the South Group of the Gezira Scheme. In plots on which 90 kg N/ha were applied, the average yield was 2.7 t/ha, and in those receiving 135 kg N/ha, it was 4.3 t/ha. In one plot, with the higher rate of nitrogen, the yield was 5.2 t/ha. Though somewhat less striking, results from the other two groups in Gezira were quite respectable compared with average yields under traditional practices. The main reasons for lower yields were late application of urea in one group and in the other a combination of problems with irrigation and limited use of the seed drill. At 2.9 t/ha, the average yield across nitrogen levels for all of the PTPs grown in Gezira was more than twice the average for all irrigated wheat in Sudan (see Table 3).

The lowest average yield during the 1986-87 season was obtained at Kosti, where the constraints are greater than in any other wheat-producing area of the country. Land preparation is generally deficient; weed infestations are quite intense; and the White Nile Corporation's pump irrigation system is more prone to breakdowns and suffers more from poor maintenance than the gravity system used in the Gezira Scheme.

1987-88—The PTP program was expanded considerably both in the Gezira Scheme and White Nile Corporation, involving 386 farmers in the former and 66 in the latter. Again, the highest average yield (2.9 t/ha) for all farmers participating in the PTP was obtained in the South Group. As in the sorghum PTPs grown at Gezira, however, variation in yield among groups was high (Table 1).

Chiefly because of problems with irrigation, performance of the PTPs at Kosti was disappointing, compared to the results from

Table 1. Mean annual yields of the Production Test Plots in the Gezira Scheme, Sudan.

	Mean Yields (t/ha)				
Farm Group	1987-88	88-89	89-90	90-91	91-92
South	2.9	3.8	3.9	2.7	NA
Center	2.8	3.6	3.4	2.5	3.5
Masalama	2.2	3.7	2.9	2.2	2.8
Wad Habouba	1.9	2.8	2.7	1.7	3.0
Wad Shair	2.3	-	3.2	2.6	3.5
North	2.3	-	-	-	3.8
Northwest	2.3	3.3	1.4	1.7	3.2
Makashfi	2.5	-	-	2.4	3.4
El Mansi	2.1	2.5	2.7	2.1	3.3
El Huda	2.2	3.3	3.2	2.0	3.2
Matouri	1.2	2.5	1.9	1.6	2.2
Matong	2.4	2.7	2.8	1.8	2.2
Gamousi	1.9	2.3	2.7	1.5	-
Tahameed	-	3.0	1.6	1.4	3.3
Highest Plot Yield	4.3	6.2	5.7	NA	NA

1986-87. Although at least one plot reached the previous year's average of 1.6 t/ha, the mean for all plots was only 1.0 t/ha, about 17% below the average of 1.2 t/ha for traditional practice in the Gezira Scheme.

1988-89—During this season, the wheat PTPs were modified. Instead of working with individual farmers in scattered plots of 1-2 ha, groups of tenants were organized to occupy adjacent plots to form blocks of 16-25 ha. Among other advantages, this made it easier to add a land-preparation component to the improved technology package and to train extension officers and farmers. The total number of wheat PTPs grown (351 in Gezira and 120 in Kosti) remained roughly the same as in the previous year.

The PTP results were better than in the previous two years. The highest average yield (3.8 t/ha) was once again recorded in the South Group, which also had the highest individual plot yield of 6.2 t/ha. This time, however, the variation among groups was not so pronounced (Table 1). The lowest average yield (for Gamousi) was 2.3 t/ha, nearly twice that for traditional practice in Gezira. The average PTP yield for the entire scheme was 3.2 t/ha (see Table 3).

Even under the more difficult circumstances at Kosti, things took a turn for the better. The average yield for all plots was 2.4 t/ha (see Table 3), with a high of 2.9 t/ha.

In spite of variation across locations and over time, three years of experience in testing improved technology through wheat PTPs demonstrated convincingly the point we set out to make. Once the major agronomic constraints have been substantially reduced, irrigated wheat in central Sudan can yield reasonably well, regardless of the less favorable climatic conditions. The apparent maximum potential yield of around 5 t/ha in the Gezira Scheme is not too far below that in Mexico's Yaqui Valley (6-7 t/ha). Of course, decisions about the economics (and political dimensions) of domestic wheat production in Sudan must be based, not on maximum yield potential, but on typical experience in the demonstration plots. From the evidence gathered between 1986 and 1989, it seemed reasonable to expect that average yields in Gezira could be raised to just over 3 t/ha and that similar results might be obtained in the White Nile Corporation, assuming considerable improvement in its pump irrigation system.

Supporting domestic wheat production

On the strength of these findings (and in the face of declining food aid, among other difficulties), the Sudanese government launched an all-out effort in 1989 to raise domestic wheat production, particularly in the Gezira Scheme. The aim was to eliminate the wheat deficit by 1992. The main elements of the government's strategy were to expand the area planted to this crop, strongly support the spread of improved technology (developed by ARC and widely demonstrated by the Global 2000 Project), and slow the growth in demand through import restrictions and rationing.

1989-90—The Project supported this initiative by expanding its program of technology demonstration during the 1989-90 season (with the addition of the variety Debeira to the recommended package). In Gezira, for example, more than twice as many farmers took part as in 1988-89 (see Table 3), and we expanded to new locations (El Duiem in the White Nile Corporation and the Rahad Scheme, which lies east of the Blue Nile). Altogether, the PTPs covered more than 2,000 ha. As in previous years, the active participation of extension agents was critical to effective implementation of the program.

PTP performance in this season largely confirmed the results from previous years. As before, the highest average yield (3.9 t/ha) in the Gezira Scheme was obtained in the South Group, which also had the best individual plot yield (Table 1).

In the Kosti area, where PTPs were distributed among six villages, the highest average yield was 4.4 t/ha. The same village that recorded this figure also had the highest yield (5.7 t/ha) for an individual plot (Table 2). The lowest average yield was 2.3 t/ha. For El Duiem, the average yield was 2.9 t/ha (see Table 3), but with marked variation between performance in the two villages where PTPs were grown (Table 2). This resulted from very poor management of irrigation and inadequate land preparation at one of the sites.

Not surprisingly, yields in the Rahad Scheme, where wheat was being introduced for the first time, were less impressive but still encouraging. The highest PTP yield was 2.5 t/ha.

Delayed harvest at locations in all areas where PTPs were grown caused yield losses from shattering estimated at about 10-15%.

Table 2. Yields of wheat PTPs in the White Nile Corporation, 1989-90.

Farm Group	Highest	Average
	(t/ha)	
Kosti		
El Zhour	4.5	2.4
Zienuba	4.0	2.6
Golee	3.5	2.3
Firdos	5.7	4.4
Hayapha	2.6	2.4
Guba	3.3	2.5
El Dueim		
West Nile	4.6	3.6
East Nile	2.9	1.7

1990-91 and 1991-92—During the project's last two growing seasons, the PTP program continued in the Gezira Scheme and at the new locations mentioned above, though with much larger numbers of farmers at Gezira (see Table 3). Average yields declined somewhat in 1990-91 but showed much improvement in the following season (Table 1).

In support of wheat production, the government went to great lengths to overcome the major constraints that account for uneven crop performance and generally lower yields than can reasonably be expected. Through a combined effort by public and private sector organizations, seedbed preparation was much improved this season. Moreover, fertilizer deliveries were sufficient and on time. Although special efforts were made to clear irrigation canals, many problems remain, chiefly because maintenance is still insufficient and farmers have only limited experience with proper irrigation of wheat.

An emphasis on efficiency

Having come this far, the government officials who are promoting domestic wheat production now face a difficult challenge: how to make up the rest of the wheat deficit through domestic production without taking excessive resources away from other important commodities, particularly cotton. The country badly needs the foreign exchange it earns from this crop. And since world prices are down and production costs are up, new efforts are needed to help farmers increase the efficiency of production and thus maintain the profitability of this enterprise. At the same time, self-sufficiency in wheat has a powerful appeal. Whereas local production (e.g., in the Gezira Scheme) takes place only a short distance from the milling facilities concentrated in Khartoum, imported wheat

must be brought more than 1,000 km from Port Sudan, adding greatly to its cost.

The answer to this dilemma lies to a large extent in more efficient use of the resources available, especially water. Toward this end, a major effort must be made to establish better maintenance of irrigation and drainage systems. Until that important investment has been made, managers and tenant farmers in the Gezira and other schemes will find it difficult to satisfy the irrigation requirements of export commodities as well as wheat and other food crops.

With respect to wheat, it is essential that further gains in self-sufficiency be made largely through improved yields rather than expansion of area. Assuming that the efficiency of irrigation can be enhanced, it should be possible to achieve that goal through continued promotion of improved wheat technology by the extension services.

Table 3. Performance of wheat Production Test Plots in Sudan.

Irrigation scheme	Area (ha)	No. of farmers cooperating	Avg. yield (t/ha)
1986-87			
Gezira	41	19	2.9
Kosti	31	6	1.6
1987-88			
Gezira	1,051	386	2.2
Kosti	105	66	1.0
1988-89			
Gezira	975	351	3.2
Kosti	178	120	2.4
1989-90			
Gezira	1,635	784	2.8
Kosti	267	144	2.5
El Duiem	61	29	2.9
Rahad	40	9	2.1
1990-91			
Gezira	2,772	1,228	2.0
Kosti	42	20	2.2
El Duiem	63	29	2.0
Rahad	127	57	1.5
1991-92			
Gezira	2,503	1,192	3.2

In addition, researchers can do much to improve current recommendations by tailoring agronomic practices more closely to particular production environments and by taking advantage of new germplasm. During the past several years, ARC and Global 2000 staff have conducted on-farm tests of two new wheat lines—Veery 'S' and S948-A-Se7—the latter released under the name of El Nielen. During 1989-90, these materials gave average yields of 3.4 and 3.3 t/ha, respectively, in farmers' fields, compared to 3.1 and 3.2 t/ha for Debeira and Condor. Apart from their yield advantage, the former have greater heat tolerance and show better adaptation than the varieties currently recommended. On the basis of these findings, ARC and the Global 2000 Project commenced seed increase of the new lines, with a view to providing the Gezira Seed Propagation Administration and National Seed Administration with enough foundation seed for large-scale production.

The Project's Impact

In Ghana, where a Global 2000 Project was established at about the same time as that in Sudan, the country's Crops Research Institute has conducted independent, nationwide studies on the adoption of improved maize technology promoted by Global 2000 staff and others. Although studies of this sort have not taken place in Sudan (with the exception of a limited survey carried out by agricultural economists during the 1989-90 season in the Gezira Scheme), there is quantitative

evidence of the effects of the Global 2000 Project, particularly with respect to yields of wheat. From this and other indications, it is clear that the project fulfilled its objectives and expectations. As explained below, substantial impact was evident at the farm level, within the extension services, in research, and in national agricultural policy.

In farmers' fields

Thousands of growers planted wheat PTPs and achieved yields far exceeding the average for the country's entire irrigated area (Table 4). High wheat yields came as a surprise to most people, primarily because of the common belief that wheat cannot thrive south of Khartoum. The promising performance of the PTPs was the primary reason that the Sudanese government acted so vigorously and quickly to help more farmers' take advantage of the new technology. Decision makers were also motivated by the growing seriousness of the wheat deficit, which represented a sizable drain on public funds year after year.

Government support of domestic wheat production accounts to a great extent for improvement in wheat yields under the government's crash production program (Table 4).

The results of a survey of farmers participating in the PTP program suggest that for many of them this was more than just a brush with successful wheat production. One year after growing PTPs, a sizable percentage of these farmers continued to apply the improved technology or at least some elements of it, and they obtained an average wheat yield of 2.3 t/ha. "Graduates" from the program were most likely to persist in the practices over which they had the greatest control. Thus, during the season after their participation in the project, 82% of the farmers surveyed used the recommended practices for land preparation, compared to 90% in the season when they grew the PTP and 34% for all farmers in the Gezira Scheme. A somewhat lower percentage of the graduates (74%) continued applying fertilizer before planting, compared to only 11% throughout the scheme. Clearly farmers are willing to adopt new practices that demonstrate a marked advantage and much more must be done to place key elements of improved technology within their reach.

Table 4. Wheat statistics for Sudan, 1984-92.

	Area (000 ha)	Prod. (000 t)	Avg. yield (t/ha)	Consumption (000 t)	Deficit (000 t)
1984-85	48	79	1.6	613	534
1985-86	151	199	1.3	685	486
1986-87	118	157	1.3	750	593
1987-88	144	181	1.3	780	599
1988-89	165	247	1.5	810	563
1989-90	258	408	1.6	848	439
1990-91	464	666	1.5	881	231
1991-92	382	831	2.2	-	-

Source: Data on production during 1984-91 are from FAO AGROSTAT/PC computer files, 1992.The figure on production in 1991-92 is an estimate given in the June 1992 issue of FAO's *Food Situation and Outlook*. The data on consumption are from a food security study conducted in 1988.

Despite continued difficulties, the government has achieved marked progress toward its goal of wheat self-sufficiency. In 1990-91 alone, wheat area nationwide grew by 70%, reaching 420,000 ha from a low of 48,000 ha in 1984-85 (Table 4). Some of the expansion was accomplished by introducing wheat in the Rahad and Suki Pump Schemes on the Blue Nile.

As a result of the large expansion in wheat area, together with improvement in yields, production reached an estimated 666,120 t in 1990-91, of which the Gezira Scheme was expected to contribute 377,000 t or 56%. Given that estimated consumption was about 881,000 t, the country had achieved roughly 75% self-sufficiency in wheat. In 1991-92, this proportion grew markedly, as production is estimated to have taken another sizable leap (Table 4). Preliminary area and yield figures show that wheat area actually declined during 1991-92, suggesting that the growth in production was due to substantially higher yields (Table 4).

Extension and research

The Global 2000 Program succeeded overwhelmingly in demonstrating the potential of extension officers for serving as agents of change in food production. It did so primarily by training and supporting them in the use of an effective tool for technology demonstration (i.e., the PTP program). This experience in turn underscored the importance of establishing closer links between extension and research to ensure that innovations emerging from the agricultural sciences reach their intended beneficiaries in the countryside. Once extension officers had something tangible to offer as well as the means of delivering it, they were able to perform that function quite well and, as a result, they began to acquire greater credibility among farmers.

Although staff of the Global 2000 Project worked most closely with the extension services, their activities also had many salutary effects on agricultural research in Sudan, and they reinforced these through close cooperation with ARC.

Until the mid-1980s, research on food crops was pretty much confined to investigations at the country's experiment stations, and the results were more likely to wind up in the library than in farmers' fields. This is not to say that researchers' efforts to document their work were misguided. The problem was that the academic orientation of their work had thwarted its ultimate aim of increasing the efficiency of food production and improving the lot of farmers and consumers.

The PTP program did much to change this, partly by example. In commenting on the performance of Global 2000 staff, the Director of Agriculture for the Gezira Scheme remarked that "they go into the fields and work side by side with our farmers. This has been a great inspiration to my staff, especially the younger ones." A further source of motivation for researchers was the experience of seeing their improved varieties and practices performing well in the PTPs and generating interest among farmers. In addition to obtaining valuable feedback from the demonstrations, which helped them make important refinements in the recommended technology, ARC staff gained greater confidence among Sudan's agricultural decision makers. We hope that this will eventually translate into stronger financial support for research.

To reinforce the farmer orientation promoted by the PTP program, Global 2000 staff engaged in two types of cooperative activities with ARC and other agencies. One was to conduct on-farm trials for testing the performance of experimental germplasm

and improved crop management practices. Assuming that this activity becomes a regular feature of ARC's program, it should further strengthen the links between research and extension and raise the likelihood that the technology being transferred now will soon be followed by even better varieties and other useful innovations.

The second activity was to support seed production. For any country to engage in germplasm development without also providing a reliable source of improved seed is a tacit admission that it lacks confidence in this research. In Sudan, once the PTP program had demonstrated the potential value of the wheat variety Debeira, seed production became a matter of extreme urgency and began to receive something approaching the priority it deserves.

National agricultural policy

As mentioned above, high yields in the wheat PTPs created quite a stir within Sudan's agricultural establishment, leading in October 1988 to the creation of the Technical Committee for Wheat Self-Sufficiency and the implementation, starting in 1989, of a four-year plan for achieving this objective. By 1992 the country had practically eliminated the wheat deficit (Table 4).

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Agronomic Aspects of Wheat Production in Sudan

O.A.A. Ageeb
Agricultural Research Corporation
Wad Medani, Sudan

Abstract

Wheat is grown in Sudan under irrigation during the dry and comparatively cool and short growing season, which extends for 100 days from November to February. The crop suffers from a number of abiotic and biotic stresses, which include heat stress, low soil fertility, waterlogging, and aphid infestation. National average wheat yields are low and constitute 40% of potential yields attained in research plots, demonstration farms, and by leading farmers. The low yields are mainly associated with low crop stand, late sowing, inadequate fertilizer use, poor water management, and delayed harvests. Wheat research programs have been progressively developed to seek solutions to production problems, and to verify research findings in farmers' fields. Useful information pertinent to sowing date, crop establishment, seed rate, fertilizer requirements, irrigation needs and weed management were obtained. Up to 1988, Sudan imported 75% of its annual local needs estimated at 0.8 to 1.0 million tons. Since then, the Government has launched an ambitious program to reach self-sufficiency in four years through area expansion, application of improved production technologies, and adoption of free-market policies. As a result, total wheat production from 1988 to 1992 has increased by 350% from 234,000 to 839,000 tons, which was considered adequate to satisfy current domestic demand.

Introduction

Wheat cultivation in Sudan traces back to an era B.C., but until the 1940s production was confined to the Northern State (17-22° N) whose inhabitants are traditional wheat consumers. The scarcity of land and high cost of production in the Northern State, coupled with the increasing demand for wheat consumption, led to the expansion of wheat growing area southward, to warmer southern regions, and to the irrigated schemes in central and eastern Sudan (13-15° N).

Until 1988, Sudan imported 75% of its annual local needs estimated at 0.8 to 1.0 million tons. This exerted a heavy burden on the country's meager foreign exchange resources. Encouraged by the promising results of recent on-farm research and pilot demonstration plots, the government of Sudan launched an ambitious program of food security that aimed at attaining self-sufficiency in wheat by 1992. The program was successfully implemented by expanding wheat area and the application of improved production technologies. Consequently, wheat production from 1988 to 1992 has increased by 350%, from 234,000 to 839,000 tons (Table 1). Coupled with the abolition of bread subsidies, local demand has probably been currently satisfied.

Wheat Yield-limiting Factors

Wheat productivity in Sudan is affected by a number of environmental stresses, the most important of which are discussed in the following sections.

Temperature

Wheat in Sudan is grown under irrigation during the dry and comparatively cool winter season, which extends from November to February (Table 2). The growing season is short (90-100 days). In addition, the potential yield of the present commercial cultivars is limited by high temperatures at any stage of crop development.

Soils

The soil of the irrigated schemes of central and eastern Sudan is relatively uniform, fairly levelled, calcareous heavy cracking vertisol. Drainage is impeded by its extremely low hydraulic conductivity (1.5 cm/hr). As a result, waterlogging is frequent in poorly managed soils. This leads to crop patchiness and low grain yield. The soil is alkaline (pH 8.5), deficient in nitrogen (300 ppm), available phosphorus (4-6 ppm), and probably some micronutrients (e.g., zinc), but has adequate potassium.

Pests and diseases

Wheat in Sudan is subjected to few biotic stresses that can be economically managed. Currently, wheat is free from diseases in central and northern Sudan, but in eastern Sudan where relative humidity is higher, the susceptible local varieties suffer from leaf rust and stem rust.

Aphids are the major insect pest that infest wheat; when not controlled they can cause up to a 30% decrease in grain yield. Rats appear sporadically and in years of outbreaks can cause heavy crop losses.

Weeds

On average, weeds have no economic importance in wheat production. However, during recent years, intensification and diversification of cropping systems, drought conditions, and the attendant increase in animal movement and the use of herbicides in cotton that precedes wheat in the rotation have created profound changes in the weed flora in the irrigated schemes. Perennial weeds are on the increase and other annual weeds are becoming important.

Table 2. Mean monthly temperatures (°C) at Wad Medani (1987-88 to 1991-92).

Season	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1987-88	30.5	28.8	25.1	24.1	25.2	29.7
1988-89	30.2	28.6	26.2	21.0	22.2	27.2
1989-90	30.7	28.4	23.3	24.3	23.1	30.4
1990-91	30.9	29.9	28.3	22.9	25.7	27.9
1991-92	29.4	27.6	22.9	24.2	21.1	28.2
Long-term averge (1965-1985)	30.2	27.2	24.6	23.7	25.6	28.7

Table 1. Sudan wheat area and total production (1988-92).

	Area (000 ha)				Production (000 t)			
Location	88-89	89-90	90-91	91-92	88-89	89-90	90-91	91-92
Gezira	115	165	258	224	154	257	377	538
Rahad	0	4	26	28	0	6	47	64
New Halfa	23	32	35	27	27	47	52	45
N. State	20	31	62	45	37	67	95	108
Blue Nile	0	3	14	7	0	2	30	12
White Nile	19	26	61	43	16	25	64	65
Others	-	-	3	6	-	-	2	7
Total	177	258	459	380	234	404	667	839

Agronomic factors

Average national wheat yields are low (1.4-2.0 t/ha) and considerably below (60% lower) the levels attained in research fields, demonstration plots, and by leading farmers. The low yields are mainly associated with low crop stand, late sowing, inadequate fertilizer use, moisture stress, and delayed harvest (Fakki and Fattah 1986, Fakki et al. 1991).

Wheat research programs have been progressively developed over the last four decades to: 1) seek solutions to production problems, 2) verify research findings in farmers' fields, 3) demonstrate improved production factors and packages on a large scale, and 4) study their practicability, economic feasibility, and acceptability to farmers.

Improved Wheat Production Technologies

Crop establishment

Poor crop establishment of wheat is a major cause of low yields on the heavy clay soils, which constitute 90% of the total cropped area. The problem is mainly related to one or more of the following factors: 1) inadequate land preparation including field levelling, 2) excessive water application at the planting time, and 3) improper seed placement.

Field experiments were carried out in the major wheat producing areas to test the effects of tillage system, presowing irrigation, machine planting, and methods of irrigation on crop establishment and grain yield of wheat. Land preparation by an off-set disc harrow was found to be the most optimum with regard to yield, cost, and time required to prepare the land (Salih et al. 1990).

Compared to broadcasting, a seed drill with tine furrow opener when properly used to place the seed at 5 cm depth improves crop establishment and increases grain yield by up to 28% (Mohamed 1991).

Application of presowing irrigation seals the soil cracks, improves seedbed preparation, helps towards more efficient future watering, improves crop stand, and increases wheat yields by 9 to 28% (Ageeb 1992). Furrow irrigation between 40- or 60-cm ridges as compared to basin irrigation reduces crust formation and waterlogging hazards (Babiker and Mohamed 1992).

The present system of watering small individual units requires a lot of labor for laying out these many basins. Strip irrigation as compared to the conventional basin irrigation reduces irrigation time by 30%, improves plant stand, reduces costs, facilitates combine harvesting, and results in comparable or better grain yield (Salih 1992).

Harrow-packing after seeding was introduced as a measure to increase seed-soil contact and hence improve crop establishment. The results obtained so far indicate that it reduces the time for the first irrigation, but it had little positive effect on grain yield (Dawelbeit 1992).

Sowing date

Under the climatic conditions of Sudan, characterized by high temperatures during the short growing season, a better definition of time of planting for wheat, will probably have a big effect on grain yield. Earlier studies in Sudan showed that sowing date was the most important factor affecting yield (Heipko 1966, Khalifa 1970, Ahmed 1977, Akasha 1978). According to early research recommendations, wheat sowing should take place from mid-October to mid-November. Field data (Fakki and Fattah

1986) and recent research (Ageeb 1988) have revealed that later planting was associated with high yields of the varieties currently grown. The sowing date recommendation has accordingly been changed to be through November, preferably between 12-26 November (Table 3), so that the critical reproductive phase coincides with the coldest part of the season (Ishag and Ageeb 1991).

Seed rate

Many studies showed that, on average, wide variation in seed rates has no significant effect on grain yield of wheat (Ageeb 1976, Akasha 1978, Ali 1979-82) because of the compensatory effects of yield components (Table 4). The recommended seed rate is 119 kg/ha, but farmers being aware of the shortcomings in land preparation use 143 kg/ha.

Table 3. Effects of sowing dates on grain yield (t/ha) for three cultivars (means of three seasons 1986-87 to 1988-89).

	Sowing date				
Cultivar	15 Oct.	29 Oct.	12 Nov.	26 Nov.	10 Dec.
Condor	2.3	3.4	4.1	4.2	3.8
Debeira	2.6	3.6	3.9	3.8	3.5
Wadi El Neil	3.0	3.6	4.0	4.0	3.3
	S.E. ± 0.10				

Fertilizer requirements

The responses of wheat to the application of chemical fertilizers have been extensively studied in Sudan.

Nitrogen, rate, source, and method of application—Wheat yields were found to be tremendously increased (80% more than control) by application of nitrogen fertilizer (Ageeb and Lazim 1974). Grain yields were unaffected by either source of nitrogen or by method of application while the addition of fertilizer in the early phases of crop growth (sowing or tillering) gave the greatest response (Khalifa 1973). Early nitrogen application effectively increased leaf area duration (LAD) after ear emergence, which is reflected in higher grain yield. The benefits from nitrogen were greater with early sowing of wheat (November) because of higher nitrogen-uptake during early vegetative growth as a consequence of which nitrogen was readily available to the plants (Khalifa et al 1977). With late sowing (Dec.), nitrogen uptake was much lower during early vegetative growth and this resulted in decreased leaf expansion and therefore in diminished response in grain

Table 4. Effect of seed rate (mean of two varieties) on grain yield and yield components of wheat.

	Seed rate (kg/ha)					
	11.9	47.6	95.2	142.8	190.4	S.E.
Grain yield(t/ha)	2.7	2.8	3.0	2.7	2.7	± 0.15
No.of spikes/m^2	267	309	390	375	420	±10
No.of spikelets/spike	21	20	19	18	18	± 0.5
No.of seeds/spikelet	2.1	1.7	1.7	1.6	1.5	± 0.05
1000 grain wt.(g)	35	35	35	35	35	± 0.4
Tiller contribution to yield (%)[a]	92	69	39	31	30	± 2.0

[a] Contribution of tiller to yield compared to that of main stem.

yield to nitrogen application (Table 5). Best returns from higher rates of nitrogen application were obtained from wheat crops sown at the optimum date. The cultivar Mexicali sown before the end of November could economically respond to 86 kg N/ha, while a December-sown crop responded to no more than 43 kg N/ha (Akasha 1978).

Phosphorus—The response of wheat to phosphorus application was found to vary with cultivar, method of application, nitrogen addition, and soil moisture (Said 1975, Akasha 1978, Ageeb 1986). Mexicali showed a positive response to phosphorus up to 64 kg P_2O_5/ha, while Giza 155 did not respond at all due to heavy lodging. There was a general lack of response to P in the absence of applied nitrogen. Said (1975) found that P application significantly increased N uptake at each stage of wheat growth. Generally, P uptake by wheat plants follows a similar pattern to that of nitrogen, but its rate of uptake was slower early in the season and faster later on. P applied with the seed gave better results than when it was broadcasted (Akasha 1978).

The results from recent on-farm trials in the major wheat producing areas (Table 6) clearly demonstrated the high response of wheat to the application of fertilizer phosphorus (25 to 70% increase in yield). As a consequence, it was recommended to apply 43 kg P_2O_5/ha in addition to a basal dressing of 86 kg N/ha in all wheat producing areas in Central Sudan (Ageeb and Abdalla 1988, Babiker 1989, Omer 1992).

Micronutrients—Heavy clay vertisols of central Sudan have low organic matter and high pH. Under such conditions, deficiencies of some micronutrients (Zn, Mn, Fe, etc.) are likely to occur. A number of multilocation on-station and on-farm trials were carried out in the 1991-92 growing season to find the response of wheat to the application of different commercial brands of foliar micronutrient

Table 6. Response of wheat to NP fertilizers in major production.

Rate of NP fertilizers (kg/ha)	Average grain yield (t/ha)			
	Gezira	White Nile	Blue Nile	Rahad
43 kg N	3.03	1.95	1.68	2.05
86 kg N	3.05	2.35	1.93	2.52
43 kg N + 43 kg P_2O_5	3.64	2.75	2.34	3.09
86 kg N + 43 kg P_2O_5	3.83	3.22	3.29	3.79

Table 5. Effect of sowing date and nitrogen on grain yield, LAD after ear emergence, and yield components of wheat.

Sowing date	Grain yield (t/ha)		LAD (weeks)		No. of spikes/ m^2		Grains per spike		1000 grain wt. (g)	
	0N[a]	N[b]	0N	N	0N	N	0N	N	0N	N
3 Nov. 1973	2.2	3.3	4.2	8.0	302	351	26	32	35	35
15 Dec. 1973	1.6	1.9	3.1	5.4	333	341	24	28	29	28
S.E.: Sowing(S)	0.05		0.23		15		0.9		0.4	
Nitrogen (N)	0.05		0.23		15		0.9		0.4	
S x N	0.08		0.33		222		1.3		0.5	

[a] 0N = No nitrogen.
[b] N = 129 kg N/ha.

fertilizers. The wheat response was highest under the controlled conditions at the station level (up to 37%) and lowest in farmers fields (6-21%). The increase in yield was thought to be mainly due to the observation that wheat leaves stayed green for longer periods in the sprayed fields (Ageeb 1992).

Water requirements

Estimates of daily water consumption for wheat varied over a wide range, from 3.5 to 8 mm within and between seasons. The causes of much of this variability can be related to the prevailing weather, the stage of crop development, and level of vegetative vigor (Farbrother 1974). Maximum soil moisture changes under wheat occur in the top 40 cm. Peak demand for water occurs during stem elongation, heading, and grain formation (mid-December to the end of January). Crop factor (Et/Eo) reaches a peak of 1.2 during heading and flowering time. When irrigated at 14-day intervals, it used 500 mm of water per season (Fadl 1974). In the Northern State, wheat was found to require about 640 mm of water to produce 4 t/ha of grain (Ahmed 1992).

The research recommendation is that irrigation should be applied every 14 days during the vegetative phase and every 10 days during the reproductive phase in which case about eight irrigations are needed.

Weed control

Previous research findings on the influence of weeds on wheat yield showed that yield losses were small. The practice was to control weeds prior to crop sowing by pre-watering or by heavy discing after heavy rains (Babiker 1979). However, in recent years, rainfall has been unpredictable and pre-irrigation is now rarely practiced. In most situations, wheat comes after cotton where herbicides are used, although the intensification and diversification of cropping have brought important changes in the weed flora. The perennial weeds such as *Cynodon dactylon* are increasing. In addition, other weeds such as wild sorghum are gaining importance in wheat (Babiker 1989).

Wild sorghum at population densities of 3 to 10 plants per meter of row can reduce wheat yields by 18 to 35%. The herbicide Puma, applied at 0.071 kg a.i./ha two to four weeks after planting by ground or aerial spraying, has provided excellent and lasting control of wild sorghum (Babiker 1991).

A number of post- and pre-emergence herbicides are being identified for broadleaf and grass weeds in wheat (Ageeb 1992).

Transfer of Improved Wheat production technology to Farmers' Fields

For years, agricultural research in Sudan was dominated by on-station research translated into recommendations to enhance farm production under varied situations. This approach, although it produced tangible results in many instances, fell short of appreciating the real problems and constraints facing farming communities.

The trend to on-farm research with farmer participation therefore emerged and continued to evolve and mature, taking full consideration of production constraints and farmers' decision-making criteria and risk awareness.

The adoption of on-farm research in wheat involving a tripartite relationship between researcher, extension officer, and farmer was and still is greatly promoted by the technical interface with CIMMYT and

ICARDA in the successful Nile Valley Regional Program on cool-season cereals and food legumes. The Sudan component of the program is generously financed by the Royal Netherlands Government. The overall impact of the program is extremely positive. The multidisciplinary approach and integration of research effort with the extension message is a big achievement.

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Wheat Production in the Gezira Scheme

A.E.M. Salih, O.A. Abdalla, M. Sidahmed, H. Fakl, and M.A. Ismail
Sudan Gezira Scheme, Wad Medani, Sudan

Abstract
In the early 1960s, wheat assumed its role as a vital and strategic commodity in Sudan due to increased consumption demand resulting from increasing population, urbanization, low prices of imported wheat, and changing food habits. This necessitated an expansion of the crop to warmer regions of the country. The Gezira Scheme was well suited to embrace the crop and, in fact, became the major contributor to wheat production. Wheat area and yield reached all time highs of about 257,000 ha during 1990-91 and about 2.24 t/ha during 1991-92. Development and adoption of a technical package recommended by the Agricultural Research Corporation for use by farmers in the Gezira Scheme are discussed. Economic evaluation, costs, and returns and constraints to increased wheat productivity in the Gezira Scheme are reviewed.

Introduction

For decades, wheat has been grown and consumed in northern Sudan (Lat. 16-22°N). In the early 1960s, the crop assumed its role as a vital and strategic commodity in the country due to increased consumption demand resulting from increasing population, urbanization, low prices of imported wheat, and changing food habits. This necessitated an expansion of the crop to warmer regions of the country. The Gezira Scheme was well suited to embrace the crop and, in fact, became the major contributor to wheat production in Sudan. In the Gezira, in the early 1960s, the crop started with relatively small areas that increased gradually to reach more than 210,000 ha in the mid-1970s. In the following years, the crop experienced a gradual decline due to poor planning, unavailability of inputs, inadequate pricing policies, and dependence on food grants and foreign aid from part of the Government besides other problems such as inadequate seed bed preparation, poor seed and fertilizer distribution, irregular irrigation schedules, and delayed harvest. All of these factors led to poor yields and area reduction.

In the last few years the Government has focused on agriculture, particularly food crops. This resulted in more efficient maintenance of the irrigation system, machinery for land preparation, readily available inputs in addition to the development of a technical package. These factors resulted in reversing the trend and increasing wheat area and yield to reach an all time high of about 257,000 ha during 1990-91 and about 2.24 t/ha during 1991-92. We cannot talk about the development of wheat production in the Gezira without mentioning the vital roles played by CIMMYT, ICARDA, Global 2000, the Department of Extension, and the pilot farms of the Gezira Board. In the last decade, all contributed greatly to testing and verifying the technical package and to convincing tenant farmers to adopt the package through demonstration plots and pilot farms.

The area under wheat in 1991-92 was about 223,000 ha. In July, well ahead of the wheat season, a committee was formed to draft a plan to try to implement the full technical package for wheat recommended by the Agricultural Research Corporation wherever possible.

The Technical Package

The technical package calls for a preliminary ridging of land in September to get rid of weeds that germinate after rains before they produce seed followed by disc harrowing. One dose of triple phosphate (43 kg P_2O_5) is applied before harrowing so as to be incorporated into the soil or applied by the seed drill and 86 kg/ha of nitrogen is applied at sowing. Sowing should be done by seed drill in rows 20 cm apart or a wide level disc with spouts and hoses to insure good seed coverage and distribution. The recommended seed rate is 140 kg/ha of good and clean seed. November is the recommended sowing time. The holdings of approximately 2 ha should be divided into 42 basins and irrigation applied every two weeks with a total sum of eight irrigations.

Adoption of the Technical Package, 1991-92

Data on adoption of the technical package are available through the statistics of the Sudan Gezira Board (SGB). In addition, a socioeconomic survey of farmers was carried out utilizing a stratified, multi-stage random sampling method. Sample size was 1026 tenancies (9% of the total growing area), situated in 57 blocks from all administrative groups. The survey collected detailed information on crop production, areas, labor, irrigation, sowing and harvesting dates, and technology use.

Land preparation

An area of 88,000 ha was prepared using the disc harrow. The remaining 135,000 ha were prepared by the traditional method of ridging, split ridging, and levelling.

Results from the survey showed that the average yield of farmers using the disc harrow was not significantly different from that of traditionally prepared land (2.26 vs. 2.21 t/ha). Although this suggests that the use of the disc harrow may not be an essential part of the package, disc harrowing in weed-infested or heavy soil areas resulted in dramatic yield increases.

Varieties

The variety Debeira was sown on 94% of the area while the remainder was sown to Condor. Debeira (2.39 t/ha) had a small yield advantage over Condor (2.21 t/ha).

Fertilizer application

The pilot scheme of wheat and the demonstration plots of the Extension Department, comprising some 47,000 ha, received fertilizers as recommended by the technical package. The rest of the area (177,000 ha) received only 65 kg N/ha (vs 86 kg N/ha) and the recommended phosphorus due to a shortage of urea. The survey indicated no significant difference between the two N rates.

Method and date of seeding

Seed drills were only used on 47,000 ha due to the shortage of drills, the remainder being sown using the wide level discs equipped with spouts and hoses. Approximately 1% of the area was sown by hand-broadcasting. There was no significant difference in the yields of the two mechanized methods.

Sowing started at the beginning of November and ended by mid-December. Data showed that areas sown in the first two weeks of November significantly outyielded the areas sown in the latter part of December (Table 1).

Irrigation

Farmers irrigated between five and eight times. About 87% of the total area received six irrigations and 61 and 40% of the area received seven and eight waterings, respectively. Irrigation frequency had a significant effect on yields (Table 2).

Cost of production

The average cost of production for a hectare of wheat in the Gezira Scheme in the 1991-92 season was about 11,935 Sudanese pounds (Ls), an increase of 137% compared to the previous season. This was due to the higher costs of land preparation, harvest and prices of inputs, which came as a direct outcome of the recent policies adopted by the Government towards a free market economy.

The increase in the cost of production per unit area did not greatly affect the tenant farmers because of substantial yield increases. The 1991-92 crop outyielded the previous one by 112%. Net return per hectare in 1991-92 was Ls 7530, 267% higher than 1990-91, due partly to the yield increase, but also the 46% increase in the prices paid to farmers.

Crop financing

Financing was previously obtained from a Consortium of Commercial Banks (CBC) and was covered by 1.19 t for each hectare with a predetermined price (Ls 6100/t), which was determined between the Trade Union of Tenant Farmers, SGB, and the CBC on the basis of the cost of production, which was estimated at Ls 11,935/ha. In this system, the CBC received its cost of finance in kind. If the wheat prices were higher than the predetermined price, CBC would compensate farmers. More recently, farmers have established their own bank.

Constraints to Increased Wheat Productivity in the Gezira Scheme

Irrigation system

The irrigation system network, which has a certain maximum capacity that cannot be exceeded, is designed in such a way to irrigate only 50% of the gross area of the scheme at any one time. Despite efforts by the Ministry of Irrigation, the irrigation system is getting old and the water control is not very good as a result of missing gauges and water control structures. In the case of summer crops, there are no restrictions in the amount of water diverted from Sennar Dam because their establishment coincides with the annual floods. In the case of wheat (which is a winter crop), the water diverted is drawn from the stored water in the dam basin for which there is competition between irrigation of wheat and generation of essential electric power.

Other constraints

Other constraints include:

- Lack of sufficient machinery to prepare the seed beds at the right time according to the package.
- Lack of enough sowing implements to sow the area at the optimum time.
- Harvest losses due to late harvest or improperly adjusted machines.

Table 1. The effect of sowing date on farmers' yields. Data from a survey of 1026 tenancies, Sudan Gezira Board, 1992.

Sowing Date	Average yield (t/ha)
First half November	2.53
Second half November	2.43
First half December	2.31
Second half December	2.29

Table 2. The effect of irrigation frequency on farmers' yields. Data from a survey of 1026 tenancies, Sudan Gezira Board.

No. of irrigations	Yield (t/ha)
5	1.67
6	2.10
7	2.42
8	2.93

Improved Wheat Production Practices and the Question of Economic Efficiency in the Gezira Irrigation Scheme

R. Hassan
Economics Program, CIMMYT, Nairobi, Kenya
H. Fakl
Agricultural Research Corporation, Wad Medani, Sudan
D. Byerlee
Economics Program, CIMMYT, El Batan, Mexico

Abstract

The domestic resource cost (DRC) methodology was used to evaluate the comparative advantage of existing and potential wheat technologies versus alternative crops (cotton) in Sudan's Gezira Irrigation Scheme. Results of the DRC analysis indicated that cotton dominates all wheat technologies including the full package of improved practices at 1992 trend and actual prices. Sensitivity analysis showed that for full package wheat to become the most efficient alternative in Gezira, the world wheat price must be 11% higher than 1992 trend levels. However, as wheat prices are currently below their long-run average, and since average yield levels in Gezira are much lower than potential yields under the full package of technology, at present it may not be economically efficient to expand wheat production in Gezira at the expense of cotton. Before more land is removed from cotton and sown to wheat, priority should be given to promoting faster adoption of efficient production methods to close the gap between potential and current farmers' wheat yields in Gezira. Input procurement and delivery systems should be liberalized for more efficient and timely utilization of inputs. On-farm testing of the new technology in Gezira should continue to refine research recommendations to suit the particular needs of the different locations and target farmer groups in Gezira. It is also important for Sudan to devote more resources to improving the quality and marketing of its cotton crop, given the high potential gain in cotton export prices from higher quality lint.

Introduction

During the 1980s, Sudan was able to maintain low consumer prices for wheat through food aid, overvalued currency, and direct subsidies. This, coupled with rapid urbanization, has led to a tremendous growth in wheat consumption in Sudan (Damous 1986, Hassan et al. 1991). Domestic wheat production, on the other hand, declined over the same period resulting in a huge gap between local supply and consumption of wheat (Figure 1). Wheat imports have therefore

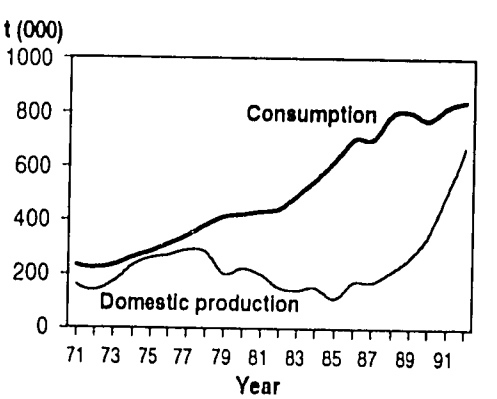


Figure 1. Total wheat production and consumption in Sudan, 1971-92.

increased substantially. The country's serious shortages in foreign exchange, large budgetary deficits, and reduced availability of food aid have made it difficult for Sudan to sustain the growing wheat deficit. The government has therefore decided to promote domestic wheat production in order to close the wheat gap. A crash program was launched in 1989 to achieve self-sufficiency in wheat by 1992. In addition to expanding wheat area, the government strategy aims at exploiting the potential productivity gains from improved wheat production technologies developed by the Agricultural Research Corporation (ARC) and independently tested in farmers' fields over the last five years by ARC and Sasakawa-Global 2000 (SG 2000). As a result of these efforts, larger areas were sown to wheat and higher yields were realized, leading to increased wheat self-sufficiency over the last three years (Figure 1). Quantitative restrictions and rationing of consumption also improved self-sufficiency by slowing growth in demand. The government has also removed the high subsidy on bread prices gradually over the past year leading to reduced consumption.

While these measures lead to reduced reliance on wheat imports and enhanced food security, the economic viability of Sudan's wheat import-substitution strategy need to be evaluated carefully. First, expanding local wheat production increases competition for land, water, and other agricultural resources between wheat and alternative enterprises, such as cotton, that are important foreign exchange earners. Second, the improved production practices promoted by ARC require the increased use of imported modern inputs. Therefore, the foreign exchange resources saved from substituting local for imported wheat must be compared to the opportunity cost of the domestic and foreign resources required to support local wheat production. The present study evaluates Sudan's decision to promote production of local wheat in terms of economic efficiency, especially with regard to whether wheat represents the best option for using the country's irrigated land resources. This analysis is part of a wider effort by CIMMYT to define conditions under which wheat can be grown efficiently in the tropics, where environmental conditions for growing wheat are sometimes difficult and wheat consumption and deficits have grown steadily (Byerlee 1985). The contribution to net social gains and the economic efficiency of wheat and competitive crops in the Gezira Scheme, which produces more than 60% of Sudan's wheat, are determined under various policy and technological scenarios.

Traditional and Improved Wheat Production Practices in Gezira

Wheat in Gezira is grown in a four-course rotation, preceded by cotton and followed by a combination of groundnuts and sorghum and then fallow. Each farmer in the scheme is allotted a tenancy of 8.4 ha. There is no double cropping in the scheme. Every year the 8.4 ha tenancy is divided into four plots of 2.1 ha each. Land allocation to wheat and cotton is decided by the Scheme administration. Farmers are required to devote one plot to cotton, another to wheat, and to leave the third plot fallow. The remaining land (the fourth plot) is allocated between sorghum and groundnuts. The four phases of the rotation, however, are completed over four years as the different crops or fallow replace one another on each plot according to the sequence.

Since wheat is a new crop, farmers often use inappropriate production practices and apply low levels of fertilizer and irrigation water. Average yields in Gezira have

accordingly stayed at a very low level of 1.28 t/ha over the past 20 years. Conventional wheat production practices in Gezira consist of poor land preparation with only two ridging operations and hand broadcasting of seed at an average rate of 120 kg/ha, leading to irregular spacing and low plant density. Disc harrowing, levelling and mechanical sowing were not used. The average amount of nitrogen fertilizer applied to wheat in Gezira during 1978-1988 was only 24 kg/ha and no phosphorus was used (SGB 1989). Farmers also broadcast the fertilizer manually, often very late. Very few farmers applied more than five irrigations on wheat over a growing season that extends to more than four months. Gezira wheat received an average of five irrigations during the 1990 season (SGB 1990).

A new package of improved wheat production practices has been extensively tested under farmers' conditions in Gezira over the past five years. On-farm testing of the new technology was conducted as part of the ARC/International Center for Agricultural Research in the Dry Areas (ICARDA) pilot project for verification and adoption of improved wheat technologies in Sudan. The project started in 1985 with funding from the Organization of Petroleum Exporting Countries (OPEC) and the Government of the Netherlands and technical backing from ICARDA and CIMMYT (ARC/ICARDA 1988, 1989, 1990). Results of on-farm research indicate the high potential gain in wheat yield from good seedbed preparation, optimal sowing by machine, and timely application of adequate amounts of fertilizer and water. These practices were found critical for crop establishment, plant growth, and optimum population. The following package is thus promoted by the ARC for Gezira wheat farmers:

- Replacing the long-season variety Giza 155 by the relatively short-maturing and semidwarf wheat cultivars Condor and Debeira.
- Disc harrowing and levelling for a better seedbed.
- Mechanical planting in 20 cm rows, at a seeding rate of 144 kg/ha for optimum population, uniform plant growth, and root development.
- Planting between 12-26 November. This period was recommended for optimal sowing so that the coolest part of the growing season (December and January) coincide with the reproductive stages (flowering and grain filling), which are most sensitive to high temperatures.
- Mechanical application of 86 kg N/ha immediately before planting, and 43 kg P/ha at seeding.
- Irrigating seven to eight times at 14 day-intervals.

Over the past five years, versions of this package have been tested independently on farmers' fields in Gezira by ARC, SG 2000, and the SGB. The full package described above was applied on the ARC demonstration plots. SG 2000 tested various combinations of the package components on farmers' fields with variations in the number of harrowings and irrigations, and mechanical planting and fertilizer application versus broadcasting. The new wheat package was also tested on the World Bank-funded Gezira Pilot Farm, without phosphorus and with less than seven irrigations on average.

Adoption patterns and causes of variation

While Gezira has seen substantial expansions in wheat area (136%) over the past five years, growth in wheat yields has been disappointing. The average yield achieved by wheat farmers over the last five seasons (excluding the nontypical 1991-92

season, when winter temperatures were abnormally low) was 1.36 t/ha, which is only 6% higher than the long-term average of 1.28 t/ha (Hassan et al. 1993). This gain in wheat yield is considered very low compared to the rapid growth in wheat area over the same period. This shows that wide gaps between the high potential for wheat production in Gezira revealed by the ARC and SG2000, and current yield levels in the scheme remain unexploited.

Several studies have argued that one major reason for the low yield of wheat and the wide gap between potential and farmers' yields is the slow adoption of the recommended package of improved practices (Hassan and Ageeb 1992, Faki 1991). These studies suggested that because of problems associated with availability of inputs, particularly fertilizer and irrigation water, many farmers could not use the full package of technologies. Table 1 gives several examples of the partial adoption of

Table 1. Farmer adoption of components of the improved wheat production technology in Gezira (1989-1990). Percentage figures show rate of adoption.

Technology component	ARC full package	Scheme average	SG 2000	Ex-SG 2000
A. Improved variety				
Condor (%)	100	58	56	100
Debeira (%)	0.0	40	33	0.0
Giza 155 (%)	0.0	2	11	0.0
B. Mechanical				
Disc harrow (%)	100	40	90	62
Levelling (%)	100	31	100	100
Mechanical planting (%)	100	44	79	54
Mechanical application of fertilizer (%)	100	8	62	5
C. Chemical				
Full nitrogen (%)	100	22	98	92
Average level used (kg/ha)	86	59	82	76
Recommended phosphorus (%)	100	18	92	72
Average use (kg/ha)	43	8	26	34
Optimal application date (%)	100	11	78	71
D. Other				
Optimal sowing (%)	100	97	96	100
Optimal date for first watering (%)	100	80	90	86
Optimal number of of irrigations (%)	100	16	80	74
Average number irrigations applied	7.4	5	6.2	6.4
Average yield (t/ha)	3.7	1.4	2.8	2.3
Number of farmers	18	80,000	111	111

Source: Ageeb et al. (1990), Sudan Gezira Board, Annual Reports (Various issues), Survey data (1989-90), SG 2000, Annual Reports (1989 and 1990), and Faki (1991).

improved wheat technologies in Gezira. The adoption of timely and adequate applications of fertilizer and water inputs has been the lowest compared to adoption of the mechanical components (except for mechanical application of fertilizer) and recommended varieties (Debeira and Condor). This is primarily due to differences in the way input markets are organized in Gezira.

While the Gezira Board is responsible for the procurement and distribution of seeds and fertilizers to farmers, most of the mechanical operations are hired from private dealers in the scheme. The level and timeliness of fertilizer application are accordingly beyond farmers' control, whereas private market arrangements seem to function more efficiently in delivering machinery services. This could be the main reason behind the low adoption of the chemical relative to the mechanical components of the new technology. Similarly, the number of irrigations a farmer is able to apply depend on several variables such as total water availability (rainfall, river level, etc.), and location of the farm in the scheme and along the irrigation canal. This indicates that, while government monopoly in the fertilizer market is a barrier to higher adoption and yields, physical and infrastructure constraints limit the ability of Gezira farmers to exploit yield gains from adequate irrigation. On the other hand, government control of seed supplies was effective as the Gezira Board was able to deliver seeds of the recommended cultivars to the vast majority of farmers.

Market distortions are relatively easy to eliminate through more liberal policies for input procurement and allocation. On the other hand, improving the supply and distribution of irrigation water may require substantial investments in rehabilitation of the existing irrigation infrastructure to increase the carrying capacity and conveyance efficiency as well as the overall water supply to the scheme.

As mentioned earlier, the relatively higher adoption rates among SG 2000 farmers compared to the average for the scheme explains the wide yield gap between the two groups. Farmers participating in SG 2000 demonstrations are selected by the Department of Agricultural Extension of the SGB. Demonstration sites are changed every year to test the new technology under a wide range of farm conditions and to diffuse the package to larger proportions of the farming population across the scheme. The extension department personnel together with SG 2000 staff explain the advantages of the recommended practices to farmers and facilitate the early arrival of machinery and inputs to participating farmers and supervise application of the technological components in farmers' fields. These farmers can, therefore, be considered favored as they enjoy relatively more timely and adequate deliveries of the recommended inputs. However, the higher adoption rates and yield advantage among ex-SG 2000 farmers (Table 1) indicate the effective role of SG 2000 field demonstrations in the transfer of wheat technologies in Gezira.

Economic Efficiency and the Comparative Advantage of Wheat Production in Gezira

This study uses the domestic resource cost (DRC) framework to evaluate the comparative advantage of wheat compared to alternative uses of Sudan's irrigated land resources in Gezira. Results obtained from previous DRC studies in Sudan are mixed and inconsistent (Ministry of Finance and Economic Planning 1992 and 1989, Nashashibe 1980, Sigma One Corporation

1983, Jansen 1986). Wheat has shown a comparative disadvantage in most of these studies. These studies, however, suffered common problems. First, none of them evaluated the efficiency of the potential new wheat production technology recently released and tested by ARC and SG 2000. Second, analyses and results in these studies were based on calculating nominal levels of costs and returns with no attempt to separate technical coefficients from prices. The results of these studies were therefore useful for only one year, as they cannot be easily updated to examine the validity of the conclusions under changing relative prices, technologies, and policy environments. In this study, costs and returns are decomposed into technical parameters and nominal values (prices) for quick updating.

The DRC framework

Wheat must show a comparative advantage over alternative crops available to Gezira farmers in order to attract research and production resources. For wheat to be the most efficient user of Sudan's irrigated land resources, the foreign exchange cost of producing wheat locally must be less than its import price. This, however, is sufficient for economic efficiency only when other production alternatives are not available, in which case the opportunity cost of domestic resources used to produce wheat will be zero.

The DRC ratio (Appendix 1) measures relative efficiency of wheat compared to the other enterprises in terms of the cost of domestic resources in local currency required to save or generate one unit of foreign exchange. This coefficient is then compared to the effective or parallel exchange rate. An alternative measure of economic efficiency that is easier to interpret is the Resource Cost Ratio (RCR). The RCR is obtained when both the numerator and denominator are expressed in the same currency units. A value of RCR between 0 and 1 implies that value added per unit of product is larger than the value of domestic resources used to produce that unit, and wheat has comparative advantage.

The major difficulty with using DRC and RCR methods relates to valuing inputs and outputs. This is particularly so when choosing the appropriate price for nontraded factors such as land, labor, capital, and water, especially when no market for the resource exists. Also, the prices of tradable inputs often do not correspond to their true economic value due to market imperfections and government intervention to control prices and ration the distribution of goods, resulting in distorted prices. The DRC framework therefore distinguishes between economic and market (private) prices. For prices to reflect the true economic value of resources and products, and for properly evaluating the economic efficiency of alternative productive uses of a country's resources, policy distortions must therefore be removed.

Competition for agricultural resources in Gezira

Competition among the four crops grown on the scheme (wheat, cotton, sorghum, and groundnut) is influenced by the capacity of the irrigation infrastructure and the cropping sequence and calender.

Land and irrigation water—Currently, the Gezira irrigation network can support only 50% cropping intensity—that is, only 50% of the land can be irrigated at one time. By introducing wheat as a winter crop in the rotation, 75% cropping intensity was possible on the 0.9 million hectares comprising the Gezira and Managil Extension Schemes. However, bottlenecks occur when some operations overlap. Nevertheless, 210,000 ha (25% of the land) remain idle during the fallow phase of the

current cropping structure in Gezira. This indicates that area planted to wheat (210,000 ha) can easily be doubled if the capacity of the irrigation infrastructure on the scheme is increased. Insufficient irrigation water is therefore the main factor limiting area expansion in the Scheme.

While land is currently not a limiting factor for expanding wheat production in Gezira, wheat competes for irrigation water with the other crops in the rotation, mainly cotton. Cotton is the only crop with a growing season that extends over the production cycle of wheat through winter, and hence competes with wheat for irrigation water. The peak demand for water occurs between mid-October and mid-November, especially when the sorghum and groundnut harvest is delayed and overlaps with the first irrigation and planting of wheat.

Labor and mechanical power—Wheat cultivation in Gezira is highly mechanized and unlike cotton requires little labor. Only three major operations overlap in wheat and cotton production: irrigation, weeding, and harvesting. The fact that wheat is not weeded and is mechanically harvested, whereas cotton weeding and harvesting are labor intensive, makes competition for labor and machinery between the two crops minimal. Given this situation, the present study considers cotton to be the major competitor with wheat and irrigation water to be the most limiting resource in Gezira.

Feasible wheat technologies in Gezira

Analysis revealed that, while yield levels achieved under full package wheat are considered a feasible alternative for Gezira, they may not be attainable by all farmers in the scheme for several reasons. First, the ARC full package of wheat technology was tested in the fields of 18 farmers in only two blocks (nine cooperating farmers per block) out of the 107 blocks in Gezira. This represents a relatively small demonstration. Second, yield levels achieved under large-scale testing of the new wheat technology by SG 2000 in fields scattered over 43 blocks across Gezira (1,635 ha in 1990) averaged 2.8 t/ha for the same period, only 75% of the average yield achieved in the full package demonstrations of ARC (Table 1).

The quality and quantity of inputs and operations applied under ARC supervision, among other things, are considered the major reason behind the high yields achieved with the full package of wheat technology. The prospects for all farmers in the Scheme to achieve the same precision and timeliness in applying the recommended technology are not very high given the current adoption rates. This is particularly true for inputs such as irrigation water, for which the level and allocation are not controlled by farmers or scheme management. Only 16% of the Gezira farmers were able to apply seven irrigations on wheat in 1990 (SGB 1990). This indicates that, even if all other inputs were made available at the right time to all farmers, irrigation water cannot be evenly distributed across the 0.9 million ha Gezira Scheme, and thus a large number of farmers may not be able to apply enough water to achieve potential yields.

Accordingly, an intermediate technology was evaluated to represent partial adoption of the full ARC wheat technology due to unavailability or delays in delivering inputs to farmers. The intermediate technology deviates from the full package mainly in using no phosphorus, less than seven irrigations, and conventional levelling. The three technology levels—the traditional practices that have dominated wheat production in Gezira, the full package of

new wheat production methods used in ARC demonstration plots, and the intermediate technology used at the Gezira Pilot Farm—are described in Table 2.

For the intermediate technology, average yields obtained on the Gezira Pilot Farm are adjusted to levels attainable under farmers' conditions and management using the 82% achievement factor of former SG 2000 farmers in Table 1. A similar achievement factor (82%) was used to adjust average full package yield levels obtained on ARC demonstrations. The 20-year average yield (1967/68-1987/88), adjusted for farmers' under-reporting of wheat yields in Gezira, was used as the yield level attainable under traditional practices. Earlier research estimated the under-reporting of wheat production in Gezira at 25% (Saleh 1983, Hassan 1989). Lack of information on potential improvements in cotton practices precluded the use of alternative technology levels for cotton production in the scheme.

The DRC analysis performed in the next sections of this paper accordingly evaluates the economic efficiency of existing as well as potential wheat technologies in using the country's irrigated agricultural resources, compared to the current practices on cotton in Gezira.

Private and Social Profitability of Wheat

Enterprise budgets were constructed for the profitability analysis. Technical coefficients for the physical input-output relationships associated with the production and marketing of the two competing crops, wheat and cotton, were compiled from various surveys (Hassan et al. 1993). Two regimes, described below, were used to price inputs, services, and products.

Market pricing

Actual prices at which farmers buy inputs and sell output were used to compute private profitability. These prices are mainly determined by the government and contain various distortions resulting from overvalued exchange rates and indirect taxation on imports and exports. Imported inputs and products were priced at different exchange rates set by the Sudan Government. Border prices were adjusted for handling and transport costs and all direct and indirect subsidies and taxes.

The average wage rate in the Scheme was used as the price of labor. Land, water, and capital, on the other hand, are not freely traded in Gezira, although farmers are charged for their use by the Gezira Scheme administration. Tenant farmers have access

Table 2. Wheat technologies in the Gezira Scheme.

Practice	Traditional technology	Potential intermediate technology (Pilot Farm)	Potential full package (ARC technology)
Seed rate (kg/ha)	120	143	143
Nitrogen (kg/ha)	43	86	86
Phosphorus (kg/ha)	0.0	0.0	18.4
Disc harrow	No	Yes	Yes
Number of irrigations	5	6	7
Levelling	No	Conventional	Precision
Planting method	Broadcast	Mechanical	Mechanical
Yield (t/ha)	1.28	1.89	3.05

to subsidized credit from the SGB at 10% interest, whereas the commercial interest rate was more than 20%. The effective price of capital was therefore considered to be 10% for computing private returns.

Economic pricing

For the analysis of social profitability, market prices of tradable inputs were adjusted to reflect the true economic values of commodities. World prices were thus converted into Sudanese pounds using the shadow rates of exchange. Before adopting the "crawling-peg" regime in February 1992, none of the multiple exchange rates in effect provided an adequate estimate of the scarcity value of foreign currency in Sudan (El Badawi 1990, Brown 1992). While the official and parallel rates set by the government overvalued Sudan's currency, the free market rate contained a large risk premium, since the market was illegal.

Private and social profitability were compared and the extent of distortions in relative prices was examined in this study for the 1990 data when surveys were conducted. The free market exchange rate prevailing in 1990 (Ls 24.6 = US$ 1) was used as the shadow price of foreign currency. At the same time, the flexible exchange rate set at Ls 89.7 in February 1992 was used with trend prices to evaluate social profitability and test for the sensitivity of the results to exchange rate adjustments.

Similar to the market for foreign exchange, there is more than one source and price for capital in the Gezira Scheme. These sources include: 1) subsidized credit extended by the SGB to its farmers at 10% interest, 2) the commercial rate of return on investment in the Islamic banking system of Sudan, which averaged above 20% in 1990 (Survey of Commercial Banks, Khartoum 1990), and 3) the free market rate prevailing in informal money markets, which ranged between 50 and 100% in 1990 (Survey of wheat farmers in Gezira, 1990). Given that the rate of inflation was about 25% in 1989-90 (Ministry of Finance 1990), informal money markets provided the only investment with positive real returns. Sensitivity analysis was performed in this study by using two rates as the opportunity cost of capital to generate a real rate of return of 5 and 15%, respectively, given the current rate of inflation. As the labor market is considered competitive in Gezira, the average wage rate on the scheme was used as the opportunity cost of labor. Land and water are not traded in Gezira. The analysis therefore derives private and social returns to land and water.

Table 3 presents net private and social returns per hectare and per millimeter of irrigation water, derived (at 1990 prices) from detailed crop budgets. Private profitability calculated at 1990 market prices (Table 3, section A) indicates that wheat dominates cotton with the highest net returns realized for the full package of wheat technology. However, this ranking changes under economic pricing (Table 3, section B). While full package wheat continues to generate the highest social returns per millimeter of irrigation water, cotton dominates intermediate technology and traditional wheat practices, which are the most common in Gezira.

Social pricing reveals distortions created by the various input and output pricing policies that were in effect in Sudan in 1990. Table 3, section C measures such policy distortions by calculating the net policy effect (NPE) and effective production ratio (EPR) for the competing crop enterprises. The negative values of NPE and of EPRs less than unity indicate that both cotton and wheat producers were heavily taxed in 1990. On the other hand, Gezira farmers benefitted from indirect subsidies on fertilizers and machinery through the

overvalued exchange rates applied to these imports. At the shadow exchange rate, however, the tax on product prices was higher in 1990 than the subsidy on prices of inputs used per hectare of wheat and cotton. Table 3 shows that, if the shadow exchange rate of Ls 24.6/US$ 1.0 was the true value of Sudanese currency in 1990, traditional wheat growers in Gezira paid a net tax of more than Ls 30,000 (or US$ 1,300) on their cotton/wheat tenancy, i.e., US$ 620/ha.

These results indicate that cotton production bears a much higher tax compared to wheat in Sudan. Such distortion in relative prices and terms of trade can bias the structure of incentives against cotton and leads to inefficient allocation of productive resources away from cotton and into wheat. In brief, Table 3 indicates that, unless the improved wheat production technology of the ARC is fully adopted, wheat cannot compete with cotton for a socially optimal allocation of productive resources in Gezira. Farmers, however, will continue to earn higher returns on wheat than cotton if current price policies continue to tax cotton production relative to wheat.

The domestic resource cost analysis

The DRC analysis assumes that the availability of irrigation water is limited, so water has a positive opportunity value independent of pumping costs. Net social returns to land and water in the best production alternative were therefore used to determine the opportunity cost of irrigation water, as there is no market for irrigation water in Gezira.

Economic prices were computed for the survey year (1990) using the 1990 prices and the free market rate as the shadow price of foreign exchange (Table 3). In order to provide for the important policy changes that took place in Sudan in 1992, such as the movement towards liberalized trade and prices and adoption of a flexible exchange rate regime, the 1990 analysis was updated as follows (see Table 4):

- Long-run trend prices of wheat, cotton, fertilizer, and machinery were derived for the year 1992. Trend prices were derived from linear regressions fitted to 25 years of price data for 1965-1990.

Table 3. Net private and economic returns to land and water in Gezira (1990 prices).

	Cotton		Wheat Technologies		
	Long staple	Medium staple	Traditional	Intermediate	Full package
A. Net private returns to land (Ls/ha)	1,278	828	2,884	4,444	7,975
Net private returns to water (Ls/mm)	0.4	0.3	2.4	3.0	4.7
B. Net economic returns to land (Ls/ha)	15,360	16,944	4,094	6,164	11,009
Net economic returns to water (Ls/mm)	5.2	5.8	3.4	4.2	6.4
C. Measures of policy distortion[a]					
NEP(A-B)(Ls/ha)	-14,082	-16,166	-1,210	-1,720	-3,034
EPR	0.22	0.20	0.71	0.72	0.73

[a] NEP denotes the net policy effect and EPR the effective protection ratio. EPR is the ratio of value added (VAD) at market prices to the VAD at social prices.

- The unified exchange rate of Ls 89.7/US $1.00 adopted in 1992 was used as the shadow price of foreign exchange.
- Economic prices of domestic resources were updated for prices ruling in 1992.

When DRC ratios were calculated for the five crop enterprises using long-run price trends in 1992, long-staple cotton dominated the three wheat technology levels. While traditional and intermediate level wheat technologies are highly inefficient under trend prices (Table 4), the dominance of long-staple cotton (RCR of 0.99) over full package wheat (RCR of 1.16) is very weak.

Sensitivity analysis and the efficient range for wheat production in Gezira

Since DRC results are based on partial equilibrium methodology, linear and static technology, and assumptions of constant prices, their validity should be further tested under conditions that deviate from the basic assumptions of the DRC framework.

The effect of technical change in wheat production has been incorporated to some extent in the above analysis by calculating the efficiency of wheat production at various technology levels. Changing world prices and their effects on such measures of economic efficiency have also been tentatively explored in the previous analysis. Other factors, however, are important to determining the economic efficiency of wheat production in Gezira. A major deficiency of the present study is the assumption of a single technology level for cotton, i.e., no technological progress in cotton production. This was due to lack of data on alternative cotton practices that might lead to potential improvement in production methods.

Moreover, due to a number of processing and marketing problems that have seriously affected the quality of Sudan's cotton, Sudan has been selling its cotton for almost half the world price of comparable products, such as Egyptian cotton. In 1989, Sudan sold its long-staple cotton (average grade) for US$ 0.98/lb, whereas Egypt received about US$ 1.8/lb for the same extra-fine cotton grades (Cotton Marketing Corporation 1990). If

Table 4. Resource cost ratios for cotton and wheat enterprises in the Gezira Scheme under economic pricing (shadow exchange rate).

	Cotton		Wheat Technologies		
	Long staple	Medium staple	Traditional	Intermediate	Full package
1990 prices(US$/t)	1,958	1,530	170	170	170
Net economic returns (Ls/mm)	5.2	5.8	3.4	4.2	6.4
Value added (Ls/mm)	6.3	7.0	4.5	5.4	5.6
Resource cost ratio	1.2	1.1	1.7	1.4	0.9
Long-run trend prices for 1992(US$/t)[a]	2,025	1,575	140	140	140
Net economic returns (Ls/mm)	19.8	19.6	9.2	11.1	16.8
Value added (Ls/mm)	21.8	21.8	11.8	13.7	19.4
Resource cost ratio	0.99	1.01	1.91	1.64	1.16

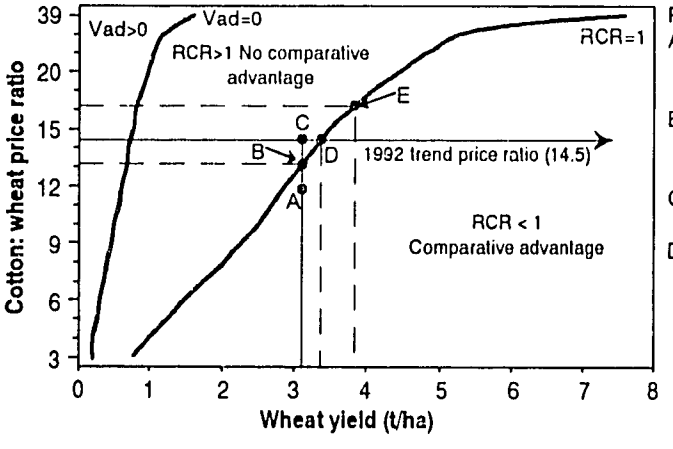
[a] The long-run trend prices were obtained from a linear regression of 25 years time-series price data (1965-90).

improvements are achieved on the marketing front, the potential for a much higher price for Sudan's cotton is great. While an investigation into the potential gains from research and investment in improving the cotton processing and marketing infrastructure in Sudan was beyond the scope of this study, it is important to test the efficiency limits of wheat production in Gezira against possible movements in the world cotton to wheat price ratio. This is also important given the many imperfections in the world wheat market and the prospects for higher world wheat prices in the future, despite recent trends of declining wheat prices with increased competition among suppliers and the record harvests of 1990-91. The weak dominance of long-staple cotton under trend prices, plus the fact that world wheat prices are expected to rise by 15 to 30% due to changing world trade regimes and lower subsidies on wheat production and exports (CIMMYT 1991), provide additional reasons for examining the sensitivity of the RCR results to changing relative prices.

RCRs were therefore recalculated for different levels of relative cotton to wheat prices. The sensitivity analysis helped delineate the region of economic efficiency of wheat production in Gezira, including threshold yields. Appendix 1 describes the procedure used to delineate efficiency ranges and yield levels at which wheat production is efficient in Gezira.

Figure 2 defines threshold levels of wheat yield and efficiency range for the full package of improved wheat production practices in Gezira over a range of relative prices of long-staple cotton to wheat. Table 5 compares yield levels realized under the three wheat technologies considered in this study to threshold yields.

Figure 2 and Table 5 indicate that the three wheat technologies are dominated by cotton at the 1992 trend prices (point C on the graph). While the actual cotton price was higher, wheat was traded at a price lower than the long-run trend prices in 1992, and thus wheat was even less efficient at actual price levels. Results of the sensitivity analysis also show that the world wheat price has to rise to US$ 155 for the full package wheat technology to become efficient at current yield levels (point B in the figure and row 3a of Table 5). This means that the world wheat price has to be



Points on the graph

A. Position of full-package wheat (FPW) at the 1990 price ratio (11.5) - dominating.
B. Threshold price ratio (13.1) for FPW efficiency region at current yield levels (3.1 t/ha).
C. Position of FPW at the 1992 trend prices (inefficient).
D. and E. indicate Threshold yield (3.4 and 3.8 t/ha) for FPW to become efficient at the 1992 trend and actual prices, respectively.

Figure 2. Efficiency range for full-package wheat technology in Geriza-trend prices.

about 11% higher than the 1992 trend price for full package wheat to become the most efficient alternative in Gezira. This measures the narrow margin of economic efficiency and dominance of long-staple cotton over full package wheat in terms of relative and absolute price movements. This is an important factor since the prospects for a stronger world wheat price may be higher under the unfolding new international economic order of freer world trade.

Moreover, Table 5 shows that for yield levels currently obtained in Gezira under traditional practices to become efficient, the import price of wheat has to be higher than US$ 240/t, which is more than 70% higher than the 1992 trend price and about three times the price of wheat in the first half of 1991. This indicates that a substantial shift in the relative world prices of cotton and wheat is needed for the traditional wheat practices currently followed by the vast majority of farmers in Gezira, to compete with cotton for the irrigated land resources of the scheme. Sensitivity analysis results also show that wheat yields in Gezira needs to rise by 10, 47, and 67%, respectively, from their current levels for full package, intermediate, and traditional wheat technologies to compete with long-staple cotton at the 1992 trend prices (row 5 of Table 5 and point D on Figure 2).

Table 5. Threshold and current yields (t/ha) for the 1990 and 1992 prices (US$/t) of wheat and cotton.

	Wheat technologies		
	Full package	Intermediate technology	Traditional practices
1. CIF trend prices, 1992(US$/t)	140.0	140.0	140.0
2. Price ratio of long-staple cotton to wheat	14.5	14.5	14.5
3. Threshold price ratio for efficiency at current yield levels[a]	13.1	9.5	8.1
a. Threshold price of wheat (US$/t)	155.0	213.2	248.9
b. CIF world prices, 1990 (US$/t)	170.0	170.0	170.0
Price ratio	(11.5)	(11.5)	(11.5)
c. CIF world prices, 1992 (US$/t)	125.0	125.0	125.0
Price ratio	(16.9)	(16.9)	(16.9)
4. Currently feasible yield levels (t/ha)	3.1	1.9	1.28
5. Threshold yield (t/ha) for production efficiency (RCR>1) at trend prices[b]	3.4	2.8	2.16
Percent yield increase required	10%	47%	67%
6. Threshold yield (t/ha) for efficiency at actual 1992 prices[c]	3.8	3.1	2.38
Percent yield increase required	23%	63%	86%
7. Threshold yield (t/ha) for positive returns (VAD>0) at trend prices	0.9	0.5	0.3

a, b, and c correspond to points B, C, and D of Figure 2, respectively.

Also, one should not forget the fact that Sudan currently receives about half the world price of comparable kinds of cotton due to quality problems in its lint exports. This also shows the high potential returns to investment and research directed toward more efficient cotton processing and marketing, which would improve the quality and competitiveness of Sudan's cotton exports and thus decrease the attractiveness of wheat.

Conclusions

Relative profitability and the DRC methodology were used to evaluate the comparative advantage of the existing and potential wheat technologies versus cotton in Gezira to determine if wheat represents the most efficient option for using Sudan's irrigated land resources. Results of the DRC analysis indicate that, while wheat dominates cotton when the complete package of improved wheat production methods is applied, the traditional wheat production practices used by the vast majority of Gezira tenants and the intermediate technology level tested in the Scheme are highly inefficient compared to cotton at 1990 prices. However, long-staple cotton dominated all wheat technologies (including full package) at the actual and trend prices in 1992.

Sensitivity analysis showed that it will require a world wheat price that is 11% higher than its long-run trend for full package wheat to become the most efficient alternative in Gezira. As wheat prices are currently below their long-run average, and since average yield levels in Gezira are much lower than potential yields obtained under the full package of improved wheat technologies, at present it may not be economically efficient for Sudan to expand wheat production at the expense of cotton in Gezira. Before more land and water are switched from producing cotton to wheat, the gap between potential and farmers' wheat yields needs to be closed so as to make wheat farming in Gezira efficient. According to sensitivity analysis results, Gezira tenants who currently produce wheat using traditional methods would have to raise their yield levels by more than 80% to compete with cotton at the 1992 price levels, i.e., from 1.28 to 2.4 t/ha.

Policy makers in Sudan must therefore focus on removing the obstacles to higher and faster adoption of improved wheat production technologies tested by ARC in Gezira. Input procurement and delivery systems need to be liberalized for more efficient and timely utilization of modern inputs. More flexibility is also needed in allocating land and other resources among competing crops within the public irrigation schemes so that employment of domestic resources can respond to changing international economic opportunities.

On-farm testing of the new wheat technology in Gezira should continue, particularly at locations where water shortages are severe, to realize the true range of yields that can potentially be obtained in the Gezira Scheme. Adaptive research should attempt to modify the package of wheat technologies currently promoted by ARC to suit different locations in the scheme. It is also important for Sudan to invest more research resources and efforts to refine the lint quality and improve the marketing processes of its cotton crop. This is crucial for the question of economic efficiency, as potential yield gains from improved wheat production methods need to be weighed against potential gains from quality upgrading in cotton.

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Appendix 1: The Domestic Resource Cost (DRC) Framework

The DRC method (see Monke and Pearson 1989 and Morris 1989) provides the analytical tool for evaluating economic efficiency among alternative enterprises. The basic formula for the DRC ratio is shown in equation 1:

$C_i = \Sigma_r N_r X_{ri} / (P_i Q_i - \Sigma_j R_j Q_{ji})$ where:

- C_i measures the value of domestic resources used in saving or generating a unit value in activity i,
- N_r is the opportunity cost price of nontradable primary factor r,
- X_{ri} is the quantity of factor r used in activity i,
- P_i and Q_i are the import or export parity price and quantity of tradable product i, and
- R_j and Q_{ji} are the import or export parity price and quantity of tradable input j used in activity i.

The denominator of equation 1 derives value added in activity i (VAD_i) and the numerator calculates the economic value or cost of domestic resources (CDRS) used to produce Q_i. When CDRS is expressed in local currency and VAD in foreign currency, C_i computes the DRC ratio of activity i. Thus, the DRC analysis measures relative efficiency in terms of the cost of domestic resources in local currency required to save or generate one unit of foreign exchange. This coefficient is then compared to the effective or parallel exchange rate.

An alternative measure of economic efficiency that is easier to interpret is the Resource Cost Ratio (RCR). The RCR is obtained from equation 1 when both the numerator and denominator are expressed in the same currency units. The value of RCR is then interpreted as follows:

- $0 < RCR_i < 1$ implies that value added per unit is larger than the value of domestic resources used to produce that unit; thus i has comparative advantage.
- $RCR_i > 1$ implies no comparative advantage.
- $RCR_i < 0$ implies that the value of the foreign and domestic tradables used to generate one unit of i is larger than the unit price of i (negative value added); hence there is no comparative advantage.

Threshold Yield and Efficiency Range Analysis

It is clear from equation 1 that the RCR of wheat is a function of the price of cotton, as the price of cotton determines the social value of land and irrigation water and hence affects the value of domestic resources—CDRS (numerator of equation 1).

$$RCR_w (P_w, P_c, P, a) = [CDRS (P_c, a)] / [VAD(P_w, P, a)] \quad (2)$$

Equation 2 defines the RCR of wheat (RCR_w) as a function of the price of wheat (P_w), price of cotton (P_c), and a vector of other prices (P), and technology and policy parameters (a). To test the sensitivity of the results to changing relative world prices, the following relationships between efficient wheat yields and the relative prices of cotton and wheat are defined:

- Threshold yield. Used to define the range of wheat yields (Y_w) below which the value added (VAD) is negative, i.e., local wheat generates foreign exchange losses;
  $VAD = Y_w P_w - \Sigma_i P_i Q_{iw}$ (3)

  From equation 3, threshold yield levels are defined along the curve at which VAD is equal to zero. Rearranging equation 3 leads to:
  $Y_w = (S_i P_i Q_{iw})/P_w$ (4)

  Holding constant the numerator of equation 4, we solve for levels of wheat yield (Y_w) for different levels of the international price of wheat (P_w).

- Efficiency range. Represented by the area in which $0 < RCR_w < 1$. Rearranging equation 2 according to the condition that RCRw = 1, we get:
  $CDRS(P_c, a) = VAD (P_w, P, a)$ or,
  $Yw = [CDRS(P_c, a) + S_i P_i Q_{iw}]/P_w$ (5)

  Holding other variables constant, equation 5 is used to solve for levels of Yw for various combinations of Pc and Pw.

Some Indicators for Wheat Production Prospects in Sudan

H.H.M. Fakl
Agricultural Research Corporation, Wad Medani, Sudan
M.A. Ismail
Sudan Gezira Board, Barakat, Sudan

Abstract

Sudan's strive towards wheat self-sufficiency has been accompanied by government support, control over wheat production and disposal, and high research input. Future prospects will be affected by farmers decisions under liberal production policy and subsidy removal. This paper addresses factors that may influence farmer decisions. Rising by five fold over the past three decades, high and increasing wheat demand has been well established, especially in urban areas. Despite the potential for high yields, wheat profitability and its contribution to farm income have been relatively low. While its yield variability, due to variation in winter temperatures, has been high, its yield trend has been significantly rising. Wheat represents a logical choice in most irrigation schemes due its utilization of land, water and capital at their slack periods and its limited use of labor when its requirements in other crops are high. Cotton is the main competitor to wheat in the use of winter water. Although wheat has lower gross margins per unit of land and irrigation water than cotton, those to labor and cash capital are higher. With improved technology, its returns to land and water are even comparable to those of cotton. Under a free crop choice, the wheat area would exceed half a million hectares at optimum crop organization in the irrigated sector. About one third of that area would be at a low technology level. Limited subsidy or increased input availability would lead to desired national production targets. The effect of wheat price on production is reflected by a relatively high supply elasticity. Its substitutability to sorghum is manifested by their high cross supply elasticities. With improved technology, wheat yields and farmers incomes will significantly improve. Current input/output price relationships would, however, induce lower input levels that would induce lower total wheat production.

Introduction

Sudan has strived for the last three decades to attain wheat self-sufficiency. This has been accompanied by large efforts towards crop adaptation to the relatively less favorable environments within the irrigation systems in central and eastern Sudan. Since this also entails economic viability of wheat to farmers there, the government has until recently practiced control over its production process, its prices and its disposal avenues. The provision and pricing of inputs and the determination of wheat farm-gate prices were manipulated to ensure a profit margin to the average farmer.

Except for northern Sudan where private production and marketing are usually practiced, the bulk of the wheat is produced in government irrigation schemes. These comprise the Gezira, New Halfa, Rahad, and the Blue and White Nile pump schemes, which together accommodate more than 90% of the crop. The

administrations in these schemes determine wheat areas and cultivars, provide or organize land preparation, supply inputs including seed, fertilizers, pesticides, and arrange for harvest and crop delivery to flour mills. Inputs are credited to farmers whose responsibility is to supply their own or hired labor for manual operations. Prices were determined annually based on expected production costs and the parity price of imported wheat.

Bread prices have been controlled at subsidized levels to consumers. The subsidy, which constitutes the difference between the price paid to farmers and that charged to bakeries, is substantial and constitutes a burden on government expenditures. It was estimated at 4% of the government expenditure in the 1987-88 budget (Ministry of Finance and Economic Planning 1988).

On the other hand, research has provided technologies that have resulted in tangible wheat yield improvements. However, despite government support and the increase in the wheat yield potential, wheat profitability for producers has been relatively low. Questions arise on the competitiveness of wheat and its production prospects if farmers in irrigation schemes are to make their own decisions on the desirable crop mix. The issue gains utmost importance through the recent government policies that aim at greater liberalization in the production process and a consistent removal of subsidies on wheat bread.

The objective of this paper is to assess some economic indicators that are expected to influence farmers' decisions on wheat production aspects under limited government controls in irrigation schemes. The indicators considered in postulating farmers response are: 1) the nature and development of wheat demand, 2) wheat financial benefits to producers, 3) wheat yield variability, 4) wheat position and its competitiveness in the farming system, and 5) the economic assessment of technology use in wheat.

Wheat Demand

Reliable figures on wheat demand in Sudan are difficult to obtain due to continued price fixation and the persistence of short supplies whether of domestic or external origin. However, it is evident that a substantial part of the demand has remained unsatisfied. This is especially apparent in urban areas where the bulk of the wheat is consumed. The rising wheat demand is, however, reflected by actual wheat consumption, which has increased enormously during the last three decades. The current average per capita consumption is over 33 kg as compared with 20 kg in 1971 and 6 kg in the early 1960s. Sudan currently consumes about 850,000 t, met by local production for the first time during the 1991-92 season.

The driving force for wheat demand in Sudan is urbanization, rising incomes, and population growth. According to projections based on 2.8 and 5% rates of growth in population and income, respectively, wheat demand is expected to exceed 1 million tons by the mid-1990s (Ministry of Finance and Economic Planning 1988).

Most of the demand is concentrated in urban areas where wheat has largely replaced the use of sorghum. Except for northern Sudan and the New Halfa area in eastern Sudan, sorghum and millet represent the stable food sources in rural areas. Based on established consumption habits in urban areas, the price elasticity of

wheat demand is expected to be low, reflecting a relatively stable per capita consumption level. With an estimated figure of 0.8, income elasticity is, on the other hand, relatively high (Ministry of Finance and Economic Planning 1988) and indicates expectancy of high consumption with rising incomes. With increased urbanization, the demand for wheat is expected to increase.

There is substantial room for substitution between wheat on one hand and sorghum and millet on the other hand, but such substitution is relatively low in urban areas. It will take considerable time until a shift in preference is reversed towards sorghum consumption.

The above points show that the demand for wheat will remain high and that production should respond to the ever-rising requirements if demand is adequately reflected to producers through the correct price signals.

Financial Benefits of Wheat for Producers

The bulk of wheat production has shifted gradually through the years from the north to the sorghum-consuming areas in central and eastern Sudan. Essentially, wheat represents a cash crop in its most important producing areas. It has to profit producers and should fit in current farming systems so that its production can be maintained or expanded. Profitability represents a major indicator in this case. This can probably be reflected by the considerable wheat area fluctuations in Northern Sudan. Despite the consumption needs of the population there, the variations in wheat area and its share of total cultivated area have been largely associated with farmers' response to the market.

Wheat profitability is reflected by comparing its average net returns and its contribution to total farm income with those of other main crops in three irrigation schemes over the 1981-92 period (Table 1).

Table 1. Net returns from crops[a] in irrigation schemes and their relative share in farm income, 1981-92.

Scheme/Item	Cotton		Wheat		Groundnut		Sorghum	
Net returns (Ls/ha)[b]:								
Gezira	26	(78)[d]	173	(97)	391	(96)	158	(81)
New Halfa	304	(52)	206	(77)	421	(76)	128	(96)
Rahad[c]	220	(34)	153	(70)	383	(108)	220	(125)
Average	260	(55)	177	(81)	398	(93)	169	(101)
% of total income								
Gezira	39		21		29		11	
New Halfa	45		24		26		5	
Rahad	50		7		35		18	
Average	45		17		30		11	

[a] Computed at the 1981-82 price level.
[b] Ls = Sudanese pound; exchange rate in 1981-82 was Ls1.31 to US$1; current exchange rate is Ls127 to US$1.
[c] Wheat averages for Rahad are only for the last two seasons.
[d] Figures in parentheses are standard deviations.

Net returns in Table 1 are calculated at the 1981-82 price levels by deflating actual values by the official exchange rate of the Sudanese Pound (Ls) to the US Dollar. With an average net return of Ls177/ha, wheat ranked third among the four field crops. Its contribution to total tenancy net returns averages 17%, higher only than that of sorghum.

Yield Variability

With respect to its profitability, wheat variability is explained with the substantial yield variation over time. Table 2 shows the degree of variation of the main field crops in the Gezira and New Halfa irrigation schemes.

With a coefficient of variation of 35%, wheat variability was especially high in the Gezira Scheme. It was, however, more or less comparable to other crops in New Halfa, but slightly higher than groundnuts and sorghum. Taking into consideration that wheat receives much attention from the schemes' administrations and it enjoys uniform supply of inputs and management practices as compared to sorghum and groundnuts, its yield variability levels should have been lower.

Table 2. Variability in crop yields (t/ha) in Gezira and New Halfa, 1980-92.

	Gezira		New Halfa	
Crop	Av. yield	C.V. (%)	Av. yield	C.V. (%)
Cotton	1.50	24	1.44	26
Wheat	1.26	35	1.17	24
Groundnut	1.38	21	1.69	19
Sorghum	1.07	28	1.00	23

Source: Records of the Sudan Gezira and New Halfa Schemes.

On the other hand, yield trends are increasing in all schemes (Figure 1). Yield levels in northern Sudan are higher than those of other schemes. The increasing yield trend, mainly due to technological improvement, compensates for a considerable part of the risk due to yield variability. Despite the presence of many management factors that affect wheat yields within and across seasons, yield variability over time is largely explained by the variation in winter temperatures. Analysis of time-series data reflects significant correlation between average wheat yields in the Gezira and the mean temperatures in December, January, and February. Although the highest correlation (r=-0.75) was recorded for the mean temperature in February, canonical correlation of the yield with the mean temperatures in these months was also high (r=0.87).

Wheat Competitiveness

In spite of its relatively low returns, wheat possesses an important advantage as the most suitable winter crop option in the

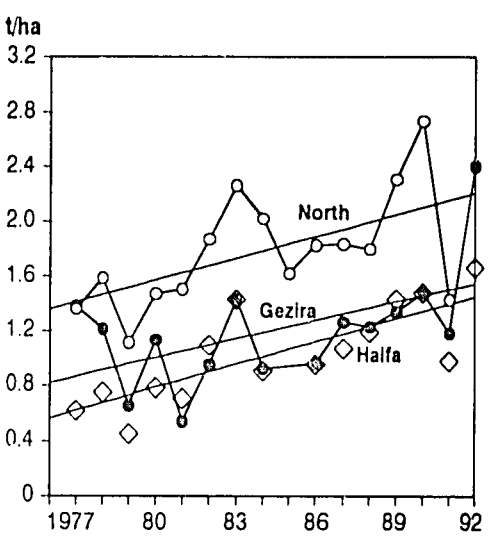

Figure 1. Wheat yield trends in three major production schemes.

cropping systems of the irrigation schemes. It utilizes land and irrigation water during a slack period and because of its low labor requirements, it does not compete for labor at peak harvest times of summer crops (Figure 2). Wheat is expected to be a logical choice as a winter crop for years to come. Vegetables and some other crops (faba bean, chickpea, and spices) compete on a small scale during the winter, occupying no more than 10% of the area available for winter cropping. Other potential crops may be winter fodder and winter maize, although their competitiveness has yet to be verified.

Wheat's cultivation should, nevertheless, be governed by its economic competitiveness and its area should be dictated by the availability of irrigation water. Cotton represents the main competitor for winter water and its area is, in turn, controlled by the extent of cultivation of summer crops, primarily sorghum and groundnuts. Some competition, however, exists with summer crops if their sowing is delayed in which case their irrigation continues into the winter months.

With the need to produce summer crops, particularly sorghum, cotton will not fully utilize the available water during winter. The degree of competitiveness between wheat and cotton is examined by a simple linear programming model, which maximizes total real net returns with water and land constraints only under the assumption of no overlap between summer crops and wheat. Figure 3 shows the results of wheat and cotton area combinations, delineated by varying the areas of summer crops and analyzed by a quadratic regression model. The two crops are complementary up to 181,000 ha of cotton, after which its expansion would result in nearly a proportional decrease in wheat area. This means that there are good opportunities to produce wheat if it is economically feasible. Further opportunities exist to expand on wheat area with reduced irrigation levels, lower than those estimated for optimum plant growth.

The competitiveness of wheat compared to cotton can be delineated by a comparison of their gross margins to scarce production factors at current costs and prices. This is depicted by Table 3 in which wheat is represented by three levels of technology that differ in fertilizer doses, number of irrigations, and land preparation practices. The low level utilizes 92 kg N/ha and six irrigations. The medium and high levels receive eight waterings and phosphate fertilizers while in the high level more land

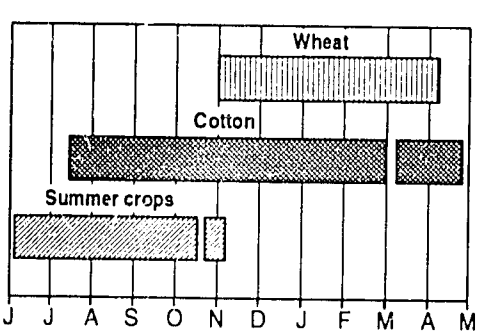

Figure 2. Cropping calender in irrigation schemes.

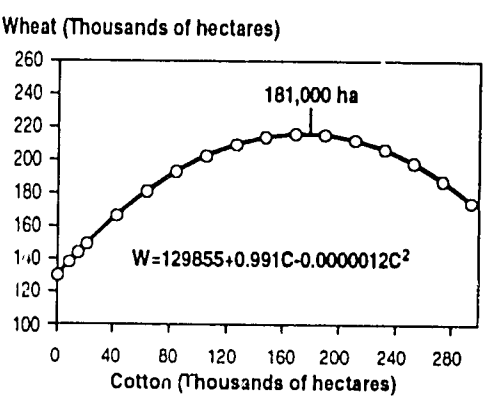

Figure 3. Relationship of wheat and cotton areas at optimum crop allocation and variable area of summer crops in Gezira.

preparation operations are performed. Cotton is represented by the cultivar Barakat at the usual management practices.

Despite its lower gross margins per unit of land and irrigation water, wheat returns to labor and cash capital outlays are higher. This provides the opportunity for wheat expansion in relation to cotton as labor, finance, and their costs become scarce. Moreover, use of high technology in wheat will be conducive to its higher returns to all factors including irrigation and land for which cotton is usually more competitive.

With respect to foreign exchange earnings, cotton has greater advantages over wheat. Assuming no imperfections in the input and output market, their respective value added were $899 and $350/ha. However, with high wheat technology, its value added will increase to $604/ha. Nevertheless, wheat has the advantage of lower foreign exchange requirements as compared to cotton, in spite of the reversed proportional requirements to their total production costs.

Taking constraints in irrigation schemes into consideration, a linear programming sector model was initiated using 1991-92 costs and prices to examine optimum cropping patterns in the irrigated sector with and without government intervention (Faki et al. 1992). Irrigation water, labor, rotation, and consumption requirements of sorghum were considered as the main constraints in each scheme while fertilizer was constrained at the sector level. Three

Table 3. Gross margins of wheat and cotton to production factors.

Item	Cotton (Long)	Wheat Low	Wheat Medium	Wheat High
Gross returns				
Average yield (t/ha)	1.685	1.428	1.904	2.856
Price (Ls/t)	40,889	16,000	16,000	16,000
Gross returns (Ls/ha)	68,901	22,848	30,464	45,696
Variable costs				
Machinery	4,367	4,248	4,415	5,548
Labor	6,426	1,142	1,571	2,047
Material	35,671	12,859	14,628	16,247
Other	5,650	0	0	0
Total	52,114	18,249	20,614	23,842
Factor requirements				
Labor (man days/ha)	166.6	14.3	19.0	23.8
Water (m^3/ha)	11,995	5,997	7,996	7,996
Cash capital (Ls/ha)	50,508	17,964	20,221	23,929
Efficiency indicators (gross margins)				
Land (Ls/ha):				
Including labor	16,786	4,598	9,850	21,854
Excluding labor	23,212	5,740	11,420	23,901
Water (Ls/m^3)	1.94	0.96	1.43	2.99
Labor (Ls/man day)	139	402	600	1,004
Cash (Ls/Ls/month)	0.051	0.053	0.094	0.171

Source: Authors' calculations based on estimates of the Sudan Gezira Board.
Ls = Sudanese pound.

technology levels were tested depending on the water and fertilizer amounts applied. Table 4 shows the results with respect to wheat areas, its production, and technology level.

Under a free farmers' decisions and with the prevailing input availability, the cropping pattern would include the cultivation of 528,000 ha of wheat, representing 43% of the net cultivated area in the irrigated sector and producing 758,000 t. About 51% of these areas would be in the Gezira Scheme. However, with such constraints on water and fertilizers, 30% of the wheat will be grown under low technology levels. With policy interventions to produce certain amounts of grains, high technology should be applied at the expense of input use in other crops. This applies, in particular, to schemes where extremely poor yields are obtained in the absence of adequate amounts of water and fertilizer.

Depending on the nature of policy options, wheat area would generally decrease as cotton area is increased. If the water supply is raised by 25%, wheat area and production would be enhanced. Further increases in cotton would lead to a reduction in wheat area even if full relaxation of inputs is achieved. However, the shift to high wheat technology use would result in attaining the same level of production.

In a scenario with increased input costs and crop prices, an assumption that simulates the present situation, both wheat area and its production would decrease by about 20%. Cotton would, by contrast, expand by more than five times. This indicates that

Table 5. Summary of average wheat productivity with on-farm trials in four irrigation schemes in Sudan, 1985-89.

Scheme	# of seasons	Yield (t/ha)	% yield increase	MRR (%)[a]
Gezira	4	2.776	62	643
New Halfa	4	2.036	89	532
Rahad	1	1.568	51	-
Blue Nile	1	2.198	120	940

[a] Marginal Rate of Return (% increase in net benefits over that in variable packages costs).

Source: Coordination Meeting of the Nile Valley Regional Program on Cool Season Food Legumes and Wheat (1991).

Table 4. Wheat area (000 ha), production (000 t), and technology use (% of farmers) in the irrigated sector with different policy options.

Policy options	Area	Prod.	Technology	
			High	Low
Free cropping pattern	528	758	70	30
Approx. of current pattern, relaxed input availability	371	653	75	25
Cereal production targets and fixed cotton area	302	600	90	10
Cereal and cotton production targets and 25% more water	489	770	80	20
More cotton production targets, relaxed input levels	261	600	100	00

Source: Faki et al. (1992).

input subsidy removal would imply a shift of emphasis towards more cotton and less wheat.

The effect of a wheat price change on its supply is considerable. This was examined by the model together with variations in sorghum prices where the two crops are close substitutes. Figure 4 shows the supply response of the two crops. The arc supply elasticities were 2.03 and 1.43 for sorghum and wheat, respectively. A higher response of sorghum to its price changes in the irrigated sector is recorded as compared to that of wheat, which is nevertheless substantially elastic. The high substitutability of the two crops is reflected by their considerable cross supply elasticities which were 1.69 for wheat in response to a sorghum price change and 1.19 for sorghum in response to a wheat price change. These figures indicate that national production needs could be geared effectively through crop pricing policies.

Technology Use

The effect of improved wheat technology on yields and farmers' incomes has been verified in different regions with on-farm research over a considerable number of seasons. Table 5 summarizes the effect of timely sowing, improved land preparation, adequate plant nutrition, and irrigation on wheat yields in four wheat producing areas

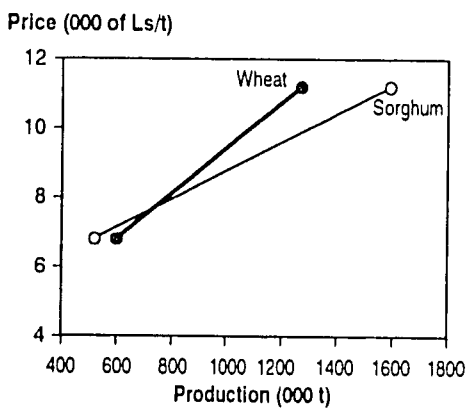

Figure 4. Supply response of grains in the irrigated sector.

The high yield increases with the technolog package that ranged between 51 and 120% were associated with paramount marginal rates of returns that reached 940%, implyin high returns to investment in higher technology use.

However, with recent changes in the structure of costs and prices, the level of us of technology is expected to change. This is depicted by an example on fertilizer use. The following functional relationship was estimated for the effect of nitrogen and phosphate fertilizers on wheat with researcher-managed trials under field conditions in two locations in the Gezira (M.A. Satti, pers. comm.). The derived functions were deflated by 30% to estimate an expected response under farmer management:

$$Y1 = 1121 + 24.66\,N + 65.97\,P - 0.240\,N^2 - 0.866\,P^2 \quad (1) \text{ and}$$

$$Y2 = 1414 + 33.32\,N + 34.15\,P - 0.319\,N^2 - 0.878\,P^2 + 0.628\,NP \quad (2)$$

where: Y1 and Y2 are wheat yields in the two locations in t/ha, N is the amount of nitrogen in kg N/ha, and P is the amount of phosphate in kg P_2O_5/ha.

With current fertilizer and farm-gate wheat prices, the economically optimum rates would be 40 and 64 N and P_2O_5 kg/ha for the first location and 55 kg N/ha with no use of phosphate or 21 kg P_2O_5/ha with no use of nitrogen for the second location. In general, the optimum total fertilizer doses would be 63 and 90% of the recommended in the two locations, respectively. With the over-proportional rise in prices of other

inputs relative to that of wheat, use of lower levels will be economically viable. This may imply lower total wheat production.

Conclusions

Despite government support and the existence of a potential for high yields, sorghum profitability has remained variable and relatively low. This has important implications on expected farmers' decisions under current policies of liberalization and subsidy removal. On the other hand, wheat enjoys high and increasing demand that would stimulate local production. It also represents the most suitable option as a winter crop in the farming systems in central and eastern Sudan due to its utilization of slack resources during winter. In spite of its lower returns to land and water compared to cotton, its returns to labor and capital are higher. With high technology, even its returns to the former two factors are comparable to those of cotton. In fact, a range of complementarity exists between cotton and wheat due to the need for cultivation of summer crops that compete with cotton. At 1991-92 cost and price levels, wheat would be grown in an area of over 200,000 ha under a free-cropping pattern. Most of it should be under a high technology level. With increased input costs, its area and production would decrease. The optimum level of input use would decrease affecting total wheat production. Input availability, a producer subsidy, and use of high technology are conducive to attaining national production targets.

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Rainfed Wheat in Tropical Environments: The Nigerian Experience

B.K. Kalgama, M.C. Ikwelle, and O.G. Olabanji
Lake Chad Research Institute, Maiduguri, Nigeria

Abstract
*In Nigeria, wheat research and production in the highlands under rainfed conditions is still in its infancy. Research on the Mambilla Plateau (1,800 masl) in Taraba State has shown that wheat cultivation under rainfed conditions will not only increase total wheat area, but will also shorten the breeding cycle and development of new varieties. An average grain yield of about 2.2 t/ha has been recorded on the Mambilla Plateau. The optimum sowing date was mid- to late August. Stem borer (*Sesemia calamistis*) is the major insect pest. Leaf spot (*Septoria *spp.*) and foot rot (*Helminthosporium *spp.*) are the major diseases.*

Introduction

Wheat (*Triticum aestivum* L.) has been grown in northern Nigeria for centuries, possibly as a result of introduction by the Arabs through the trans-Saharan trade. The early efforts to grow wheat in Nigeria were restricted to small plots in the low-lying soils of fertile river flats or along river banks in the Sudano-Shelran zones of the country where the climatic factors of the cool, dry season are favorable to wheat production.

In Nigeria, favorable temperatures are obtained between latitudes 10 and 14°N during the cool, dry season from November to February when wheat can be cultivated under irrigation (Olugbemi 1973).

Wheat cultivation under irrigation requires very large investments in infrastructure and often the cost of production for the irrigated crop is very high. With the ban on wheat importation into Nigeria, which was temporarily lifted recently, there was a great need to increase both wheat area and yield.

Rainfed wheat in the highlands of Nigeria could increase the much desired output as well as reduce production costs to a great extent when compared with wheat grown under irrigated conditions.

Attempts at rainfed wheat production in Nigeria have been made at various times. The Institute for Agricultural Research (IAR) at Samaru, Zaria tested some materials at Bokkos and Tahoss in Jos, Plateau State without conclusive results. Palmer (1976) reported that lines from rainfed trials in Jos had well developed grains that were not adversely affected by high temperature. Most recently, the Lake Chad Research Institute (LCRI), which has the national mandate for genetic improvement of wheat and barley in Nigeria, embarked on testing some wheat lines and varieties under rainfed conditions in the Nigerian highlands.

Varietal Evaluation

Beginning in 1987, LCRI began varietal evaluation of rainfed wheats at Gembu in Mambilla Plateau (6 to 7°N and 10 to 11°E). Tables 1-3 show the results over the 1987-89 period. Results on grain yield in 1987

(Table 1) showed the highest yield was obtained from Chre'S'-386 (2,156 kg/ha). Eleven entries yielded significantly higher than the average yield. Three check varieties (Indus 66, Siete Cerros, and Inia 66), which are traditionally irrigated, produced the lowest grain yields (Table 1).

Table 2 presents the results of the 1988 wet season. Highly significant differences were observed in five of the six agronomic characters assessed. All entries headed between 50 and 60 days after sowing. The highest yielder was again Chre 'S'-386 (2,149 kg/ha). Six other entries each yielded more than 1,000 kg/ha. All entries showed better adaptation than the check variety (Siete Cerros).

Table 2. Mean performance of 11 lines of bread wheat in a rainfed trial at Gembu (Mambilla Plateau), Nigeria.

Entry no.[a]	Days to 50% heading	Plant height (cm)	No. of spikes/m²	Grain yield (kg/ha)
5	51	63	118	1,317
7	56	71	132	1,310
8	51	73	170	888
11	56	71	133	1,791
12	55	74	126	691
13	51	74	141	1,104
15	57	70	144	1,339
16	58	93	143	2,149
17	57	93	121	1,097
20	52	69	164	642
22	57	69	124	490
LSD 0.05	NS	14.84	24.0	514
CV (%)	7.56	15.53	14.33	48.53

[a] See Table 1.

Table 1. Bread wheat evaluation under rainfed conditions at Gembu, Nigeria, 1987.

Lines/varieties	Yield (kg/ha)	Plant height (cm)	Days to 50% heading
2. Titmo Sa 420	906	65	50
3. Veery'S'-1931	912	65	52
4. WRMRKAL-284	919	28	50
5. R.27-GHL 98	1,175	21	49
6. Blue Jay'S'-1721	1,381	80	49
7. Hork'S'-1729	1,156	70	50
8. Top'S'-Napo 1729	1,125	69	55
9. Veery'S'-601	944	68	53
10. Todwhile'S' 188	656	64	50
11. YD'S'-1938	1,312	90	52
12. AFM-T_1-397	1,094	95	52
13. Maya Puni 1766	1,406	78	52
14. WRB'S' 158	781	60	49
15. JUP BJY 251	1,687	73	50
16. Chre'S'-386	2,156	96	51
17. MFEKM'S'-977	1,062	70	50
18. V.641225-1945	750	62	51
19. ILT-GB-1951	894	82	52
10. Atlas 57 1907	1,031	67	50
21. Indus 66	562	60	52
22. Siete Cerros	450	79	50
23. Inia 66	437	92	49
Mean	1,027	74.27	50.45
CV (%)	39.37	15.01	2.27

Source: Ikwelle (1990).

In 1989, Hork 'S'-1729 (entry no. 7) had the highest yield (3,650 kg/ha). Table 3 shows that Chre'S' (entry no. 16) had the highest mean yield (2,135 kg/ha) for the 1987-89 period. This line is currently being multiplied and distributed for further evaluation at other sites, particularly the Jos and Obudu plateaus. Other varieties with mean yields greater than 2,000 kg/ha for the period included Hork'S'-1729 (entry no. 7) and JUP BJY 251 (entry no. 15).

The mean temperatures during the growing period over the three years ranged between 24.0 and 25.8°C (maximum) and 14.9 and 15.0°C (minimum). However, rainfall during the crop cycle in 1989 was 850 mm, some 30% higher than the previous two years.

Sowing Date

Sowing date trials were done in 1988 and 1989 on the Mambilla Plateau. The results show that the optimum date for sowing wheat in the highlands is mid- to late August (Olabanji et al. 1990). This period coincides with about the last third of the rainy period, which provides the crop with about 550-650 mm of rain from planting to maturity; it then matures under dry weather in November. Earlier sowings matured in the rain and the grains molded.

Table 3. Grain yield (kg/ha) of 11 entries of bread wheat under rainfed conditions at Mambilla, Nigeria, between 1987-1989.

Entry no.[a]	Year 1987	1988	1989	3 years' mean yield
2	906	738	3,480	1,708
3	912	653	2,870	1,478
7	1,156	1,488	3,650	2,098
9	944	444	970	786
11	1,312	2,005	2,070	1,796
13	1,406	1,103	2,470	1,660
15	1,687	1,352	3,200	2,080
16	2,156	2,080	2,170	2,135
17	1,062	1,226	2,920	1,736
19	894	590	3,420	1,635
21	562	706	2,480	1,249
Mean	1,182	1,126	2,700	
CV (%)	39.4	48.5	28.4	

[a] See Table 1.

Pests and Diseases

Major problems associated with rainfed wheat production are pests and diseases that thrive due to the climatic conditions, particularly the high humidity that occurs during the growing season. Stem borer (Sesemia calamistis) is the most important insect pest. The larvae of this pest bore into the stem and cause the whiteheads and dead hearts observed in the field. Leaf spot (*Septoria* spp.) and foot rot (*Helminthosporium* spp.) are the major diseases.

Conclusion

There is great potential for rainfed wheat production in the Nigerian highlands. A large number of materials is being evaluated to identify adaptable materials. Studies on pest and disease incidence and weed control are currently underway. A full package of technology for rainfed wheat production in Nigeria is envisaged. This will not only increase the total wheat output in the country, but will also shorten the breeding cycle for developing irrigated wheat varieties as two or more crops can be grown annually under irrigated and rainfed conditions.

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Integrated Pest Management of Cereal Aphids in the Nile Valley: Problems and Potential

R.H. Miller
International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria

Abstract

There is a considerable amount of information on the pest and natural enemy complexes in wheat in the Nile Valley countries of Egypt and Sudan. Similarly, various projects have led to the development of chemical and cultural control techniques, including resistant varieties, that may be incorporated into an integrated pest management (IPM) program for wheat. Research is needed on the economics of pest control in wheat, on the effectiveness of endemic natural enemies, and on the potential for introducing new natural enemies or augmenting populations of those in the field. A pilot IPM project, which is based on the use of aphid-resistant varieties, the preservation or augmentation of natural enemies, and minimal use of chemical pesticides, is feasible in the future.

Introduction

Aphids are the most serious insect pests attacking wheat and barley in Egypt and Sudan. Aphids cause their damage by sucking fluids from their hosts, vectoring diseases, and providing a sugary substrate (honeydew) for fungal pathogens on leaves. In addition, plants attacked by aphids are often rendered more susceptible to other diseases and insect pests. Aphid control in the Nile Valley is accomplished primarily through chemical insecticides, which are frequently applied up to three times per season. Attempts to develop alternative control strategies have thus far not been successful or are in a rudimentary stage of development. Desires to preserve the environment, protect human health, and reduce hard currency costs associated with chemical pesticides have led policy makers and agriculturalists to support integrated pest management (IPM) in controlling disease and insect pests of wheat and other important crops such as cotton and sugarcane.

IPM is defined as the integrated use of a variety of pest control techniques to reduce pest populations to economically acceptable levels with minimal injury to the environment (Miller 1991). Inherent in the IPM concept is the consideration given to protecting human health and preserving the environment. In IPM, sound ecological and economic principles determine pest control strategies to optimize and sustain crop production. Ecology-oriented IPM programs are frequently more complex than prophylactic spray programs and therefore require greater training of farmers and extension workers. As a result, IPM programs may not be readily accepted by farmers or agricultural administrators who may fear crop failures associated with new and unfamiliar strategies. Also, the real value of IPM may not be in the increased or sustained production it fosters, but in protecting or revitalizing a damaged environment.

It is difficult to assess the environmental impact of IPM programs. Ecosystems involve multiple trophic levels and communities

linked by intricate intra- and interspecific interactions. The effect of eliminating sprays from an ecosystem may therefore be subtle, or most obvious in components of the system not normally considered by farmers, such as soil microbes, birds, or water fauna and flora. In severely disrupted systems, several years may be required before ecological homeostasis may be regained and, if localized extinctions have occurred, may only be achieved with species re-introductions.

IPM programs have been most successful and visible in systems where pesticide misuse has led to noticeable disruption of trophic level interactions or obvious declines in crop production and human health. These systems are frequently typified by the use of high amounts of inputs necessary to sustain relatively high yields. An example is the successful management of irrigated rice in Indonesia (Kenmore 1991) where a massive training program taught farmers to preserve natural enemies of pests that had been aggravated by pesticide overuse after the government had severely restricted pesticide use. IPM has also been successful in situations where an introduced pest has followed its host plant into a new growing region, even if the crop involved is of relatively low value and the farming community is impoverished. An example of this is the successful control of the cassava mealybug in Africa. Here, natural enemies of the cassava mealybug were collected from cassava's home range in South America and then reared and released in the cassava-growing belt of tropical Africa (Kiss 1991).

IPM has long been discussed as a long-term objective of wheat production in the Nile Valley, but there has been a lack of focused activity directed specifically toward this goal. The purpose of this paper is to review research conducted under the auspices of the Nile Valley Regional Project on Cool Season Cereals in Egypt and Sudan since 1988 to evaluate the potential for implementing IPM in aphid control in these countries, to identify possible impediments to this objective, and to propose solutions to overcome them. The long range goal is to stimulate formulation of a comprehensive IPM program for wheat aphids in Egypt and Sudan.

Aphids In the Nile Valley

Several common aphid species attack wheat in the Nile Valley of Sudan and Egypt (Table 1); four species predominate in Egypt. Of these, *Rhopalosiphum padi* L. causes the most serious yield losses in Middle and Upper Egypt while *Rhopalosiphum maidis* Fitch is the most serious pest of rainfed barley along the northwestern coast. *Sitobion avenae* F. rarely attains population levels high enough to be considered a serious pest of either wheat or barley. *Schizaphis graminum* Rondani is commonly observed throughout Egypt and may occasionally cause serious yield losses

Table 1. Cereal aphids and their natural enemies reported in NVRP-sponsored studies in Egypt and Sudan, 1988-1992.

Egypt	Sudan
Aphids	
Schizaphis graminum Rondani	*S. graminum*
Rhopalosiphum padi L.	*R. maidis*
Rhopalosiphum maidis Fitch	
Sitobion avenae F.	
Diuraphis noxia Mordvilko	
Natural enemies	
Coccinella spp.	*Coccinella* spp.
Chrysopa spp.	*Cydonia* spp.
Syrphidae	*Chrysopa* spp
Arachnida	Syrphidae
Diaeretiella rapae M.	
Aphidius spp.	

(Miller et al. 1992). The biotype structure of *S. graminum* populations has not been ascertained at present (M.G. Mosaad, pers. comm.) although some evidence exists that biotype C may be present.

In Sudan, *S. graminum* is the dominant wheat aphid in the Nile Valley with biotypes A and H dominating aphid populations (Sharaf Eldin 1992). Low populations of *R. maidis* are also observed early in the growing season, but are displaced by *S. graminum* during the latter part of the growing season in late January and early February (ARC 1988). Aphid infestations in the Gezira irrigation scheme, the newly developed Rahad wheat growing area, and the New Halfa region are almost exclusively comprised of *S. graminum*.

Aphid infestations in Egypt and Sudan are controlled by one or more applications of chemical insecticides. Field scouts monitor aphid populations and spraying is recommended when aphid populations exceed 30% infested plants in Egypt and 35% infested plants in Sudan. Pirimor and Malathion are frequently used in Egypt, while Ekatin has been used effectively and almost exclusively in Sudan for several years. New pesticides are evaluated each year in both countries.

In Sudan, chemical products, including Decis, Sumithion, Danitol S, Pirimor, Furadan, and Brifur provided poor to adequate aphid control (Sharaf Eldin 1992). Neem extracts and Pirimor had less effect on natural enemy populations than other products. A seed dressing of Gaucho 70 provided the best aphid control and outperformed Ekatin. Furthermore, Gaucho 70 performed well alone and when mixed with fungicides frequently applied as a seed dressing and did not adversely affect natural enemy populations. Seed dressings, such as Gaucho 70, have not been considered in Egypt due to current restrictions on soil pesticides aimed at avoiding ground water contamination. There is no evidence that Gaucho 70 contaminates ground water in Sudan when properly applied.

Grain yield losses have been estimated at up to 20% in Egypt (Tantawi 1985). More recent studies within the Nile Valley Regional Program (NVRP) show that yield loss in wheat differs among varieties and that resistance to aphids can substantially reduce aphid-induced yield losses. Mosaad et al. (1992) expressed yield losses in aphid-infested plants in Upper Egypt as a percentage of yield obtained in the same varieties but protected by spraying (Table 2). Yield of the most resistant bread wheat and durum wheat lines averaged over 90% of the sprayed controls, while the least resistant bread wheats averaged about 70%

Table 2. Yield reduction of bread wheat and durum wheat lines tested at Shandawil, Egypt in 1989-90. Aphid tolerance in infested lines is expressed as a percentage of the same lines treated with Malathion (after Mosaad et al. 1992).

Most resistant		Least resistant	
Entry	% of control	Entry	% of control
	Bread Wheat		
41	97.4	28	75.4
13	97.3	21	75.4
38	96.9	1	74.4
25	96.6	45	73.2
3	96.4	19	67.3
Mean	96.9		73.1
SE	0.2		1.5
	Durum Wheat		
5	97.2	13	71.9
25	95.6	34	67.7
9	94.7	7	65.8
10	94.2	4	64.0
29	93.7	12	61.6
Mean	95.1		66.2
SE	0.6		1.7

and the durum wheats about 66%. In a similar study, El Ghani et al. (1991) obtained grain yields in aphid resistant lines ranging from 3 to nearly 6 t/ha while susceptible lines averaged slightly over 1 to about 4 t/ha (Table 3). In this study, the percentage yield reduction attributable to aphids ranged from less than 10% in the highest yielding lines to between 30 and 40% in susceptible bread and durum wheats. Tammam and Towfelis (1992) described average yield losses in unsprayed plots of 18% in bread wheat and 16% in durum wheat compared to the same entries protected by malathion under moderately high aphid *R. padi* infestations.

Grain yield losses due to aphids in Sudan have been estimated at nearly 30% in Sudan in unsprayed fields (Figure 1; Kannan 1992). Yield losses determined from plots sprayed at different infestation levels of *S. graminum* clearly indicate that a level of 35% infested plants results in the greatest yield preservation. This level has been used as a threshold to implement spray programs in the major wheat growing areas (N. Sharaf Eldin, pers. comm.).

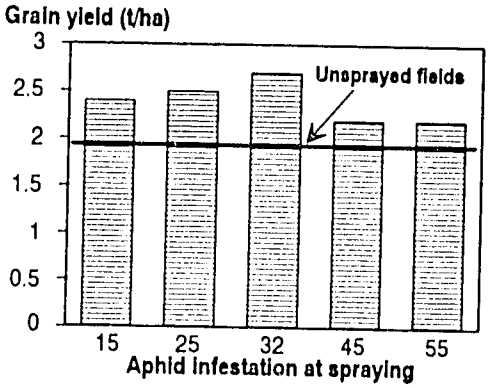


Figure 1. Grain yield obtained by spraying at different aphid infestation levels at Rahad, Sudan in 1992.

Table 3. Grain yield (t/ha) and yield reduction (%) due to aphid infestations of the five highest and lowest ranking genotypes under natural infestations at Shandawil, Egypt in 1990-91 (after El Ghani et al. 1991).

Durum Wheat				Bread Wheat			
No. Entry	Spray	No Spray	% reduction	No. Entry	Spray	No Spray	% reduction
			Aphid-resistant lines				
5	4.86	4.02	3	6	3.36	3.25	3
20	4.15	3.82	8	5	4.24	4.07	4
41	6.40	5.84	26	9	2.30	2.20	5
26	3.12	2.81	10	23	3.85	3.64	7
23	3.66	3.26	11	15	2.66	2.47	7
Mean	4.27	4.12	8.20	Mean	3.28	3.13	5.20
SE	0.56	0.55	1.39	SE	0.36	0.35	0.80
			Aphid-susceptible lines				
1	5.80	3.24	44	25	4.00	2.46	38
16	5.87	4.41	42	10	3.72	2.45	34
37	6.26	3.73	40	14	4.01	2.75	31
25	5.18	3.16	39	12	2.11	1.63	23
9	6.89	4.31	37	8	4.94	3.84	22
Mean	6.00	3.57	40.40	Mean	3.76	2.63	29.60
SE	0.28	0.21	1.21	SE	0.46	0.35	3.11

Natural Enemies

Natural enemies of aphids are present in the Nile Valley of both Egypt and Sudan (Table 1), although species composition differs between countries. In the Sudan *Coccinella* spp. is the most common predator (Figure 2) followed by *Chrysopa* spp. *Cydonia*, a coccenellid, was observed in 1990-91 and was more efficient than *Coccinella* (Figure 2B; Kannan 1992). As shown in all areas (Figure 2ABCD), natural enemy populations lag behind those of *S. graminum* and are not effective in regulating them. Aphid populations generally peak in mid-January and rapidly decline as the crop matures and daily temperatures rise.

The most striking difference between the natural enemy complexes of Egypt and Sudan is the absence of hymenopterous parasitoids in the Sudan. It is possible that Sudan's harsh climatic, outside of the relatively cool winter growing season, suppresses parasitoid populations. Heavy pesticide applications on cotton and other crops planted concurrently with wheat may have also suppressed parasitoid populations.

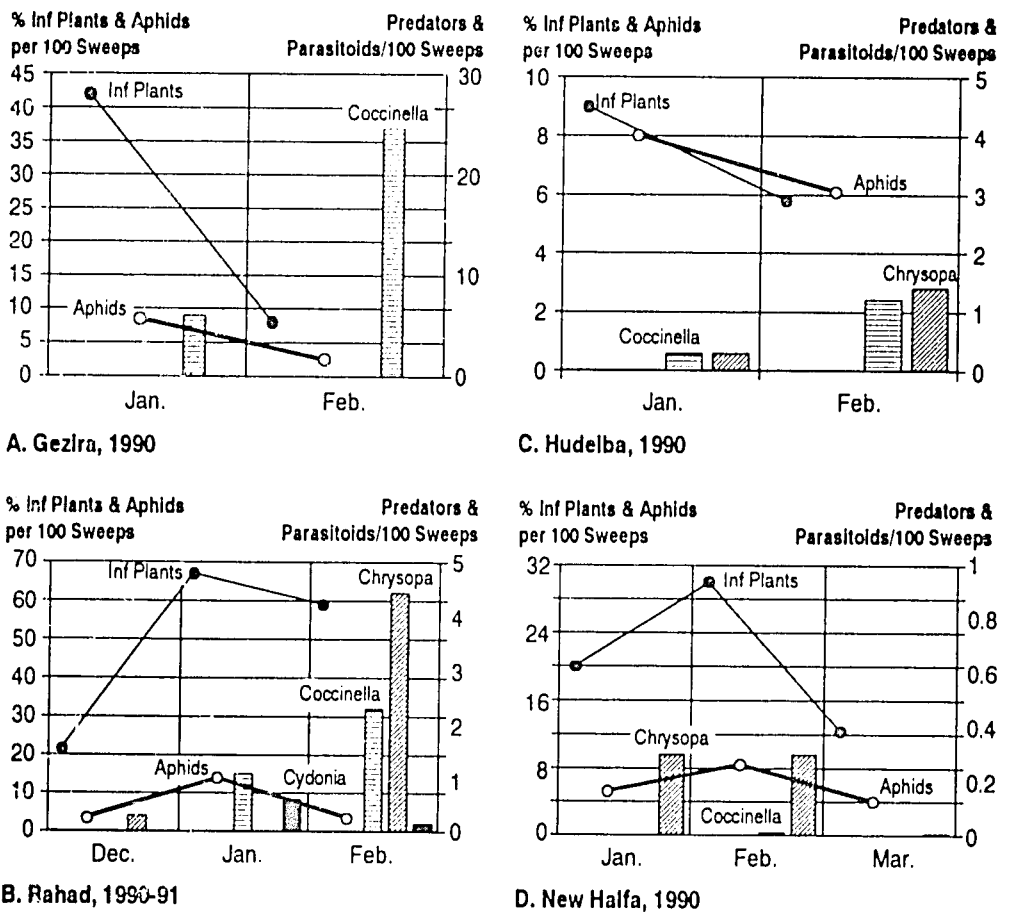


Figure 2. Aphid infestations and population densities of natural enemies sampled at four locations in Sudan.

In Egypt *Coccinella* spp. and *Chrysopa* spp. are the dominant aphid predators followed by syrphid flies and spiders. Two braconid parasitoids have been reported, but they appear too late in the season and in such low numbers as to preclude regulation of the aphid population. In general, aphid populations peak in February and March in Middle Egypt and slightly earlier in warmer Upper Egypt (Figure 3). Predator and parasitoid populations lag significantly behind aphid populations and never achieve sufficiently high population densities to regulate them (El Heneidy et al. 1992).

A spray program described by El Heneidy et al. (1992) was ineffective in controlling aphids in experiments conducted in Egypt (Figure 3). The pesticides also had little effect on natural enemy populations. Following two applications of Malathion, the number of aphids per plant decreased in the earlier part of the season in Middle Egypt, but the percentage of infected plants did not change significantly (Figure 3A). The aphid populations rebounded from the first spray treatment within a week. Natural enemy populations may have slightly decreased due to the early spray

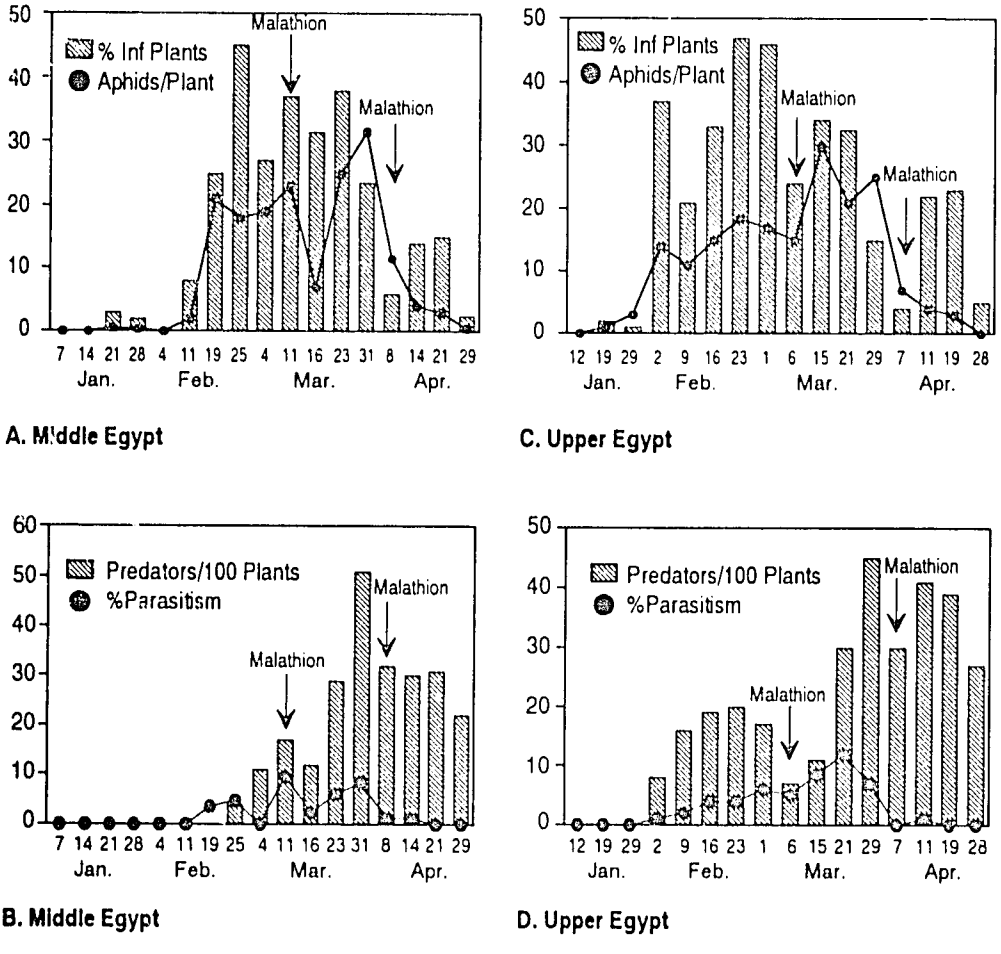


Figure 3. Response of aphid and natural enemy populations to insecticide treatments in Middle and Upper Egypt in 1992.

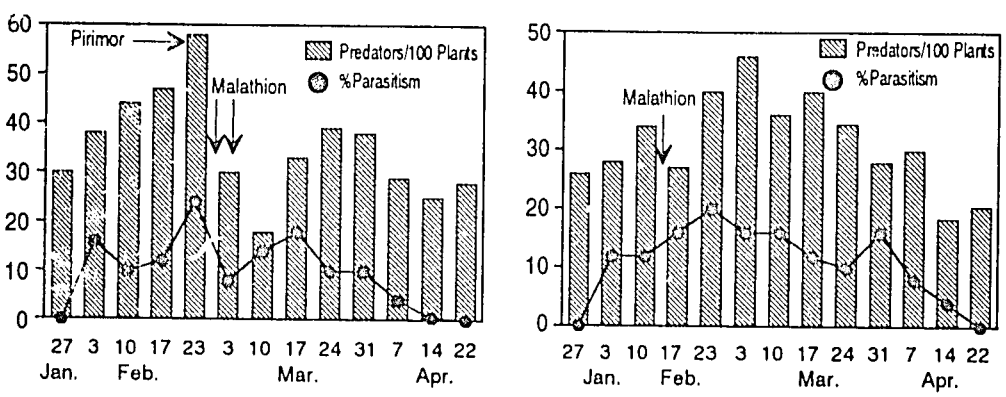
(Figure 3B), but also rebounded within a week. There was no effect on either aphid density per plant, the percentage of aphid-infested plants, or on natural enemy populations due to the second spray treatment applied in April. Aphid populations appeared to be already in decline at the time of this spray application, as were parasitoids. Predator densities remained nearly constant.

Similar results were observed in a repetition of the spraying treatments in Upper Egypt the same year. Aphid densities per plant and the percentage of plants infested by aphids actually increased over levels at the time of spraying a week following the treatment (Figure 3C). Populations of natural enemies showed no response to the spray treatment (Figure 3D). The second spray treatment was again applied while aphid populations were declining, possibly due to plant senescence and increasing daily temperatures.

A similar experiment had been conducted the previous season in Upper Egypt at Al Maragha and Shandawil (Figure 4AB; El Heneidy et al. 1991) using one application of Pirimor and two of Malathion at the first site and a single application of Malathion limited to aphid-infested hotspots at the latter. The heavy pesticide applications at Al Maragha may have resulted in a subsequent decrease in parasitism and predators, but the limited application at Shandawil caused no noticeable effect. No aphid population data were collected during this experiment. However, visual rankings of low, medium, or high aphid densities were made based on inspection of the plants. As in 1992, little or no effect was attributable to the pesticide application.

Germplasm Development

In 1984 an aphid screening laboratory was established in Giza, Egypt, to identify wheat lines possessing aphid resistance. Nearly 5000 lines per year, originating from the Egyptian national program, ICARDA and CIMMYT, and institutions outside of West Asia and North Africa, have been tested in this laboratory against *S. graminum* and *R. padi* (Miller et al. 1992, El Einen et al. 1989). Laboratory tests have shown that progeny from crosses made with the commercial Egyptian varieties Giza 157, Sakha 61, and



A. Al Maragha

B. Shandawil

Figure 4. Response of natural enemy populations to insecticide treatments in Upper Egypt in 1991.

Sakha 69 and the Amigo-lines containing the R2 translocation from rye are resistant to *S. graminum*. The best performing lines have been assembled into a small yield trial and tested for two years under naturally occurring aphid infestations in Middle and Upper Egypt. Table 4 shows results from these yield trials evaluated for resistance to *R. padi*. The lines shown performed better than the commercial variety Sakha 69 used as a local check adapted to Nile Valley conditions. The best performing lines in these trials possessed moderate levels of aphid resistance combined with high yield. Lines with higher levels of aphid resistance yielded less. This nursery is still under evaluation in Egypt and was recently distributed to five countries on the Arabian Peninsula where climatic, agronomic, and pest problems resemble those of the Nile Valley.

Wheat relatives may provide a source of resistance genes for future crosses. Youssef et al. (1992b) identified several *Aegilops* accessions possessing resistance to *S. graminum* and *R. padi* (Table 5) from a nursery provided from ICARDA's Genetic Resources Unit. The nursery is still under evaluation and newly collected material is being prepared for testing against various aphid species.

Discussion

The accumulated data on wheat aphids in the Nile Valley suggest that a sufficient number of control "tools" and the expertise to wield them are available in Sudan and Egypt for successful IPM. IPM strategies and obstacles common to both Egypt and Sudan are discussed herewith.

Utilization of aphid-resistant varieties in combination with enhancing natural enemy populations should be the keystone of wheat IPM in the Nile Valley. Results from Egypt's yield trials suggest that wheat varieties possessing acceptable yield and moderate

Table 4. Grain yield (t/ha) and percentage leaf area occupied by *R. padi* for best yielding wheat lines from selfed BC3/BC4 in 1990 and 1991 (after Youssef et al. 1992a).

		R. padi reaction		Grain yield	
No.	Cross	1990	1991	1990	1991
1	134XS69/274/2[ab]	20-30	20	**1.024**	**1.483**
2	134XS69/357/6	40-50	30	**0.897**	**1.387**
3	134XS69/295/5	30-40	50	**0.884**	**1.182**
4	134XS61/304/3	30-40	40	**0.940**	**1.405**
5	134XS61/305/1	30-40	40	**0.860**	**1.131**
6	134XS61/321/1	30-40	40	**0.835**	**1.270**
7	136XS69/377/5	40-50	60	**0.894**	**1.197**
8	136XS69/358/2	20-30	20-30	0.777	**1.540**
9	136XS69/394/366/1	20-30	20-30	**0.975**	**1.393**
10	136XS69/376/1	20-30	20-30	**0.889**	**1.430**
11	136xs69/376/2	30-40	40	**0.851**	**1.343**
	Overall Mean	33	36	0.893	1.342
	S.E.	2.3	3.7	0.020	0.040
	S69 (mean)	60	60	0.804	1.128

[a] 134 = Bushland: Amigo TAM 101; 136 = Bushland: Amigo TAM 105; S69 = Sakha 69; S61 = Sakha 61.
[b] Bold type indicates lines/values with yields greater than that of S69.

aphid resistance may be useful in reducing the frequency of pesticide applications, and may eliminate their need altogether when aphid infestations are low. Different *S. graminum* biotypes may be present in Egypt and Sudan. This may account in part for the relatively poor performance of *S. graminum*-resistant Egyptian wheats in Sudanese field tests. Winter weather conditions in Sudan that promote *S. graminum* development may also contribute to the "swamping out" of aphid resistance due to the massive aphid population. Solutions to this problem include the identification of *S. graminum* biotypes in Egypt. *S. graminum* screening is carried out a screening laboratory in Giza using stock cultures of *S. graminum* generated from locally collected parents. Such screening targeted toward Sudan may have to be relocated to Sudan. Reconfirmation of the biotypes observed in Sudan is also necessary as the differential screening nursery contains wheat lines developed for temperate North America and is poorly adapted to growing conditions in Sudan.

Table 5. *Aegilops* accessions showing resistance to *S. graminum* (after Youssef et al. 1992b).

Species	Accession	Ploidy	Genetic formula	Mean aphid rating
	Resistant to *S. graminum*			
Ae. speltoides	400047	2X	S	1
Ae. speltoides	400049	2X	S	1
Ae. triuncialis	400121	4X	UC	1
Triticum tauschii (formerly *Ae. squarrosa*)	400359	2X	D	1
	Resistant to *R. padi*			
	Entry numbers			
Ae. triuncialis	16,17,18,19,23,202,203,250			
Ae. geneculata	40,41,43,56,57,58			
Ae. umbellulata	277,279,2295			

ICARDA Genetic Resources Unit Nursery.

Aphid population performance differs along the length of the Nile Valley. However, a single economic threshold is employed across all wheat growing regions. Pesticide use would possibly be lowered without significant yield loss if a higher threshold was used in areas where aphid populations do not normally perform well.

Scouting and application procedures should be reviewed in each country. While the basic strategy of spraying when a critical aphid population is attained is sound, the actual practice may be faulty. Observations suggest that too large a region is sprayed on the basis of scouting reports originating from a relatively small portion of that region. Similarly, the effectiveness of the spray application should be determined by follow-up surveys in the sprayed areas. If aphids are still present, then the chemical used and the application technique should be revised to the lowest possible dose of chemical applied in the most economical and safest manner. Logistical problems may introduce delays in applying sprays to infested areas which allow aphids to cause economic loss. Lowering the economic threshold to initiate spraying earlier will lead to overuse of pesticides. A better strategy is to avoid technical problems by adequate prior planning that anticipates possible bottlenecks.

The actual cost of control programs should be considered when developing economic thresholds and injury levels. Because pest control programs are frequently subsidized by government agencies in both countries, the true cost of the control program may be overlooked when the control program is designed. Because several government agencies may handle different aspects of the program, the true magnitude of personnel and transportation costs, the price of the active ingredient, and the cost of obtaining

and maintaining equipment may be obscured. The term "economic threshold" as used in NVRP reports is also misleading because it is based only on yield and pest population interactions rather than considering market factors affecting the crop and its protection.

There are control techniques that should be employed, or at least investigated, within an IPM context in both Sudan and Egypt. Natural enemy populations may be enhanced in both countries. Factors regulating predator and parasitoid populations should be identified. Functional response studies and studies on other predation parameters (Hassell 1978) are needed to identify the potential of current natural enemy populations in regulating aphid populations. Population enhancement, either by augmenting natural populations by releasing reared predators such as *Coccinella* or *Cydonia*, or by altering the environment to enhance naturally occurring populations may be useful (Parella et al. 1992). Introduction of new parasitoids into Egypt to augment those already established or into Sudan to establish them should be considered.

The interaction of the wheat-insect system with other crops is not well defined. In Sudan, there is almost certainly an interaction between the heavy pesticide use on cotton and the aphid/natural enemy complex on wheat, although this has not been demonstrated. Similar spillover effects are likely present in Egypt but have not been documented.

In Egypt, management practices on crops grown concurrently with wheat and on crops providing refuges for aphids and natural during the summer months should also be considered when developing biological control strategies. Natural enemies resistant to commonly used pesticides on crops surrounding wheat fields and on wheat may be developed and released. Results of seed dressings such as Gaucho 70 in Sudan should be considered for use in Egypt.

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Questions/Discussion

A comment was made that most of the aphids present are vectors for Barley Yellow Dwarf Virus but that BYDV presence or absence was not mentioned. Dr. Miller said that research over the past three years has indicated the presence of the virus in the Nile Valley in Egypt and that it may also be present in Sudan. ELISA analyses have identified the major strains present in Egypt and this survey work was continuing. He indicated that past BYDV incidence, while very variable, was probably not as economically serious as initially feared.

Dr. Miller was questioned on the possibilities that aphids were building up resistance to malathion. He replied that there are several explanations for the minor effect of malathion in the experiments outlined in his paper, one of which is resistance in the aphid populations. This is suggested by the fact that malathion was ineffective in different experiments in two successive years. However, other researchers in Egypt have used malathion in yield loss assessments with excellent results. This could suggest that application errors may have occurred in the reported experiments, or perhaps the chemical itself was defective. He said that the lesson to be learned was that spraying programs, experimental or commercial, should be monitored to interpret and resolve problems such as these.

When asked if a standardized methodology for assessment of aphid infestation had been developed, he replied that population rating scales, so important for screening for aphid resistance, as well as defining economic threshold levels, had been developed in Egypt and Sudan. Though not identical, both rating systems take into consideration aphid density per plant, the percentage of infested plants, and in the case of greenbug, damage to the plant.

Finally, Dr. Miller was questioned whether the instability in genetic resistance indicated in Sudan was also found in Egypt. He explained that aphid population behavior, like plant development, varies due to changes in the environment. He said that in Egypt, despite fluctuations, aphid populations are almost always sufficiently high to result in infestations that cause observable damage. The problem observed in Egypt is that seedling resistance identified in the laboratory doesn't always carry through to the adult plant in the field. He felt that variability observed in Sudan may result from differences in environment from site to site, affecting aphid behavior and plant performance. He indicated that many aphid-resistant Egyptian lines perform poorly in Sudan and this is probably due to slight vernaliztion requirements, met in Egypt but not in Sudan, and perhaps due to biotype differences between the two countries.

Pest Problems of Wheat in Sudan

N. Sharaf Eldin
Agricultural Research Corporation, Wad Medani, Sudan
H. Omer Kannan
Rahad Research Station, El Fau, Sudan

Abstract
In Sudan, wheat aphids, termites, and the spotted sorghum stem borer are the main insect pests of wheat. Considerable research has been conducted in close collaboration with the ICARDA/ Nile Valley Regional Program. All programs were oriented towards an integrated pest management approach and addressed its important components. Intensive work was carried out on population dynamics, relative distribution, and abundance of the natural enemies of aphids during both the growing and off-seasons. Investigations were initiated to investigate the possibility of early augmentation with natural enemies for biological control. Screening of a great number of breeding lines against aphids showed some promise, but a closer cooperation by all relevant disciplines is still needed. In the area of chemical aphid control, the economic threshold level was established as 35% infested plants. The search for lower rates and safer chemical and botanical insecticides continued with emphasis on seed-dressing materials and granulated insecticides. A breakthrough in protection of wheat is anticipated through the use of a new seed-dressing material in the next few years. For termites, cultural measures have been successfully utilized for control with outstanding results.

Introduction

Although wheat has been under cultivation for hundreds of years in northern Sudan, no serious losses due to pests have ever occurred to justify control measures. A possible explanation for this could be the minimum use of chemical insecticides on all crops in the area, which maintained an undisturbed natural balance.

However, wheat production in the new areas south of Khartoum (Gezira, Rahad, New Halfa, White Nile, and Blue Nile) has been faced with a number of insect pest problems, notably the aphids.

Pests of Wheat

Important pests of wheat in Sudan include aphids, termites, stem borers, leaf miners, rodents, and birds. Of these, aphids are the main economic pests. Termites, leaf miners, and stem borer occur regularly, but seldom reach an economic threshold. Birds and rodents appear erratically and can cause substantial grain losses in years of heavy outbreaks.

Aphids

The two important aphid species are the green bug, (*Schizaphis graminum* Rond) and the maize aphid (*Rhopalosiphum maidis* Fitch). Both species attack wheat in all parts of the Sudan, but *S. graminum* is the more important one and responsible for most of the damage and yield reduction. *R. maidis* appears early (December) and colonizes the heart of the plants, and then leaves the crop at the onset of booting and does not seem to cause any economic loss (Muddathir 1978).

When comparing the relative importance of aphids on wheat in the traditional and the

new areas, it is apparent that they have a higher economic impact in the new areas. Grain losses due to aphid attack in the new areas are estimated to be in the range of 25-30% (Sharaf Eldin 1976). This is possibly due to heavy insecticide use to control cotton pests, which has upset the delicate balance of natural enemies that feed on different aphid species attacking both cotton and wheat.

Aphids have not yet been reported as serious disease transmitters, but recently a light incidence of barley yellow dwarf virus (BYDV) has been reported from the New Halfa area. One of these two species is thought to transmit the disease (Ahmed 1992).

Economic threshold level for spraying—Since aphids cause economic losses, annual chemical control has become necessary in Sudan's new wheat areas. To determine the most effective spraying intervals, assessing the level of infestation at which economic injury level is sustained was the first step. A number of infestation levels from 5 to 65% with a difference of 10% between levels was monitored. Results confirm that a 35% infestation level is the economic threshold level (ETL) for spraying against aphids in the Sudan (Sharaf Eldin 1985, Kannan 1991).

Assessment of aphid infestation can be based on two parameters: 1) the percentage of infested plants or 2) the number of aphids per plant; the former method is now being used for commercial spraying. But due to opposing views on the validity of relying on percentage of infestation alone, integration of both methods into what is termed as the "degree of infestation" is now under investigation. This will be compared with the current ETL.

Chemical control—Chemical control being a quick and effective method has been practiced for over 20 years in the new areas. Several hundred single and mixed insecticides in different concentrations and dosage rates have been screened against the two aphids. After undergoing the required two or three years of testing at the research farm and in farmers' fields, a substantial list of chemicals has been approved for commercial use by the Technical Pests and Diseases Committee. For economic reasons, only a few of these are in use, most particularly the specific aphicide, Pirimor. Others include Ekatin, Metasytox R50, Dursban, and Reldan.

Recently, a policy of testing lower dosage and safer insecticides has been adopted; neem seed and leaf extracts are being tested at different dosage rates against the aphids and their natural enemies. Newly produced chemical insecticides as seed dressings and granular formulations—being safer, more specific to the target insect, and less costly—are now receiving special consideration in our screening program. Gaucho 70 produced now in powder form for seed dressing and as granules and Furadan have given extremely promising results. Gaucho 70 as a seed dressing gave excellent protection of the crop against the two aphids throughout the 90-day season (Table 1). It also improved crop stands, which resulted in higher grain yields. Gaucho 70 is active at a low dosage rate of 1 g/kg of seed and is anticipated to mark a breakthrough in wheat protection against aphids (Sharaf Eldin 1992).

Spraying is recommended whenever 35% infestation is reached. Subsequent sprays are determined by the build-up of infestation. On average, one or two sprays are required during the cropping season. In the past, the area of the block was taken as the sample unit, but now more intensive

surveys have been undertaken and the sample size has been reduced to 36 ha. This will help in selective spraying, which will reduce the number of sprays in the future.

Since spraying against aphids was initiated in the late 1960s, the number of sprays has varied from one year to another, reaching a maximum of two during the 1991-92 season. Accordingly, the total cost of protection and the ratio of cost of protection to the total cost of production has varied as shown in Table 2.

Biological control—A number of predators, including *Cydonia*, *Coccinella*, Syrphids, and Chrysopids exist in different parts of the

Table 2. Mean number of insecticide sprays in commercial fields and the cost of protection.

Season	No. of sprays	Cost of chemical + application (Ls/acre)	Protection cost[a] (%)
1985-86	1.58	19.0	6.9%
1986-87	1.05	11.5	4.0%
1987-88	0.98	13.9	4.3%
1988-89	1.01	15.6	2.8%
1989-90	1.38	27.9	2.9%
1990-91	1.51	51.3	2.4%
1991-92	2.15	113.0	2.2%

[a] Percent of total production costs.
Ls = Sudanese pound

Table 1. Large-scale screening of insecticides against wheat aphids (Percentage infested plants. Data transformed to Arcsin).

Chemical rate/ha	Date of aphid count				
	13 Jan.	18 Jan.	21 Jan.	26 Jan.	3 Feb.
Gaucho 200 g[a]	1.708a	0.855	0.605a	0.003a	0.605a
Gaucho 150 g[a]	4.627a	2.064a	2.204	4.181abc	1.901ab
Dani 20% 0.4 L[b]	62.443b	70.304b	1.814	0.003a	8.930bc
Dani 20% 0.2 L[b]	57.650b	69.597b	1.458	1.708ab	9.383c
Dani 20% 0.15 L[b]	58.270b	74.277b	11.410	6.840c	16.940d
Sumi 50% 0.4 L[b]	65.897b	80.307b	0.003	1.458ab	3.803abc
Sumi 50% 0.2 L[b]	66.797b	72.463b	2.779	4.870bc	9.103c
Ekatin 25% 0.25 L[b]	67.383b	83.700b	5.028	3.174abc	7.148abc
S.E. ±	(8.347)	(5.170)	(2.472)	(1.282)	(2.1311)
	9 Feb.	**13 Feb.**	**20 Feb.**	**27 Feb.**	**5 March**
Gaucho 200g[a]	0.003a	0.605	0.003	0.003	0.003a
Gaucho 150g[a]	4.210ab	3.413	1.458	0.003	0.855a
Dani 50% 0.4 L[b]	10.180ab	4.357	4.978	6.953	6.913b
Dani 50% 0.2 L[b]	7.073ab	5.800	4.097	4.804	5.483b
Dani 50% 0.15 L[b]	17.623b	11.387	7.000	5.887	6.447b
Sumi 50% 0.4 L[b]	5.993ab	1.458	2.557	2.204	2.921ab
Sumi 50% 0.2 L[b]	15.600ab	4.570	3.910	3.544	6.100b
Ekatin 25% 0.25 L[b]	21.383b	6.900	4.591	3.610	5.591b
S.E. ±	(4.969)	(2.446)	(1.691)	(1.589)	(1.557)

Dani = Danitol S, Sumi = Sumithon.

[a] Applied as seed dressing.
[b] Sprayed on 19 Jan. 1992.

country with different intensities. They exercise some natural control and are perhaps responsible for keeping aphid populations below economic levels in the north. Normally, the natural enemies appear late in the season after the aphid population has already reached damaging levels, and to synchronize the appearance of the predators with that of the pest, an early augmentation with the natural enemies is needed. Accordingly, some investigations were initiated to monitor the effect of releases of different numbers of the adult coccinellid in field experiments. Some positive results were generated, but because of logistic problems the studies were suspended.

Resistance—Natural resistance in plants to aphid attack constitutes one of the most effective and desirable methods of insect control. With the global concern over the use of chemical insecticides, great emphasis is now given to breeding resistant varieties. In recent years, efforts have been devoted to screening a number of breeding lines of wheat provided by ICARDA, CIMMYT, Egypt, and the national program. Screening was mainly carried out in the field and assessment of resistance was based on percentage infested plants, number of aphids per plant, and visual rating of the damage. So far, success has been limited, although some level of resistance was found in a few breeding lines with inferior agronomic characters. This calls for a closer cooperation of all relevant disciplines.

It has been observed that the same breeding lines react differently to aphid attacks at different locations. This poses the possibility of different green bug biotypes in these areas and has necessitated the initiation of studies to determine if biotypes are indeed present using the green bug differentials.

Termites

Termites (*Microtermes thoracalis*) are soil-inhabiting insects found throughout the tropics and subtropics. Their infestation depends on the nature of the soil, temperature, moisture conditions, and the presence of dry plant tissues. In Sudan, they are common in heavy clay soils and are reported to be important in the Rahad Scheme where infestation is encountered in patches, mostly in the highlands receiving inadequate irrigation. The insect primarily feeds on and damages the main stem. Infested plants, especially young ones, turn pale, wilt, and die particularly under dry conditions.

Under severe conditions, termites can cause considerable stand losses (Kannan 1992). Research has revealed that dry spells, untreated seeds, inadequate fertilizer, and long intervals between irrigation are conducive to termite attack and significantly reduce yield (Table 3).

Currently in Sudan, wheat seed is treated with an insecticide before planting to reduce the effect of termites and, in addition, farmers are advised to irrigate at shorter intervals during hot spells during the season.

Stem borers

The spotted stem borer (*Chilo partellus* Swinh) and the dura stem borer (*Sesamia cretica* LED) are sporadically encountered, mainly on the edges of the field. Infestation is very low, i.e., about 0.1% and does not require control measures. The larvae feed inside the stems leading to yellowing and the death of plant and empty heads. To maintain the low level of infestation, cultural practices are recommended that destroy the damaged plants where pupation and larval diapause have taken place.

Leaf miner

The wheat leaf miner (*Pseudonapomyza spirosa* Sp.) is very sporadic and infests mainly the edges of the field. A hymenopterous parasite has been isolated from the miner and it is possible that this is keeping the insect in check.

Rodents

Arvicanthus niloticus SUND (Nile rat) and *Mastomysus natalensis* SUND are the two most prevalent species in fields and villages. They can cause substantial yield losses in years of heavy outbreaks. Estimates of wheat grain losses ranged between 15 and 70% in the Gezira Scheme during the 1975-76 season.

A control campaign is annually launched during April-June in Gezira; zinc phosphide baits in the fields and Warfarin in the villages are used. Kelrat, a recently released safe rodenticide, is an anti-coagulant that can be used both in field and village and is preferable to Warfarin because only a single feeding is enough to kill the rat.

Birds

The weaverbird (*Quelea quelea aethiopica* SUND), considered one of the most important pests of cereals in Sudan, can fly long distances and attacks grain fields in great numbers and causes considerable losses. It inhabits trees near rivers or other water sources where it breeds and from where it attacks crops (Schmutterer 1969).

The house sparrow (*Passer domesticus arboretus* Bp.) lives around villages near grain fields and normally does not fly long distances in search of food.

Destroying nests at breeding sites—the traditional control method—is laborious and less effective especially for the weaverbird. Poisoning drinking water with avicide (fenthion) has proved successful and more practical where it can be used safely. However, the method now in wide use, and which is more effective and economic, is aerial spraying of Queletox on breeding and roosting sites early in the morning or at dusk.

Table 3. The effect of Fernsan D seed dressing, fertilizer application, and irrigation intervals on termite infestation (mean of six counts).

	1990-91		1991-92	
Treatment[a]	Infested plants (%)	Yield (kg/ha)	Infested plants (%)	Yield (kg/ha)
1. Seed dressing + 1P[b] + 0N	13.3	1,080	2.6	800
2. No seed dressing + 1P + 1N[b]	13.9	1,570	7.4	
3. Seed dressing + 1P + 2N[b]	9.0	1,620	1.7	1,200
4. Seed dressing + 1P + 1N	13.6	1,120	1.7	1,030
5. Seed dressing + 1P + 0N	29.3	390	18.8	780
6. No seed dressing + 1P + 1N	26.0	360	32.8	600
7. Seed dressing + 1P + 1N	21.3	790	14.2	640
8. Seed dressing + 1P + 2N	25.6	520	14.7	470

[a] Treatments 1-4 irrigated 10 days before and 7 days after flowering; treatments 5-8 irrigated 10 days before and 10 days after flowering.

[b] 1P = 43 kg P_2O_5/ha; 1N = 86 kg N/ha; 2N = 172 kg N/ha.

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Questions/Discussion

Dr. Eldin was asked to comment on the safety of Gaucho seed dressing. He replied that the chemical appears active up to about 90 days after emergence, but analyses of the mature grain have found no residues. He was also questioned whether the seed dressing would be effective when infestations appeared late in the growing cycle (as in Egypt). He said that, in Sudan, attacks by aphids start before flowering and consequently the seed dressing was highly effective but admitted that the later attacks in Egypt may not justify its use.

Physiological and Biochemical Criteria for Evaluating Genotypic Responses to Heat and Related Stresses

D.W. Lawlor
Institute of Arable Crops Research, Rothamsted Experimental Station, Harpenden, Herts., United Kingdom

Abstract

The concepts behind the use of biochemical processes and their physiological consequences for improvement of wheat productivity in hot, dry, and bright environments are considered. The example of photosynthetic metabolism is taken: the structure of the system and the limitations to assimilation caused by light harvesting and electron transport, ribulose bisphosphate synthesis, and ribulose bisphosphate carboxylase-oxygenase (Rubisco) enzyme activity are outlined. A major limitation to CO_2 fixation, particularly in hot dry environments, is the oxygenase activity of Rubisco, which is the origin of the carbon lost in photorespiration. Photorespiration increases greatly as a proportion of CO_2 fixed at higher temperatures. Gas exchange analysis can be used to detect genotype differences in heat response. For efficient photosynthesis, it is essential to maintain balance between the supply of energy and that of carbon dioxide and an active mechanism of CO_2 fixation for assimilate production. Assimilate consumption must also be balanced with assimilate production in the long term as accumulation of assimilates in the photosynthetic apparatus may lead to feedback inhibition of the mechanism. Imbalance in metabolism caused by large energy flux relative to CO_2 assimilation results in high energy states of chlorophyll and electron transport components, accumulation of cellular reductant (e.g., NADPH) and leads to formation of reactive forms of oxygen. The latter are potentially damaging to metabolism, causing chlorophyll bleaching and lipid oxidation. Hence, thylakoid membranes may be damaged, their functions impaired and photo-inhibition results. Protective mechanisms, particularly the carotenoid system, 'detoxify' these damaging compounds. The onset of energy imbalance can be detected by decreased CO_2 assimilation and increased chlorophyll fluorescence, which indicates the energy status of the thylakoids. The use of these techniques for selection of heat and water stress tolerant genotypes is discussed.

Introduction

A plant's genes—the genotype—determine the number, type, and extent of the traits produced—the phenotype—which determines the plant's response to its environment, both the 'average' and the range of conditions, including extreme events. Responses can be considered as both general and specific; the general is shown by all autotrophic higher plants, and reflects particular requirements for a range of light, water, nutrients, and temperature (Edwards and Walker 1983). Response to each of these factors may be described by a response curve (Figure 1). Below a threshold of the particular condition, the plant processes (e.g., growth, reproduction, and photosynthesis) cannot occur but above the threshold the rate of the process increases, eventually reaching a maximum over a narrow or wide range of conditions (Brooks

and Farquhar 1985). With further increase in the magnitude of the environmental factor, the rate decreases, often precipitately, and eventually stops at an upper limit. Specific responses are similar but differ quantitatively depending on the genotype, exhibiting different thresholds, rates of response to the environmental factor, and different absolute rates and maxima obtained. Such specific genotypic differences are of great importance in plant breeding and crop adaptation to stress conditions (Lawlor 1987a).

The magnitude of the differences between plants depends on their evolutionary history, phylogeny, and ecological type (e.g., sun and shade plants). Major differences exist. For example, in the angiosperms, the C3 and C4 forms of photosynthetic metabolism allow different photosynthetic responses to environment; C4 plants (e.g., sorghum and maize) are particularly adapted to hot, brightly lit,

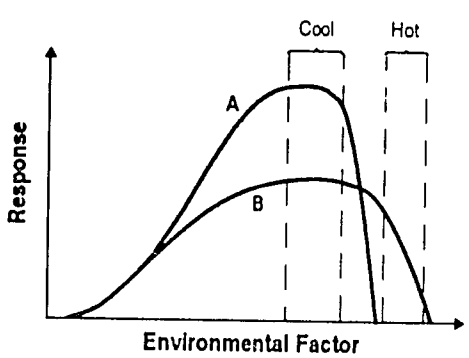

Figure 1. Theoretical response of a plant process (e.g., rate of growth or photosynthesis) to an environmental condition such as heat. The two genotypes, A and B, differ in both the optimum for the response and the high threshold (temperature) at which the process ceases. Selection for characteristics of B would be a disadvantage in the average environment of A and vice-versa for A in B. However, between the two environments the value of A or B features would not be so clear.

often dry environments whereas C3 plants (e.g., wheat) are generally more efficient in dim light and cooler, moist conditions (Edwards and Walker 1983). There is a great range of ecological preferences of species within a genus, e.g., durum wheats (*Triticum durum*) of Mediterranean environments and hexaploid wheats (*Triticum aestivum*) of temperate regions. Also, within a species, e.g., the hexaploid bread wheats, there is considerable variation in responses. The range of potential responses of plants to complex environments is enormous, with constellations of characteristics that confer ability to grow and survive. For example, plants adapted to very bright light have leaf canopy architecture, leaf structure, and metabolic features enabling them to grow in hot and dry conditions, whereas those adapted to dim light have adaptations of the same mechanisms so that components differ quantitatively between high and low light plants. Within the wheats, relatively small changes in composition may affect the ability to utilize solar radiation and to minimize damage under conditions that decrease CO_2 supply (e.g., stomatal closure during water stress).

There is strong correlation between environmental factors, which constitute a habitat. For example, solar radiation experienced by crops depends on geographical location and cloud cover; periods of large energy flux are thus associated with infrequent or reduced rainfall, low atmospheric humidity, and high temperatures. However, more extreme conditions prevail at some time in most areas, such as dry periods in the wet humid tropics. Farmers target periods within the normal environment that are favorable to production of a particular crop. Plants adapted to extreme drought conditions will have features reducing water loss, maintaining photosynthetic rate and

protecting metabolism against damage caused by cellular desiccation and excessive energy loads.

To produce wheat with large and stable production in extreme environments such as those of the hot dry tropics, it is essential to exploit natural variation in the genotypes, which may confer productivity combined with resistance to damage. The genes must provide a combination of traits that will allow the crop to develop an optimum leaf area and to produce adequate numbers of ears and grains upon which yield production depends. Both of these traits require formation and growth of tillers in addition to the main stem. Also, plants must make and maintain ample photosynthetic machinery of high efficiency to maximize total assimilate production (Lawlor 1987a). A further requirement is the ability to store assimilates before anthesis and to remobilize them for grain-filling under adverse conditions (Evans 1993). All these processes must operate in fluctuating and often extremely stressful conditions; human demand for increasing wheat production under conditions to which the species is not adapted (e.g., very hot, dry areas) places added burdens on the plant, not only to survive, but to make large yields with a minimal supply of nutrients, water, etc. To do so requires major changes in the plant's biochemistry, which is likely to be slow to achieve by classical breeding, and, indeed, may not be possible unless the basic biochemical and physiological characteristics are amenable to change by genetic engineering techniques.

Wheat shows enormous variation within and between species with biochemical adaptations (the integrated results of which are visible as structural differences and measurable as differences in biomass and yield or physiology) enabling genotypes to survive and produce yield. Plant breeding attempts (via the obvious phenotypic features) to exploit the differences in these biochemical processes and combine different desirable traits and improve phenotypic characteristics to achieve the required productivity. Agronomy modifies the environment so that the potential maximum productivity can be expressed fully. Only by matching genotype needs with the agriculturally-modified environment can maximum potential be achieved (Lawlor et al. 1989, Evans 1993).

Relevant to this conference is the capacity of genotypes to produce in very hot, dry environments with very bright light and, particularly, to maintain productivity even in relatively infrequent extreme conditions (Figure 1), those to which the plant is not normally exposed, but to which it must be adapted if damage is to be avoided. Here the biochemical and physiological basis of plant responses to extremes of light, temperature, and water supply is explored. The question posed is: what biochemical features, controlled by the genotype, are required for an efficient phenotype, i.e., one able to survive and yield in extreme environments (Lawlor 1983, 1987a)?

Plant breeding has largely concentrated on the empirical combination of traits and on selection of desired characteristics, e.g., high yield and stability of yield, under particular environments, generally those in which the crop will be grown (target environments). This 'black box' approach has advantages in that it considers not a single or limited number of factors (e.g., photosynthetic characteristics, grain size) that contribute to productivity, but includes all factors, even if the mechanisms are not understood or indeed known. Therefore, selection in the target environment and repeated trials of selected material are likely to test, thoroughly, genotypic ability to produce dry matter and yield in those conditions.

However, a purely empirical approach is unsatisfactory in that it may ignore important processes which, if deliberately selected, might achieve more effective combinations of traits of greater potential for a particular or wider range of environments. This approach presupposes that the trait can be identified efficiently by suitable genetic, biochemical, or physiological markers and then combined into a suitable genotype to achieve a desired product. Many biochemical processes are well characterized, but their complexity and considerable interaction make it difficult to quantify them or to relate any one biochemical step or component to an end product (e.g., yield), which is the result of many metabolic sub-processes (Lawlor 1987a, Evans 1993). Indeed, it is even difficult to show that physiological processes, generally at a higher level of complexity than the biochemical, are directly causal in determining yield. This will limit application of genetic engineering techniques to breeding for production and stress resistance.

Genes and limiting factors

Genes code for proteins, which form the structural and biochemical components, including enzymes, of the plant cell. This metabolic machinery is responsible for assimilation of materials, e.g., carbon dioxide and nutrients (e.g., NO_3^-), from the environment to form the plant and ultimately yield. The nature of these components and how they are incorporated into physiological systems (e.g., formation of particular proteins and lipids and their combination into membranes and organelles) determine organ structure and function and thus the responses of plants to their environment. The combinations of characteristics of the components ultimately determine the system's efficiency in growth, production, and survival in extreme environments.

Returning to Figure 1, the genome represented by A might produce a key enzyme, which functions more efficiently at cooler temperatures than that of B, conferring greater productivity at the lower temperature. In hot conditions, an A-type enzyme cannot work efficiently and production decreases so that B enzyme is an advantage. However, the potential advantage conferred by a particular enzyme or biochemical component at the level of photosynthesis, the plant, or crop is an advantage only if all other components perform correctly at the particular temperature. If this is not so, as may be expected in the A plant in a hot environment, then introducing the B enzyme in the A type genome is of no value. To improve the efficiency and productivity of B would require transferring the characteristics of type A into the B genome while retaining the heat tolerance of B; this is only effective if those particular characteristics of A are not heat-sensitive. Clearly, it is of importance to know what the characteristics of the system are if the plant is to be altered. In closely related genotypes, variation in individual components, e.g., enzyme characteristics, may be very small and differences in efficiency may depend on extremely small changes in protein structure. The enzyme ribulose bisphosphate carboxylase-oxygenase (Rubisco), the CO_2 assimilating enzyme, has a molecular mass of 550 kDa, with 675 amino acid residues per active dimer in wheat, yet changing one amino acid at the active site, or even one at considerable distance from it, generally adversely affects catalytic efficiency (Andrews and Lorimer 1987). Thus, changes in genotype and phenotype, which confer advantages in particular environments, are subtle. Also the number of processes involved in the adaptation of higher plants to their environment are extremely large (Edwards and Walker 1983).

Plant growth is the result of many processes operating close to a 'systems norm', i.e., a particular rate under given conditions, with complex regulatory mechanisms that may vary with conditions to ensure efficient, long-term function. A limiting factor may be clear when one factor (e.g., nitrogen supply) is deficient in an otherwise good environment or an enzyme (e.g., of chlorophyll synthesis) is lacking. However, under conditions to which the plant is well adapted, complex interplay of multiple regulatory processes is more likely. Because of these complex systems, the specific reasons for differences between genotypes in particular environments, the G x E interaction, and the mechanisms underpinning them are very poorly understood. Ultimately, the sum of the integrated processes determines the plant's success in a given environment. Unfortunately for plant breeding, the controlling biochemical and physiological processes that confer an advantage for productivity in particular environments are difficult to identify in such a complex system. If plant breeding is to use biochemical and physiological information and knowledge of how they relate to environment, as an alternative to empirical breeding techniques, it is necessary to understand the mechanisms that confer resistance to extreme environments and to develop selection criteria and techniques that will identify the traits in potential breeding material and thus allow them to be used.

Biochemical and Physiological Factors Determining Genotype x Environment Interactions

The foregoing provides a background for analysis of processes that contribute to G x E interactions and specifically to obtain varieties with improved CO_2 assimilation and yield under hot, brightly lit, water-stressed conditions. Here we choose one plant process out of many to illustrate how particular physiological responses are determined by biochemistry and how they might be selected. The photosynthetic mechanism is considered, how its function depends on environment, and how a malfunction can be detected by fluorescence and gas exchange measurements. The possible use of these techniques in genotype selection for heat and drought tolerance is considered. The concepts are not specifically restricted to wheat and information is derived from many species; the basic processes are very similar but differ quantitatively. However, it must be realized that the total production of assimilates depends on leaf area capturing light energy to drive CO_2 assimilation, as well as on efficiency of photosynthesis per unit leaf area. Formation and growth of leaves are thus important processes that are essential for production. Also, development of ears and spikelets, followed by formation of fertilized ovules (i.e., storage sites), together with adequate transport into grains, is a prerequisite for assimilate storage and yield (Lawlor et al. 1989); they are not further considered.

Photosynthetic production: leaf area versus efficiency

Assimilation of CO_2 is considered, recognizing that other processes, e.g., assimilation of nitrate ions by photosynthesis, are also important. Total production of carbohydrates from CO_2 depends on the assimilation per unit area of leaf (itself a complicated function of light, water supply, temperature, and O_2 concentration as well as of CO_2 concentration) and on the total leaf area (and its characteristics) of the crop per unit ground area. The two main routes that could be taken in plant breeding and selection for high assimilate production

are: 1) formation and maintenance of large leaf area index, and 2) development of high assimilation efficiency per unit leaf area. Route 1 has been that taken in breeding bread wheats (i.e., hexaploids). Empirical selection has been for large leaf area index, but this may have had several damaging consequences for resource utilization; while increasing light capture and total CO_2 assimilation, it also increases water loss and demand for nutrients, etc., which are required to make leaves, arguably at the expense of grain sites. Most importantly, selection has resulted in a decreased CO_2 assimilation rate compared to the progenitors of present cultivated wheats (Evans 1993). The question has often been asked as to why this negative selection for photosynthesis should have occurred, but without satisfactory explanation. Selection for polyploidy may have resulted in larger organs, including leaves, with larger cells but their content of metabolic machinery, e.g., of the photosynthetic system, has not increased in proportion to change in leaf area.

Crucial questions are: what limits photosynthetic assimilation capacity in existing wheats, particularly in hostile environments, and how may the 'resistances' be overcome by breeding? If, as suggested earlier, the problem lies in increasing ploidy then it may be necessary to reverse the trends in breeding and selection and obtain plants with smaller cells and higher content of machinery, without losing advantages of larger sink sizes (e.g., grain numbers and capacity) or of high harvest index. A number of factors may limit assimilation rate. The schematic of the photosynthetic system (Figure 2) provides some insight (Edwards and Walker 1983, Lawlor 1987b). The pathway of CO_2 flux into the leaf is a main site of regulation, with the stomata dependent upon radiation and CO_2 concentration in the intercellular spaces (itself a function of the ambient CO_2) and rate of assimilation. Water stress decreases stomatal conductance. Regulation of conductance is critical not only to CO_2 assimilation, but also for water loss. Carbon isotope discrimination provides a method of assessing the relative importance of these effects (water use efficiency = WUE).

A structural feature of leaves that may have a strong effect on the efficiency of photosynthesis is the ratio of mesophyll surface area to leaf surface area, which affects diffusion rates of CO_2 into cells and is important if the conductivity of the cell surface to CO_2 is low. Another important feature is the nitrogen content or the related total soluble and Rubisco protein and chlorophyll contents per unit leaf area (Lawlor et al. 1989). All represent the amount of metabolic machinery in the leaf and therefore relate to potential assimilation.

Productive wheats have large amounts of N per unit leaf area; a large and regular supply of N (applications of fertilizer) is needed to develop high photosynthetic capacity and to prevent remobilization of proteins from old to young leaves or to ears, resulting in decreased efficiency of CO_2 assimilation when large rates are required for ear growth and grain-filling. However, a very large content of components is not effective in increasing photosynthetic rate, which decreases per unit of N in leaves of large N content compared to those of low N. This inefficient use of N is an additional reason for seeking more efficient CO_2 assimilation rather than increasing leaf area. Returning to the question of cell size, it is possible but not proven that diffusion and transport of metabolites and products are slower in large than small cells and may be a basic rate-limiting step (Lawlor et al. 1989).

Productivity of modern, high yielding wheats is very much related to organ numbers and size. Selection of specific features, such as short stems, have reduced lodging and freed assimilates for reproductive growth while the increased ear and grain numbers provide increased sink capacity. The need for large crop leaf area, achieved via larger numbers of leaves of greater size, is explicable as the main route to maximize biomass. However, the major penalty, already mentioned, of large leaf area index (LAI), especially in hot, dry regions, is the substantial loss of water. If LAI were reduced, but CO_2 fixation maintained or increased, then it would reduce the water use and increase WUE. An aside: increasing atmospheric CO_2 increases the CO_2 assimilation rate and reduces stomatal conductance, resulting in increased production and yield, decreased water loss, and substantially improved WUE. Under these conditions, carbon isotope discrimination is a valuable method of selecting for high WUE, as mentioned earlier. Breeding for greater productivity and stability in dry and hot environments by route 2—increasing photosynthetic

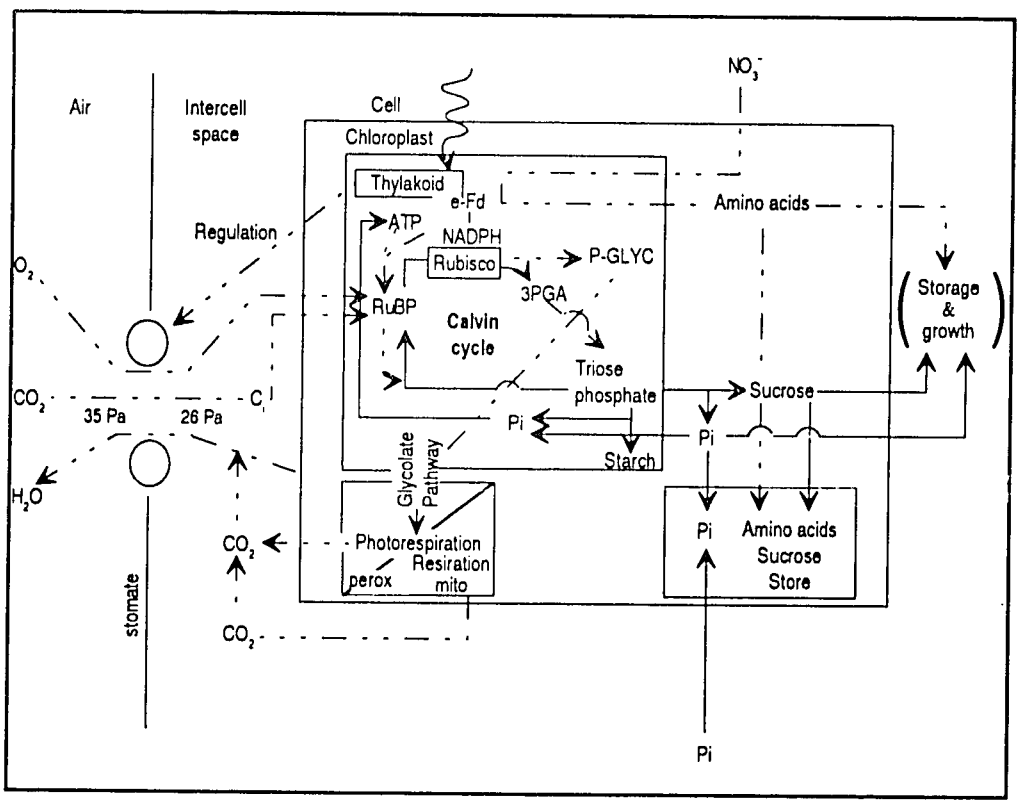

Figure 2. Schematic of the structure of the photosynthetic system in a C3 leaf such as wheat; CO_2 diffusion down the concentration gradient to Rubisco provides the substrate for carbohydrate production. Light energy is used to make RuBP for CO_2 assimilation. The function of the complete system determines the photosynthetic efficiency and capacity; stresses such as heat may damage specific components and alter the balance between different parts of the system (Lawlor and Keys 1993).

efficiency—would be advantageous, but this depends upon identifying and overcoming the factors limiting CO_2 fixation.

It appears relatively simple to change the size of plants and their organs, e.g., greatly increased yields resulting from the incorporation of dwarfing genes into wheats that allowed improvements in harvest index and reduced lodging, but it is more difficult to alter the inherent characteristics of metabolism. The next phase of plant breeding may require direct attention to more complex metabolic problems than in the past, if significant advances in productivity are to be achieved. Note the improvements in wheat yields over the last half century occurred without improvement in greater total biomass production per unit of land and with decreased efficiency of photosynthesis per unit leaf area in high yielding varieties.

Mechanisms Regulating CO_2 Assimilation by Leaves

What are the mechanisms regulating the assimilation of CO_2 (and NO_3^-) by leaves? Currently, there is controversy resulting from the complexity of the metabolic system (Figure 2) and of the CO_2 supply routes to the sites of fixation. Simplifying the system greatly, the following subprocesses are essential:

- Light energy capture and transduction with the formation of biochemical carriers of energy (ATP) and reductant (NADPH),
- Utilization of these for production of the acceptor for CO_2 assimilation ribulose bisphosphate (RuBP),
- Supply of CO_2 involving stomatal regulation of CO_2 diffusion,
- Rubisco catalyzed carboxylation of RuBP by CO_2,
- Oxygenation of RuBP resulting in photorespiration which offsets gross assimilation,
- Transport of assimilates in and to cells and tissues,
- Consumption of assimilates by sink organs.

Energy capture and transduction

These are the functions of the thylakoids of chloroplasts (Lawlor 1987b). Light energy capture, charge separation, with electrons energized and passed to and reducing the components of the electron transport chain, sets in motion the events of photosynthesis and ultimately results in production of dry matter. The light harvesting chlorophyll protein complexes are associated with photosystems II and I (PSII and PSI), and together they function to capture and convert light energy to chemical energy. This requires the electron transport components and results in reduction of electron acceptors in the stroma, namely ferredoxin (Fd) and the soluble acceptor ($NAFP^+$), giving Fd_{red}, and NADPH. The amounts and types of chlorophyll protein complexes vary according to the plant and environment, particularly light intensity and quality, during development. Efficient use of light requires a balance between the chlorophyll antenna, which captures incident photons, and the number and activity of the reaction centers (RC), which are specialized chlorophyll dimers able to eject electrons to acceptors in the thylakoid membrane when energized by the antenna. In weak light, a large antenna is required to harvest infrequent photons and to channel sufficient energy to the RCs. In bright light, however, the large flux of photons excites the antenna more frequently and therefore only a small antenna is needed (speaking teleologically) to energize the RCs. A large ratio of antenna to RCs and a large number of RCs per unit leaf area are essential to use

the light energy available and achieve high rates of electron transport.

Electron transport involves many steps with electrons being transferred from one acceptor to another along a chain. Electron transport is also coupled to proton transport into the thylakoid lumen; this proton pumping results in a gradient of proton energy (the proton motive force), which drives ATP synthesis from ADP and Pi by the enzyme Coupling Factor (CF) in the stroma. Therefore, achieving rapid rates of electron transport and balance between ATP and NADPH synthesis requires regulation of a number of processes via amount and activities of components in thylakoids (Brooks and Farquhar 1985). This is achieved by different expressions of genes for components, controlled by light and other environmental factors, and by organization of thylakoids into granal stacks, which restricts the CF to the external surfaces and increases the antenna size, but at the expense of ATP and NADPH synthesis.

Thylakoids developed in bright light have few granal stacks and relatively little membrane, but they do have an increased capacity for electron flow and for synthesis of ATP and NADPH compared to those from weak light. If ATP synthesis, for example, is slow relative to other processes, as it may be in very bright light, it may limit photosynthetic rate and other processes, e.g., protein synthesis in chloroplasts (Pradet and Raymond 1983). Reduced synthesis of ATP may also result from an inadequate supply of inorganic phosphate ions (Pi) and if recycling of Pi between cell compartments (e.g., cytosol, vacuole, and chloroplast) is inadequate (Lawlor and Jacob 1992). This illustrates the integrated nature of the photosynthetic process and the many limitations that may occur, depending upon the environment.

Synthesis of ribulose bisphosphate (RuBP)

The balance between ATP synthesis and NADPH formation is important for regeneration of RuBP by the photosynthetic carbon reduction (Calvin) cycle. This complex multi-enzyme cycle must have sufficient capacity (amount and activity) to regenerate RuBP rapidly if high rates of photosynthesis are to be achieved (Edwards and Walker 1983, Lawlor 1987b). RuBP reacts with CO_2 on Rubisco in the chloroplast stroma, giving rise to 3-phosphoglyceric acid, which then enters the carbohydrate synthesis pathways. In bright light, the potential for CO_2 fixation is considerable although the actual rate depends on the response of the partial processes leading to RuBP regeneration. Environmental conditions, such as temperature, also affect the behavior of the systems but the quantitative relations are unclear.

Characteristics of Rubisco

This enzyme is of the greatest importance in CO_2 assimilation and largely determines photosynthetic efficiency. It is a large multimeric protein of 550 kDa molecular mass with eight active sites per molecule for the reaction of RuBP and CO_2; the reaction is extremely slow (a turnover number of about 2 s^{-1}), so to achieve rapid rates of CO_2 assimilation, large amounts of protein per unit leaf area are required (Andrews and Lorimer 1987). In wheat leaves, Rubisco constitutes between 40 and 60% of the total soluble protein. Other enzymes have reaction rates 100 to 1,000 times faster and are also smaller molecules, thus constituting much less of the leaf protein and N, requiring much less nitrogen for synthesis. Inefficiency of Rubisco is one reason for the very large N content of leaves required for productive crops. Rubisco activity is not saturated with CO_2 at current atmospheric concentrations, for when C3 leaves are supplied with additional CO_2, their

photosynthetic rate increases and with it production of dry matter and, generally, yield. Hence, the CO_2 assimilation capacity potentially available in Rubisco and the photosynthetic system is not now fully utilized.

Another very important, adverse, feature of Rubisco is that it catalyzes the reaction of O_2 with RuBP; this oxygenase reaction occurs at the same enzyme sites as CO_2 fixation and CO_2 and O_2 are mutually competitive inhibitors (Jordan and Ogren 1984, Andrews and Lorimer 1987). Because oxygen in the atmosphere is at a much larger concentration than CO_2, and the CO_2 inside the leaf is considerably below atmospheric concentration, there is a substantial rate of oxygenation in C3 leaves. The oxygenase reaction gives 3PGA and also phosphoglycolate (PG), which is metabolized via the glycolate pathway in C3 mesophyll cells; four carbon atoms (2 PG molecules) entering the glycolate pathway results in one CO_2 being released in the mitochondria during photorespiration. The proportion of photorespiration to photosynthesis depends on the O_2/CO_2 ratio and is therefore a function of their partial pressures in the atmosphere and leaf intercellular spaces. High temperatures increase the oxygenase activity of Rubisco and also the solubility of O_2 relative to that of CO_2 so that photorespiration increases greatly as a proportion of net photosynthesis with elevated temperature. Thus, C3 photosynthesis becomes very inefficient in hot environments when leaf temperature exceeds 30°C. The glycolate pathway cannot be inhibited beyond the oxygenase reaction, to eliminate photorespiration, for accumulation of metabolites leads to inhibition of photosynthesis (Edwards and Walker 1983). An alternative is modification of Rubisco to reduce or eliminate the oxgenase reaction.

To increase and maintain CO_2 fixation at high temperatures, improvements in the characteristics of Rubisco are needed, e.g., eliminating the oxygenase reaction, and increasing the reaction rate and affinity for CO_2. In nature, Rubisco properties have improved over evolutionary time, e.g., Rubisco of photosynthetic bacteria is much less efficient than that of angiosperms, but the differences between higher plants are relatively small, particularly within the C3s (Andrews and Lorimer 1987). Changes required to enzyme structure for increased efficiency are likely to be subtle. C4s have rather less efficient Rubisco than C3s, but have avoided the problem of photorespiration by circumventing Rubisco characteristics, adding on to C3 metabolism a CO_2 pump utilizing phosphoenolpyruvate carboxylase. This increases the CO_2 concentration at the site of RuBP carboxylation in the bundle sheath cells of C4 plants. These extensive biochemical and structural modifications reduce or prevent the oxygenase reaction and make C4 plants much less dependent upon atmospheric CO_2 concentration and (of great importance) tolerant of high temperatures (Edwards and Walker 1983).

Plant breeding has not substantially altered the characteristics of Rubisco or other components of the photosynthetic mechanism and is unlikely to do so in the foreseeable future. It appears (earlier discussion) that breeding may have inadvertently decreased overall photosynthetic efficiency. However, it may be possible in the future to improve the process via alterations to the amounts and proportions of components that will confer advantages for crop production.

Carbon transport and assimilation

At high temperatures, the rates of metabolic activity, including growth and respiration, are increased relative to cooler conditions, although the increase may not conform to a $Q_{10} = 2$. Transport of assimilates and of Pi across the chloroplast envelope does not seem to be limiting, although accumulation of starch in chloroplasts, the consequence of Pi deficiency, is often observed under warm conditions. Pi deficiency may be important in regulation of C efflux, but little is known of temperature effects. Genotypic ability to transport and utilize assimilated C could be tested by measuring starch accumulation in leaves following active photosynthesis. Methods for detecting starch are relatively simple and could be applied to large numbers of samples, but it is more difficult to quantify starch (and other biochemical constituents) without much time and effort.

Metabolism of the primary products of photosynthesis to sucrose is regulated by the amounts and activities of the enzyme sucrose phosphate synthase. There is complex regulation related to amounts of carbohydrates in tissues. Sucrose is translocated from the cell to the phloem across the plasma membrane by a still poorly understood transport system, but there is no evidence that this mechanism is a limiting factor *per se*. The demand for assimilates by sink organs is more important for it determines removal, over long periods, of assimilates that may affect photosynthetic rate by feedback mechanisms (Lawlor 1987b). Sink demand is greatly increased by high temperatures, which accelerate development of organs and their rates of growth and respiration. Depletion of assimilates within the tissue may decrease or remove feedback inhibition of the photosynthetic mechanism.

Consequences of Metabolic Imbalance in Photosynthesis for Thylakoid Energetics

Plants have only limited mechanisms for avoiding excessive and potentially damaging light fluxes to the photosynthetic apparatus, e.g., orientation of leaves away from the direct sun rays decreases the flux of energy. Wheat genotypes adapted to hot, dry, bright conditions may benefit from erect leaves and awns and leaf rolling due to water loss may reduce the full impact. Normally, when reaction centers are filled with electrons, the energy captured by the antenna is used for electron transport and NADPH and ATP synthesis, but if consumption of ATP and NADPH, normally used in metabolism, e.g., for CO_2 and NO_3 assimilation, is blocked or their synthesis is impaired, then excitation energy accumulates in the antenna and reaction centers. Damage occurs if the energy captured by the antenna chlorophylls cannot be used in photosynthesis or by alternative methods of dissipation. Damage to the photosynthetic mechanism follows rapidly if controlled energy dissipation is inadequate (Cornic and Briantais 1991). The sites of damage may be, for example, at the thylakoid membrane that is sensitive to heat, or in the stromal enzymes (e.g., inhibition of ATP synthesis by water stress as a consequence of damage to the Coupling Factor). The results of an over-energized state are photoinhibition, generation of toxic forms of oxygen, and decreased enzyme capacity; eventually this leads to decreased assimilation and productivity. Energy is dissipated (Figure 3) directly as heat and fluorescence or transferred to carotenoids and converted into heat (Bilger and Björkman 1990, Krause and Weis 1991). These mechanisms act as a safety valve, reducing the possibility of damage to chlorophyll (photo-bleaching) and proteins

of the reaction centers (D1 protein), which characterize photo-inhibition (Demmig-Adams and Adams 1990).

Another important consequence of a highly reduced electron transport chain is that electrons pass to acceptors such as O_2, forming several reactive forms of oxygen, e.g., superoxide, which in combination with a proton, gives the perhydroxy radical, hydrogen peroxide and the hydroxyl radical (see Lawlor 1987b). All are highly toxic and must be rapidly destroyed, e.g., superoxide is converted by the enzyme superoxide dismutase to hydrogen peroxide, which is in turn broken down by catalase to water and O_2. There are several other mechanisms for regulating the energy and reductant state of cells, e.g., ascorbate and reduced glutathione (a tripeptide with thiol groups) operate in a detoxification cycle. Plants lacking these mechanisms are quickly damaged by light. In addition, the importance of carotenoids must be emphasized; triplet states of chlorophyll, which can be very reactive and damage other molecules, are removed by the carotenoids. Carotenoids also undergo epoxydation reactions with excited states of oxygen and detoxify singlet oxygen and regulate the NADPH levels in cells with violaxanthin and zeaxanthin in membranes operating in a cycle to oxidize NADPH. This type of regulation is most important for maintenance of thylakoid energy balance under varying light flux and changing rates of metabolism (Demmig-Adams and Adams 1990).

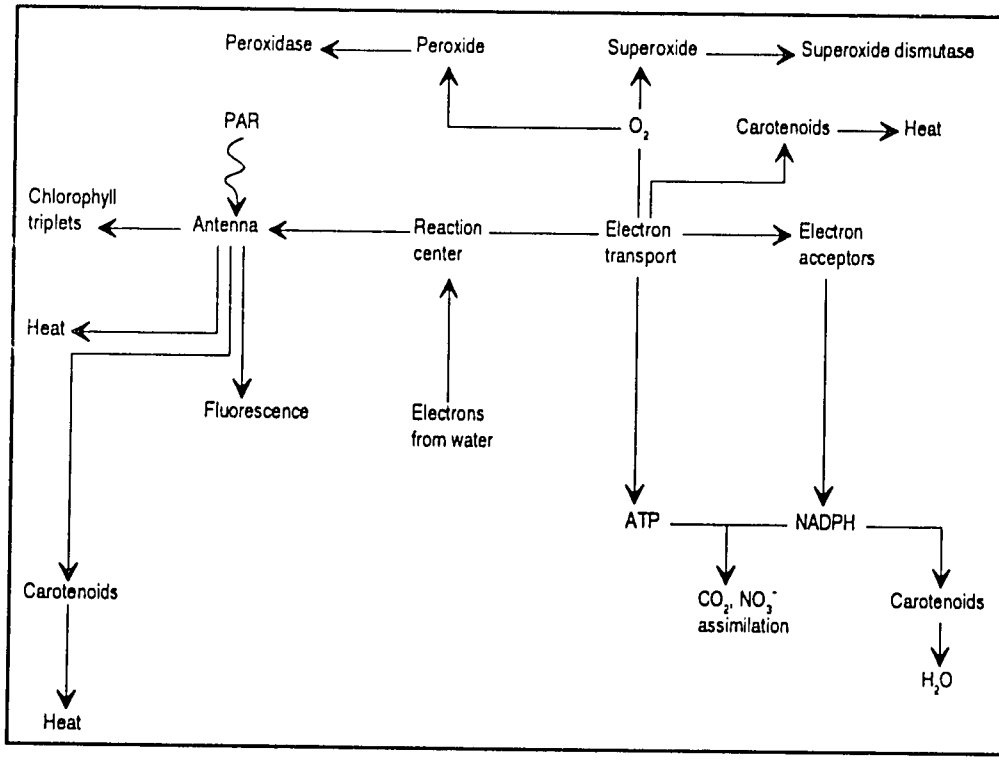

Figure 3. Scheme of the ways in which light energy and reduced compounds can be used in photosynthesis, including detoxification mechanisms.

From the point of view of breeding genotypes resistant to heat and water stress, it is probable that the ability to regulate energy and reduction state of cells and remove any toxic compounds formed is of great importance (Lawlor 1983, Lawlor and Khanna-Chopra 1983). Yet measurement of such biochemical components is very difficult. However, the state of the system is indicated by the fluorescence emission (Schreiber and Bilger 1987, Krause and Weis 1991).

Fluorescence as an Indicator of Energy Status of Thylakoids and Photosynthetic Metabolism

Chlorophyll fluorescence (at about 680-720 nm wavelength) indicates the energetic state of the chlorophyll matrix. When dark adapted leaves are illuminated (Figure 4), fluorescence is emitted, the so-called

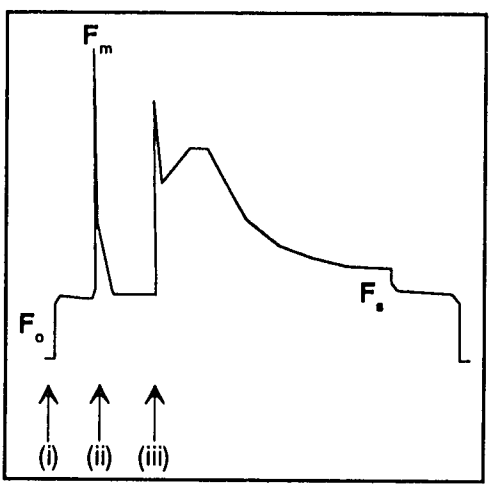

Figure 4. Fluorescence emission from a leaf exposed to very dim light (i), giving the basal fluorescence (F_o), then to a very brief flash of bright light (ii), which saturates the electron transport system and gives maximum fluorescence (F_m) followed by normal light (iii). The changes indicate the state of the photosynthetic system and the utilization of the captured light energy (F_s).

Kautsky transient. Fluorescence rises rapidly from a minimum (F_o) to a maximum (F_m) because the energy is not used in electron transport as the RC has lost the electron to the quinone acceptors in the chain but further transport is not possible. Only when energization of the membrane allows ATP synthesis to start and stromal enzymes are activated does CO_2 assimilation proceed consuming NADPH and $NADP^+$ is recycled to accept electrons. Consequently, the RCs can function, energy in the antenna decreases, and fluorescence drops. Eventually, a steady state is obtained between the rate of CO_2 fixation and light capture, indicated by fluorescence emission. The variable fluorescence ($F_v = F_m - F_0$) is an important indicator of the energy status of the thylakoid. Conditions that block electron flow increase fluorescence and a low ratio of F_v/F_m indicates inefficient utilization of captured light energy. The use of modulated fluorescence techniques allows measurement of fluorescence under normal illumination conditions so that the processes using energy ('quenching'), e.g., by photochemical processes such as CO_2 assimilation and nonphotochemical processes involving carotenoids, can be determined. The method is a sensitive probe of the state of the photosynthetic system; it can be used to compare genotypes under a range of conditions in the field and is relatively fast and can be automated.

Fluorescence indicates the stress (heat, water, nutritional) experienced by plants. Genotypes that are less sensitive to the inhibitory effects of stress may be identified by a low fluorescence under particular conditions; an increase indicates stress damage (Schreiber and Bilger 1987, Stuhlfauth et al. 1988). Thus, it reflects the integrated response of metabolism to many physiological and environmental factors. However, changes in fluorescence may be

relatively insensitive indicators compared to other physiological processes, e.g., more severe drought is needed to induce substantial fluorescence than to reduce expansion growth of tillers and leaves. Biomass production and yield may therefore be affected by small LAI and reduced light interception, coupled with fewer grains, before fluorescence changes. Fluorescence analysis, combined with gas exchange measurements, will be most profitable when used to select, comparatively in the same environment, genotypes resistant to severe conditions such as heat and drought. Selection may not confer high yielding capacity because the physiological traits that combine to reduce the likelihood of stresses may restrict the ability of a crop to yield under more favorable conditions. In developing and testing selection criteria, it would be valuable to correlate behavior of indicator systems such as carotenoid or protective enzyme content/activity. Such analysis may indicate if genotypes do, in fact, utilize these mechanisms to avoid heat damage and show points in metabolism affected directly by stress.

Criteria for Selection of Crops with Large Assimilation Rates under High Temperatures

There is uncertainty as to the ideal composition of the photosynthetic system for large rates of CO_2 assimilation under high temperatures combined with water stress and bright light. Given the inefficiency of Rubisco and its temperature sensitivity, it is essential to maintain large amounts of Rubisco in the leaf to prevent its premature remobilization (therefore adequate N supply is essential during growth, including grain-filling). To maximize Rubisco activity, adequate RuBP supply is essential. Hence photosynthetic enzyme activity must be large plus the availability of ATP and NADPH must be assured, for which the chlorophyll antenna must be large enough to ensure rapid capture of available photons. Electron transport capacity must match that of other parts of the system. Hence, the aim is to achieve the formation of a large capacity, high activity photosynthetic system capable of producing large rates of CO_2 fixation to match the demands for assimilate supply coming from the sinks. Currently, these detailed aspects of biochemical function are difficult to determine, methods are slow and inexact, and concentration on any one aspect runs the risk of neglecting other, equally important, parts of the system.

There is also the problem of adaptation to conditions during growth, e.g., expression of particular genes is under environmental control. As conditions may substantially alter plant composition and function, selection in one environment may prove unsuitable for genotypes in the different "target" environments. Net CO_2 fixation rate (measured by portable infrared gas analyzers) may be used for selection as it integrates all aspects of the biochemistry, e.g., light harvesting, Rubisco and Calvin cycle functions and transport of intermediates and products (Lawlor 1987a). By examining photosynthesis under a range of conditions, including heat and water stress, it is possible to assess genotype responses and differences, but measurements are relatively slow and comparisons must be made on material of the same age to avoid senescence effects. Measurements should be made under normal and extreme conditions to fully assess plant responses.

Conclusions

Analysis of photosynthesis indicates that the capacity for, and balance between, the capture of light energy by the thylakoid system, transduction of that energy into NADPH and ATP, and utilization of these two compounds in CO_2 assimilation are essential features for a productive system. Utilization of assimilates by sinks is also very important. Active photosynthesis requires balance between the processes of light energy capture, transduction to chemical form, and its consumption in biochemical processes. If carbon assimilation is impaired by heat or water stress (by stomatal closure or damage to metabolism), accumulation of energy in thylakoids leads to production of damaging metabolic intermediates that can be removed by specific mechanisms. Such energetic/metabolic imbalance can be detected by chlorophyll fluorescence. By combining fluorescence and photosynthesis measurements, it may be possible to analyze the genotype in the target environment and the G x E interactions and thus obtain genotypes better suited to particular environments.

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Questions/Discussion

Dr. Lawlor was questioned on the effect of environmental stress in the reproductive phase. He replied that, to his knowledge, the most sensitive phase is in pollen formation and fertilization. It appears that meiosis is affected by heat and possibly pollen tube growth is also inhibited. There are also effects of stress on the size of ears—number of spikelets and number of potential grain, which arise during early growth of the reproductive organs. Grain-filling is affected by the supply of assimilates and the shortening of the filling period.

He was asked whether it might be useful to follow starch content during grain-filling as an indicator of heat stress tolerance. He agreed that assimilate content of carbohydrates, soluble sugars, and starch indicates the availability for the grain. He suggested that the contents at anthesis may be informative as it may determine early grain growth.

Temperature Analysis and Wheat Yields in the Gezira Scheme

H.S. Adam
University of Gezira, Wad Medani, Sudan
O.A.A. Ageeb
Agricultural Research Corporation, Wad Medani, Sudan

Abstract

Temperature is the single most important climatic element affecting the growth, development, and yield of wheat in the Gezira. The normal mean temperatures for December, January, and February are 24.1, 23.6, and 25.4°C, respectively (1951-80). This paper analyzes the temperature regime during the last 10 years (1981-82 through 1991-92) and relates the analysis to the yield of wheat in the Gezira Scheme. Results show that it is important to consider 10-day averages of mean temperature in addition to the monthly averages. Also, good management may offset the harmful effects of high temperature and yield relates well with the mean temperature over the whole season.

Introduction

Wheat has become a very important food crop in Sudan. About 70% of the area occupied by wheat in Sudan is in the Gezira Scheme where it is grown under irrigation during the short winter season (November to February). The normal mean temperatures for December, January, and February are 24.1, 23.6, and 25.4°C, respectively (1951-80). Temperature is the single most important climatic element affecting the growth, development, and yield of wheat in the Gezira. The objective of this paper is to analyze the temperature regime during the last 10 years and relate the analysis to the yield of wheat in the Gezira Scheme.

Methodology

The maximum and minimum temperatures for December, January, and February were recorded at the Wad Medani Agrometeorological Station (14° 44'N) for the last 10 years. Ten-day and monthly averages were computed for each month. Yield data for the 10 seasons (1981-82 through 1991-92) were collected from the Sudan Gezira Board. Table 1 shows the 10-day and monthly averages of mean temperature and wheat yield data.

The temperature regime during the best year (1991-92) was compared with the worst year (1981-82). Wheat yields in 1990-91 were compared with 1991-92 for the whole scheme and on the research farm. Yields from 20 ha in the Darwish block during 1986-87 to 1988-89 were compared with scheme and research farm yields. Yields during the 10 seasons were also plotted against the mean temperatures of December, January, and February.

Results

The average mean temperature for the last 10 years in December was higher than the 1951-80 mean by 0.9°C while January and February were cooler by 0.3 and 0.7°C, respectively.

The highest yields obtained in the last 10 years over the whole Gezira and Managil Schemes was 2.24 t/ha in 1991-92. The temperature regime during the December-February period was the most favorable with mean temperatures of 22.9, 21.4, and 21.4°C during December, January, and February, respectively. The lowest yield was 0.78 t/ha in 1981-82. The mean temperatures for December, January, and February were 26.3, 25.4, and 24.1°C, respectively. The temperature was high compared to 1991-92. However, there are other seasons when December and February were warmer than 1981-82.

The importance of looking at 10-day averages is illustrated by the following. In 1981-82, the mean temperature during the last 10 days in January was 28°C and in the last 10 days of February, it was 29°C. This very high temperature, which was not reached in any corresponding 10-day period in any other season, may have been the reason for the very low yield in 1981-82.

In 1990-91, very high temperatures occurred during the first 10 days of December (29.8°C) and the last 10 days of February (28.2°C). The yields in 1990-91 over the whole Gezira were only 47% of the yields in 1991-92. However, during the same season, the yields from the research farm in 1990-91 were 78% of the 1991-92 yields from the same farm. This shows the effect of good management involving frequent irrigation, adequate fertilizers, and optimum sowing date. With good management, the yields in the unfavorable season were depressed by only 22% (research farm), while over the whole scheme the reduction in yield was 53%.

Table 1. Monthly and 10-day (I, II, III) mean temperatures (°C) and mean yields in the Gezira Scheme over the last 10 years.

	81-82	82-83	83-84	85-86	86-87	87-88	88-89	89-90	90-91	91-92	Average 81-92
Dec. I	27.6	23.9	28.8	25.9	21.7	25.6	27.0	24.1	29.8	24.9	25.7
Dec. II	26.1	22.2	27.3	27.0	22.7	25.3	27.3	23.3	27.5	22.9	25.0
Dec. III	25.3	24.1	21.9	23.3	24.5	23.4	24.3	22.6	27.7	21.1	24.1
Mean Dec.	**26.3**	**23.4**	**26.0**	**25.4**	**22.8**	**24.7**	**26.3**	**23.3**	**28.3**	**22.9**	**25.0**
Jan. I	24.7	20.3	25.2	25.1	21.7	24.1	20.0	25.7	22.5	18.6	23.1
Jan. II	23.3	20.6	22.3	22.8	25.3	22.1	18.6	21.5	23.9	21.3	22.8
Jan. III	28.0	19.6	22.5	24.4	24.9	24.7	22.0	25.6	22.4	24.1	23.9
Mean Jan.	**25.4**	**20.1**	**23.3**	**24.1**	**24.0**	**23.6**	**20.3**	**24.3**	**22.9**	**21.5**	**23.3**
Feb. I	20.9	23.8	26.8	27.1	27.0	24.7	20.4	23.2	24.5	20.9	23.8
Feb. II	23.3	25.2	29.1	25.1	27.0	24.1	22.7	25.1	24.9	21.4	24.7
Feb. III	29.0	25.7	27.6	28.0	28.5	26.9	23.3	20.9	28.2	21.6	25.8
Mean Feb.	**24.1**	**25.0**	**27.8**	**26.8**	**27.2**	**25.2**	**22.1**	**23.2**	**25.7**	**21.4**	**24.7**
D + J + F	**25.3**	**22.8**	**25.7**	**25.4**	**24.7**	**24.5**	**22.9**	**22.8**	**25.6**	**21.9**	**24.3**
Yield (t/ha)	**0.78**	**1.42**	**0.92**	**0.96**	**1.06**	**1.13**	**1.34**	**1.56**	**1.05**	**2.24**	**1.25**

Yields from the research farm were higher in 1986-87 than in 1987-88, while the reverse was true for yields from the scheme. Temperature comparisons show that December was cooler in 1986-87, January about the same or slightly warmer, but February was much warmer in 1986-87. The fact that the yields from the scheme were lower in 1987-88, while those from the research farm were higher may indicate again the that good management was able to offset the harmful effects of February's high temperatures.

Finally, the yields from the Scheme were plotted versus the mean temperature for December, January, and February. Figure 1 shows that there is a curvilinear relationship and a reasonable fit. It seems the cumulative effect of temperature is important throughout the season.

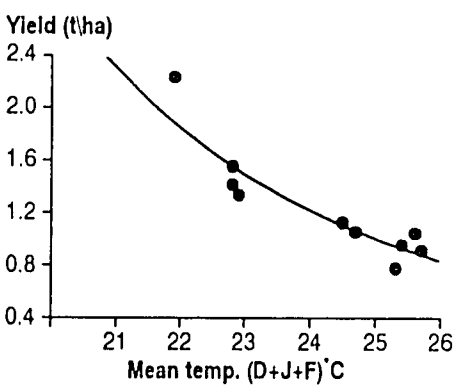

Figure 1. The relation between the December-February mean temperatures and average yields in the Gezira Scheme over the last 10 years.

Conclusions

This research reaches three major conclusions:

- It is important to consider 10-day averages of mean temperature in addition to the monthly averages.
- Good management may offset the harmful effects of high temperature.
- Yield relates well with mean temperature over the whole season.

Questions/Discussion

It was suggested to Dr. Adam that he might try using a "stress days" concept (i.e., the number of days when temperatures exceed a certain level) for explanation of temperature effects. There were a number of comments regarding his view that effects of heat could be reduced by good management. He re-iterated that proper management—optimum seeding date, frequent irrigation, and adequate fertilizers—could substantially reduce the effect of high temperatures. This was clear in 1989-90 and 1990-91 when some farmers obtained 5-6 t/ha in spite of the hot conditions. It was also stressed that irrigation at critical periods could be particularly effective in reducing heat stress.

Role of Photoperiod and Vernalization in the Adaptation of Wheat under Heat and Moisture Stresses

M.G. Mosaad
International Center for Agricultural Research in the Dry Areas (ICARDA)
G. Ortiz Ferrara and M.M. Nachit
International Maize and Wheat Improvement Center (CIMMYT), Aleppo, Syria

Abstract

Breeding for earliness while maintaining stabilized productivity of wheat is a major concern of plant breeders, especially for its important escape mechanism from terminal heat and drought stresses, and for cropping intensification. Vernalization requirement, photoperiod response, and temperature are the main determining factors in crop earliness. Four bread wheat (BW) and four durum wheat (DW) genotypes were evaluated for their responsiveness to vernalization, photoperiod, and heat stress under field conditions. A plastic house screening technique was evaluated for its suitability to differentiate drought resistance traits. The basal vegetative period of the six insensitive cultivars to photoperiod (P) and vernalization (V) was approximately the same as their days to heading under heat stress field conditions. The P-insensitive and V-sensitive BW cultivar Dorghal headed very late, while P- and V-sensitive DW cultivar Kabir 1 failed to reach heading stage under heat stress field conditions. Grain yield under the driest regime was closely and positively correlated with biological yield, kernels/spike, main stem grain yield, and water use efficiency (in relation to grain and biological yield). This supports the view that selection for these traits under drought conditions will be efficient for developing high yielding cultivars for moisture-limited areas.

Introduction

Earliness in cereals is a very important escape mechanism from terminal heat and drought stress. It is known to be influenced by such factors as vernalization (V), photoperiod (P), and solar radiation. Borlaug et al. (1964) reported that the low sensitivity to day length of the wheats developed in Mexico is undoubtedly one of the factors contributing to their wide adaptability throughout the world.

The successful adaptation of wheat to diverse environments worldwide appears to be mainly a consequence of breeding and selection for flowering time which confer optimal yield in these environments. The processes determining the timing of flowering and development, i.e., V and P responses, and those influenced by growth temperature can, therefore, be considered as highly significant to wheat's adaptation and hence, yield (Halloran, 1975, Pirasteh and Welsh, 1980). Water use efficiency (WUE) is an important physiological characteristic that is related to the ability of wheat to cope with water stress. Withholding irrigation or inducing water stress has increased WUE (Bapna and Khuspe 1980, Rao and Bhardwaj 1981, Johnson et al. 1984). Since WUE is a potential selection criterion for wheat improvement, an understanding of how it is affected by stress must be attained.

The objectives of this study were to:

- Characterize eight wheat genotypes for their response to vernalization, photoperiod, and heat stress under field conditions;
- Identify morphophysiological traits associated with yield under four moisture regimes; and
- Assess the WUE of eight bread and durum genotypes under stressed and optimum conditions.

Materials and Methods

Cultivars

Eight bread wheat (BW) and durum wheat (DW) genotypes with a wide range of variation for their response to water stress, earliness, growth habit, and vernalization response were chosen for this study.

The four BWs consisted of two genotypes with reported drought tolerance (Cham 6 and Dorghal) and two cultivars with good adaptation under optimum moisture condition (Yamama and Debeira). Similarly, two drought-tolerant DW genotypes (Om Rabi 5 and Kabir-1) and two genotypes with good performance under optimum conditions (Stork and Gallareta) were studied.

Vernalization and photoperiod responses

Germinated seeds of the eight genotypes were vernalized following the technique described by Parvis and Gregory (1952). Vernalized and unvernalized seedlings were transplanted to pots and placed in two separate growth cabinets inside a plastic house with 12 and 16 hours of light duration. Heading date was recorded as described by Haun (1973). The basal vegetative period (BVP) defined as days to heading under 16 hours plus 42 days of seed vernalization was measured. The eight wheat genotypes were characterized based on their response to P and V according to the technique described by Ortiz Ferrara et al. (1993).

Moisture regime experiment

Four watering regimes, consisting of 35, 55, 75, and 95% of field capacity, were used to evaluate the eight wheat genotypes under plastic house conditions. Temperature was kept constant between 22°C day/16°C night. Plastic pots 16 cm in diameter were filled with a 2.5-kg mixture of two parts clay loam soil and one part sand. The soil mixture had a field capacity and permanent wilting point of 30 and 7%, respectively. Before planting, 0.8 g of urea, 0.5 g of ammonium sulfate, and 0.2 g of superphosphate were applied to each pot. Six seeds were planted in each pot and the germinated seedlings were thinned to three uniform plants after 10 days.

Pots were checked daily and weighed. When the surface of the soil became dry, water was added to bring the moisture level to the required treatment percentage. The amount of water added for each regime was recorded so that water consumptive use (WCU) for each pot could be determined.

The experiment was set up as a randomized complete block design with four replicates. Data analysis was done using a MSTAT-C statistical package. The following traits were measured: days from planting to heading (DHE), days to maturity (MD); grain-filling day (GFD = MD - DHE), flag leaf area (FLA), plant height (PH), spikes per plant (S/P), spikelets per spike (S/S), kernels per spike, (K/S), and 100 kernel weight (KW).

At maturity, plants were cut at the surface of the soil to determine biological yield (BY). Plant heads were classified into main stem head and tiller heads. Grain was removed from the heads, then weighed to determine main stem grain yield (MSGY) and tillers grain yield (TRGY). Total grain

yield was calculated as MSGY + TRGY. Harvest index (HI = TGY/BY) was calculated. WUE was calculated in relation to biological yield (WUEBY) and grain yield (WUEGY).

Summer field experiment

During the summer of 1992, the eight wheat genotypes were planted in the field at Tel Hadya, Syria (36°N) to study their performance under heat stressed conditions. Characters measured to characterize the eight genotypes included: growth habit (1=erect; 9=prostrate), vernalization requirement (1=low, 9=high), and DHE.

Results and Discussion

Growth habit (GH), vernalization requirement (VR), and days to heading (DHE) of the two groups of varieties under heat stressed field conditions are presented in Table 1. Significant differences were found between genotypes. Dorghal (BW) and Kabir 1 (DW) had higher scores for both GH and VR. This resulted in a delayed heading date for Dorghal (66 days) and a failure in Kabir 1 to reach the heading stage.

Table 1 also shows the basal vegetative period (BVP = number of days to heading under 16-hour day length with vernalized seed), the mean effect of a short-day length of 12 hours (ΔP), and the mean effect of unvernalized seed (ΔV) for the eight genotypes. All genotypes were classified as insensitive to photoperiod (P), except the DW Kabir 1. This cultivar showed a higher degree of sensitivity to P. The BW cultivar Dorghal and the DW cultivar Kabir were sensitive to V. The BVP of the six insensitive cultivars to P and V (Table 1) was approximately the same as their DHE under heat stress-field conditions. The P-insensitive and V-sensitive cultivar Dorghal headed very late, while the P- and V-sensitive genotype Kabir 1 failed to complete normal spike development under heat stress.

The GH, VR, and heading date of the tested wheat genotypes under heat stress support the classification of the genotypes according to their P and V responses (Table 1). Our results agree with the findings of Midmore et al. (1982) and Ortiz Ferrara et al. (1994). These results confirm that wheat genotypes insensitive to both P and V will be earlier and escape from heat and drought prevalent in hot and dry environments.

Midmore et al. (1984) reported that genotypes that were relatively insensitive to P and V had the best performance at all sites, especially in those with higher temperatures during the season. Late genotypes sensitive to V or very sensitive to P gave a poor relative performance at the hot lowland sites where yield and kernel number/m² showed negative correlation with days to anthesis. This occurred despite more tillers and more initial spikelets/spike, and could only be partly attributed to higher temperatures affecting these genotypes during their later stages of development.

Effect of moisture regimes

Water consumption/pot was significantly reduced by increasing water stress (Table 2). The cultivars differed significantly in water consumption. Kabir 1 (sensitive to both P and V) and Dorghal (sensitive to V) had the highest while Yamama (insensitive to P and V) had the lowest in each regime. This was mainly due to the earliness of Yamama. The interaction between genotypes and moisture regimes was significant.

Increasing water stress caused significant decreases in WUEGY and WUEBY. This was particularly clear under 35% FC regime (Tables 3 and 4). Similar results have been reported by Rao and Bhardwaj (1981) and

Table 1. Agronomic characteristics of eight wheat genotypes under summer heat stress and their response to photoperiod (P) and vernalization (V) under controlled conditions.

Genotype		Field conditions			Controlled environment		
		GH	VR	DHE	BVP	Δ P	Δ V
BW	Cham 6	4.0	2.7	47.0	45.8	2.7 (-)	0.4 (-)
	Dorghal	7.7	8.0	65.7	50.6	4.8 (-)	15.2 (+)
	Yamama	1.7	1.0	42.0	45.4	2.0 (-)	-0.4 (-)
	Debeira	1.7	1.0	45.0	47.4	9.2 (-)	-0.6 (-)
	Mean	3.8	3.2	49.9	47.3	4.7	4.0
DW	Om Rabi 5	2.8	1.7	48.7	47.8	10.6 (-)	-2.2 (-)
	Kabir 1	8.1	9.0	80.0 (E)	47.6	24.8 (+)	33.2 (+)
	Stork	3.1	1.0	45.7	46.0	2.0 (-)	1.2 (-)
	Gallareta	3.4	3.0	51.0	49.0	4.6 (-)	4.4 (-)
	Mean	4.4	3.7	56.4	47.6	10.5	9.2
	LSD.05	0.9	0.4	1.5			
	CV (%)	16.5	8.4	2.7			

GH = growth habit: 1 = erect, 9 = prostrate;
VR = vernalization requirement: 1 = low, 9 = high;
DHE = days to heading; BVP = basal vegetative period;
ΔP = mean effect of photoperiod; ΔV = mean effect of vernalization.
( ) = response to P and V; + = sensitive, - = insensitive.
E = estimated.

Table 2. Consumptive water use (L/pot) of bread and durum wheat genotypes under four moisture regimes (MR).

Genotypes (G)	Field capacity (%) 35	55	75	95	Genotype mean
Bread wheat					
Cham 6	4.5	6.4	7.2	8.4	6.6 d
Dorghal	5.0	6.8	8.1	8.9	7.2 bc
Yamama	4.2	6.2	7.3	7.9	6.4 e
Debeira	4.6	6.8	8.2	9.1	7.2 bc
Mean	**4.6**	**6.6**	**7.7**	**8.6**	**6.8 B**
Durum wheat					
Om Rabi 5	4.9	6.6	7.8	8.8	7.0 bc
Kabir 1	5.0	7.2	8.6	9.9	7.7 a
Stork	4.3	6.1	7.1	8.5	6.5 de
Gallareta	4.9	6.4	7.7	9.0	7.0 b
Mean	**4.8**	**6.7**	**7.8**	**9.1**	**7.1 A**
MR mean	4.7^{IV}	6.6^{III}	7.7^{II}	8.8^{I}	7.0
CV %	3.6				
LSD 0.05	MR=0.1		G=0.2		MRxG=0.4

Table 3. Water use efficiency (grain yield, g/L) of bread and durum wheat genotypes under four moisture regimes (MR).

Genotypes (G)	Field capacity (%) 35	55	75	95	Genotype mean
Bread wheat					
Cham 6	0.9	1.0	1.1	1.3	1.0 a
Dorghal	0.8	1.1	1.1	1.1	1.0 a
Yamama	0.7	0.9	1.0	1.1	0.9 b
Debeira	0.7	1.0	1.1	1.1	1.0 a
Mean	**0.7**	**1.0**	**1.1**	**1.1**	**1.0 A**
Durum wheat					
Om Rabi 5	0.6	0.8	1.0	1.0	0.8 c
Kabir 1	0.5	0.7	0.8	0.8	0.7 d
Stork	0.5	0.9	0.9	1.1	0.9 b
Gallareta	0.5	0.6	0.9	1.0	0.7 d
Mean	**0.5**	**0.8**	**0.9**	**0.9**	**0.8 B**
MR mean	0.6^{III}	0.9^{II}	1.0^{I}	1.0^{I}	0.9
CV %	15.17				
LSD 0.05	MR = 0.1		G = 0.1		MR x G = NS

Table 4. Water use efficiency (biological yield, g/L) of bread and durum wheat genotypes under four moisture regimes (MR).

Genotypes (G)	Field capacity (%) 35	55	75	95	Genotype mean
Bread wheat					
Cham 6	1.8	2.3	2.5	2.9	2.4 a
Dorghal	1.5	2.3	2.4	2.6	2.2 b
Yamama	1.3	2.0	2.5	2.5	2.1 d
Debeira	1.5	2.2	2.6	2.7	2.2 b
Mean	**1.5**	**2.2**	**2.5**	**2.7**	**2.2 A**
Durum wheat					
Om Rabi 5	1.5	2.1	2.2	2.3	2.0 cd
Kabir 1	1.7	2.4	2.6	2.9	2.4 a
Stork	1.2	1.9	2.1	2.7	2.0 cd
Gallareta	1.2	1.8	2.3	2.4	1.9 c
Mean	**1.4**	**2.0**	**2.3**	**2.6**	**2.1 B**
MR mean	1.5[IV]	2.1[III]	2.4[II]	2.6[I]	2.2
CV %	7.3				
LSD 0.05	MR = 0.1	G = 0.1	MR x G = 0.2		

Johnson et al. (1984) and in the growth chamber (Campbell and Davidson 1979, Heitholt 1989). The cultivars differed significantly for both variables, but the interaction between G and MR was significant only for WUEBY. Cham 6 and Dorghal tended to be high for WUEGY, while Kabir 1 and Stork had the lowest WUEGY.

Kabir 1 had the highest WUEBY due to its late maturity and sensitivity to P and V, while Yamama had the lowest WUEBY due to its earliness and insensitivity to P and V.

Correlation coefficients between GY and several morphological traits are shown in Table 5. GY was closely and positively associated with LAI, TRGY in BW and DW. The correlation coefficient became weaker under the driest regime (35% FC). The associations of GY with BY and WUEBY were positive and significant for BW, while

Table 5. Correlation coefficients between total grain yield and morphophysiological traits under four moisture regimes in bread (BW) and durum (DW) wheat.

Trait		Field capacity (%) 35	55	75	95
Harvest index	BW	0.29	0.58**	0.78**	0.65**
	DW	0.32	0.79**	0.58*	0.80**
Biological yield	BW	0.89**	0.67**	0.88**	0.89**
	DW	0.30	0.21	0.32	0.16
Kernels/spike	BW	0.54*	0.57*	0.51*	-0.04
	DW	0.83**	0.70**	0.60*	0.36
Main stem yield	BW	0.70**	0.74**	0.66**	-0.22
	DW	1.0**	0.87**	0.62**	0.54*
Tiller yield	BW	0.34	0.72**	0.70**	0.89**
	DW	0.00	0.81**	0.77**	0.65**
WUEBY	BW	0.82**	0.61*	0.50*	0.86**
	DW	0.26	0.29	0.25	0.08
WUEGY	BW	0.93**	0.95**	0.88**	0.89**
	DW	0.87**	0.97**	0.91**	0.95**

they were positive but nonsignificant for DW. The association of GY with K/S and MSGY reversed from being negative and low under optimum (95% FC) to positive and significant under dry (35% FC) for BW. The DW cultivars responded differently from a low coefficient under wet to highly significant and positive under dry. The association between GY and WUEGY was high and positive across the two wheat species and the four moisture regimes.

The association between GY and DHE was low and positive across the four moisture regimes for BW. This was due to the controlled temperature conditions in which the trial was conducted.

Our results support the view of other authors that selection for high BY, K/S, MSGY, WUEBY, and WUEGY under drought conditions would be efficient traits to consider when developing cultivars resistant to this abiotic stress.

Our results show that relative yield and its attributes' performance under dry and wet conditions seem to be common starting points in the identification of traits related to drought tolerance. Table 6 shows that the drought-tolerant BW cultivars Cham 6 and Dorghal have these characteristics. They had low reductions in GY, BY, WUEBY, WUEGY, S/P, S/S, FLA, and had a higher KW and longer GFD. They were earlier than the other BW cultivars under the dry relative to the wet regime. The drought resistance DW cultivars Om Rabi 5 and Kabir 1 also showed the same response.

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Table 6. Yield and yield attributes as affected by moisture stress (35% FC) percentage reduction with respect to optimum moisture (95% FC).

Genotype	TGY	WUE (GY)	WUE (BY)	BY	S/P	S/S	100-KW	DHE	FLA	GFD
Bread wheat										
Cham 6	-67	-30	-38	-67	-47	-23	+12	-8	-31	+15
Dorghal	-62	-27	-42	-68	-60	-16	-3	-4	+10	+11
Yamama	-71	-36	-48	-73	-62	-32	-10	+1	-67	+2
Debeira	-71	-36	-44	-72	-62	-26	-19	+2	-40	0
Mean	**-68**	**-32**	**-44**	**-70**	**-58**	**-24**	**-5**	**-2**	**-32**	**+7**
Durum wheat										
Om Rabi 5	-72	-40	-35	-65	-50	-24	-4	+2	-28	+8
Kabir 1	-69	-37	-41	-71	-52	-7	+2	0	-29	+6
Stork	-77	-55	-56	-77	-69	-34	-14	+6	-45	+3
Gallareta	-76	-50	-50	-74	-60	-28	-13	+3	-46	+3
Mean	**-73**	**-45**	**-46**	**-72**	**-58**	**-23**	**-7**	**+3**	**-37**	**+5**

TGY = total grain yield; WUE = water use efficiency; GY = grain yield; biological yield; S/P = spikes per plant; S/S = spikelets per spike; KW = kernel weight; DHE = days to heading; FLA = flag leaf area; GFD = grain-filling duration.

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Genetic Variability and Differential Plant Adaptations as Indicators of Wheat Potential under Heat Stress in Upper Egypt

A.M. AbdElGhani, A.M. AbdElShafi Ali, and E.H. Ghanem
Wheat Research Dept., Field Crops Research Institute, Agricultural Research Council, Giza, Egypt

Abstract
Heat tolerance is an essential characteristic for growing wheat in Upper Egypt. Twenty-four wheat lines and varieties were evaluated for heat tolerance under two different planting dates (early and late planting) in addition to three irrigation regimes (50, 70, and 90% water soil depletion) at El-Mataana, Qena Governorate. Early planting date and the irrigation at 50% water soil depletion resulted in significantly higher grain yield than other studied treatments. Three experiments under desert conditions were carried out in the Qena Governorate in 1991-92. Four seeding rates (120, 155, 190, and 255 kg/ha) and five N levels (140, 180, 215, 250, and 285 kg N/ha) were used to evaluate grain yield of variety Giza 160 under high-temperature conditions. There was a slight effect of seeding rate on grain yield. Increasing nitrogen level up to 250 kg N/ha produced the highest grain yield. Using improved cultural practices with high yield potential cultivars can increase grain yield under high temperature conditions.

Introduction

Wheat is a major cereal crop in Egypt. Increasing wheat production is an ultimate goal to reduce the gap between production and consumption. Higher wheat prices and lower costs of production in relation to other crops have encouraged increased wheat area, approximately 20% in Upper Egypt alone during the last three years. Moreover, wheat production in Upper Egypt has been expanded in newly reclaimed areas on about 12,000 ha in the desert around Sohag and Qena Governorates. However, the Upper Egypt Governorates (Sohag, Qena, Aswan, and New Valley) have the lowest wheat productivity levels in Egypt with average yields of 3 to 4.5 t/ha.

Considerable increases in day temperature during the period from anthesis (late February) to ripening of wheat are common in Upper Egypt (Figure 1). The exposure to hot wind, even for a short time during this period, could drastically reduce spike fertility and grain-filling (Fischer and Maurer 1976). Developing high yielding cultivars that are tolerant to high temperatures will be vitally important to improve wheat production in the region.

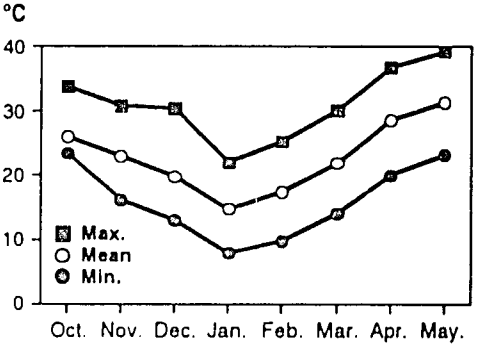

Figure 1. Monthly mean temperatures for Upper Egypt during the wheat growing season.

Heat tolerance is a polygenic trait, and selection in segregating populations is difficult. It is therefore necessary to develop novel approaches to enhance the efficiency of selection in programs of wheat breeding for heat stress. Further understanding is needed of the factors that limit plant productivity under high temperatures. The use of agricultural practices that minimize heat stress could be an important means to increase yield in these environments (Puri et al. 1977, 1985).

The objective of this report is to evaluate the influence of planting date, seeding rate, nitrogen fertilizer, and water regime on the grain yield of wheat under heat stress conditions in Upper Egypt.

Effect of Heat and Water Stresses on Wheat Yield

Twenty bread wheat entries selected from introduced materials and four local wheat varieties were included in this study. The local varieties consisted of three bread wheats (Giza 155, Giza 160, and Sakha 69) and one durum wheat (Sohag 1). The 24 entries were evaluated under two planting dates (25 November and 5 January) and three different water regimes, irrigation being applied at 50, 70, and 90% depletion of available water (DAW).

The experiment was conducted at El-Mataana Research Station, Qena Governorate of Upper Egypt during the 1988-89 growing season. The experiment design was a randomized complete block with a spilt split plot arrangement of treatments. Planting dates were whole plots and water regimes were subplots, while wheat genotypes were sub subplots. The experiment was replicated four times. Recommended agricultural practices were followed.

Some results (12 entries) are shown in Table 1 and indicate that late planting reduced grain yield by between 30 and 48%. The two entries (4 and 11) with the least percentage yield reductions had relatively low potential yields (as indicated by the yield at the first date with DAW1). The highest grain yields were obtained by Jup/Bjy'S'//Ures (entry 9) at both early and late planting dates.

These data confirm earlier work (Randall and Moss 1990) where grain yield was negatively correlated with increasing mean maximum temperature. Musich and Dusek (1980) showed that increasing temperature resulted in earlier termination of grain-filling.

Our results indicate that the deleterious effects of heat stress in Upper Egypt during grain-filling can be minimized by selection of the optimum seeding date.

The reduced irrigation treatments significantly reduced yields from a mean of 3.34 to 2.62 and 2.22 t/ha under 50, 70, and 90% DAW, respectively. At the optimum planting date, there was a progressive decrease in yield with reducing water supply. However, at the late seeding date, irrigation at 90% DAW resulted in yields that were no different than irrigation at 70% DAW, although 70% DAW produced a greater yield loss at late seeding than at the optimum date (26.3 vs 18.8%). This is in agreement with data of Dawood et al. (1988) and Kheiralla et al. (1989), who also found that water stress results in greater yield losses at late planting dates.

Table 1. The effects of seeding date and irrigation at differing levels of soil moisture depletion (DAW) on the grain yield (t/ha) of 12 selected entries in Upper Egypt.

		Planting date								Overall means						
		25 November (D_1)				5 January (D_2)										
	Variety/Line	50% DAW_1	70% DAW_2	90% DAW_3	Mean	50% DAW_1	70% DAW_2	90% DAW_3	Mean	RD_1	50% DAW_1	70% DAW_2	RW_1	90% DAW_3	RW_2	Mean
1.	Lira'S'	4.37	3.94	2.66	3.66	2.29	2.11	2.10	2.17	40.7	3.33	3.02	9.3	2.38	28.5	2.91
2.	Mon'S'/Tiresel	4.70	3.57	2.94	3.74	2.64	1.90	1.93	2.16	42.2	3.67	2.74	25.3	2.44	33.5	2.95
3.	Kt/Bage/Fn/U/3/Bza/4/Trm /5/Aldan'S'	3.64	3.54	2.42	3.20	2.39	1.47	1.50	1.79	44.1	3.02	2.50	17.2	1.96	35.1	2.49
4.	Cc/2*Tob/Mn 72131	3.69	2.96	1.98	2.88	2.73	1.76	1.57	2.02	29.9	3.21	2.36	26.5	1.78	44.5	2.45
5.	Buc'S'/Pvn'S'	4.58	3.70	2.77	3.68	2.35	2.16	2.20	2.24	39.1	3.46	2.93	15.3	2.48	28.3	2.96
6.	Bjy'S'/Coc	4.35	3.57	3.26	3.73	2.45	1.95	1.96	2.13	42.1	3.40	2.76	18.8	2.62	22.9	2.93
7.	L2266/1406.101//Buc'S' /3/Vpm/Mos 83.11.4.8//Nac	3.75	2.75	2.29	2.93	2.06	1.51	1.52	1.70	42.0	2.90	2.13	26.5	1.90	34.5	2.31
8.	Mrl'S'/Buc'S'	3.96	3.51	2.57	3.35	2.30	1.44	1.44	1.73	48.4	3.13	2.48	26.2	2.00	36.1	2.54
9.	Jup/Bjy'S'//Ures	5.14	3.76	2.82	3.91	2.87	1.96	2.00	2.28	41.7	4.00	2.86	28.5	2.41	39.8	3.09
10.	Giza 160	4.47	3.80	2.98	3.75	2.42	1.79	1.80	2.00	46.7	3.44	2.80	18.6	2.39	13.5	2.88
11.	Giza 155	4.33	2.81	2.82	3.32	2.38	2.17	2.21	2.25	32.2	3.36	2.49	25.9	2.52	25.0	2.79
12.	Sakha 69	4.85	3.73	2.15	3.58	2.54	2.09	2.10	2.24	37.4	3.70	2.91	21.4	2.12	42.7	2.91

RD = Yield reduction due to late planting = $[(D_1 - D_2)/D_1] \times 100$.

RW = Yield reduction due to reduced irrigation: $RW_1 = [(DAW_1 - DAW_2)/DAW_1] \times 100$; $RW_2 = [(DAW_1 - DAW_3)/DAW_1] \times 100$.

LSD 5%:	D	DAW	DxDAW	G	DxG	DAWxG	DxDAWxG
	0.06	0.05	0.06	0.09	0.12	0.15	0.30

There were substantial differences between entries in their reaction to restricted moisture, particularly at 90% DAW. Entries with median yield potential were least affected. The effect of water stress was less severe than that of late seeding.

Effect of Seeding and Nitrogen Rates

Three experiments were conducted in 1991-92 to study the influence of seeding rate and N fertilization on grain yield under heat stress conditions on newly reclaimed soils. Three sites were selected: El-Marashda El-Baharia, El-Marashda El-Keblia, and Abo-Tesht in Qena Governorate. These locations are sandy with 7.3-7.8 pH, low available nitrogen (0.02-0.03%), and phosphorus at 24-39 ppm.

Seeding rates (SR) were 120, 155, 190, and 225 kg/ha. The N levels were 140, 180, 215, 250, and 285 kg/ha. Six equal doses of nitrogen were applied, the first dose applied at the one-shoot stage (Feekes Scale 1) then four doses at seven-day intervals. The sixth dose was applied at the boot stage (Feekes Scale 9). The wheat variety Giza 160 was used. Irrigations were applied at 10-day intervals.

Table 2. The main effects of seeding and nitrogen fertilizer rates on the grain yield (t/ha) of wheat grown at three sites in Upper Egypt.

Seeding rate (kg/ha)	Nitrogen rate (kg/ha)				
	140	180	215	250	285
120	5.10	5.51	5.74	6.01	6.16
155	5.33	5.78	5.80	6.10	6.07
190	5.55	5.75	5.89	6.16	6.41
255	5.66	5.74	5.94	6.00	6.19
Mean	**5.41**	**5.69**	**5.84**	**6.07**	**6.21**

LSD (5%) Nitrogen: 0.22.

The experimental design was a complete block with a split plot arrangement of treatments in which seeding rates were main plots and nitrogen rates were sub-plots.

The analysis of variance indicated that seeding rates had no significant effect on yield. There were no interactions between seeding and nitrogen rates, or with locations.

Overall, there was no significant effect of a nitrogen rate greater than 250 kg/ha (Table 2).

These studies indicate that there appear to be differences between genotypes in their reaction to late seeding date and moisture stress. Future breeding and selection should be of an interdisciplinary nature to identify genotypes with the desired adaptability to farmers' conditions in Upper Egypt. Under these conditions, it is unlikely that large yield increases will result from increases of either seeding rate or nitrogen application above the recommendations. However, substantially higher yields will be obtained by planting at the optimum date and irrigating more frequently.

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Physiologists' Approaches to Screening for High Temperature Tolerance in Cereals: The Indian Experience

J.M. Peacock, ICARDA, Aleppo, Syria; **V. Mahalaksmi**, ICRISAT, Patancheru, India; **G. Ortiz Ferrara**, CIMMYT, Aleppo, Syria; **C.J. Howarth**, Institute of Grassland and Environmental Research (IGER), Aberystwyth, U.K; **M. Nachit**, CIMMYT, Aleppo, Syria; and **J. Hamblin**, ICARDA, Aleppo, Syria

Abstract

In India, although wheat production has been expanding by around 2.5-3.0% per year, there has been a dramatic shift from rainfed to irrigated wheat; of the total area the share of rainfed wheat land has decreased from 67% in 1961 to 25% in 1986, or from around 9 million hectares in the early 1960s to 6 million by 1984. However, this area, along with Turkey, is still the largest in the world. The wheat, which is sown in the post-rainy (rabi) season, depends largely on residual water. Its productivity and stability depend on the development of material that is able to germinate well. To ensure good germination, farmers tend to plant in late October or even later because the high soil surface temperatures earlier in the season severely reduce germination and establishment. However, when sowing is delayed, the valuable water, which is lost from the profile, is not available to the plant. The problem is, therefore, very clear: to develop germplasm that will germinate at the high soil temperatures that prevail at the onset of the rabi season. A proven method of improving crop establishment under high soil temperatures in India is described. A laboratory method that simulates this field heat damage and can be used to verify the field performance of selected genotypes is also described. The importance of an integrated approach using techniques as diverse as field screening and molecular biology for the understanding and improvement of wheat under heat stress is emphasized. In conclusion, the authors outline what the future approach of physiologists and breeders could be at ICARDA for these hot marginal regions.

Introduction

In India, as a whole, since the early 1960s, wheat production has been expanding by around 2.5-3.0% per year, with an increase in area from about 13 million to over 23 million hectares in the 1980s. There has, however, been a dramatic shift from rainfed to irrigated wheat: of the total area in wheat production, the share of rainfed land has decreased from 67% in 1961 to 25% in 1986, and the actual area of rainfed wheat has steadily dropped from around 9 million hectares in the early 1960s to 6 million by 1984 (Byerlee 1992). Therefore, unlike many areas in the world, the wheat cropping area in India is not expanding by cultivation of the marginal areas.

However, the 6 million hectares of dryland wheat in India, along with Turkey, represent the largest in the world throughout Central and South Asia. Throughout central and southeast India, rainfed (*barani*) wheat, which is sown in the *rabi* season, is grown almost exclusively on deep black vertisols (Figure 1) and depends largely on residual water. Its productivity

and stability of production depend on the development of material that is adapted to the prevailing climatic conditions in these regions.

Measurement of the environment or the agroclimatic conditions for the region or regions in question has been central to the authors' approach with other crops and regions (Peacock et al. 1988). In addition to limited soil water, the major climatic constraint to wheat production in this zone is high temperature, particularly high soil temperatures at the time of sowing (Bagga et al. 1987, Byerlee 1992). High germination and good crop establishment are essential under these conditions (Soman and Peacock 1985). To ensure good germination, farmers tend to plant in late October or even later (Figure 2). However, farmers must be

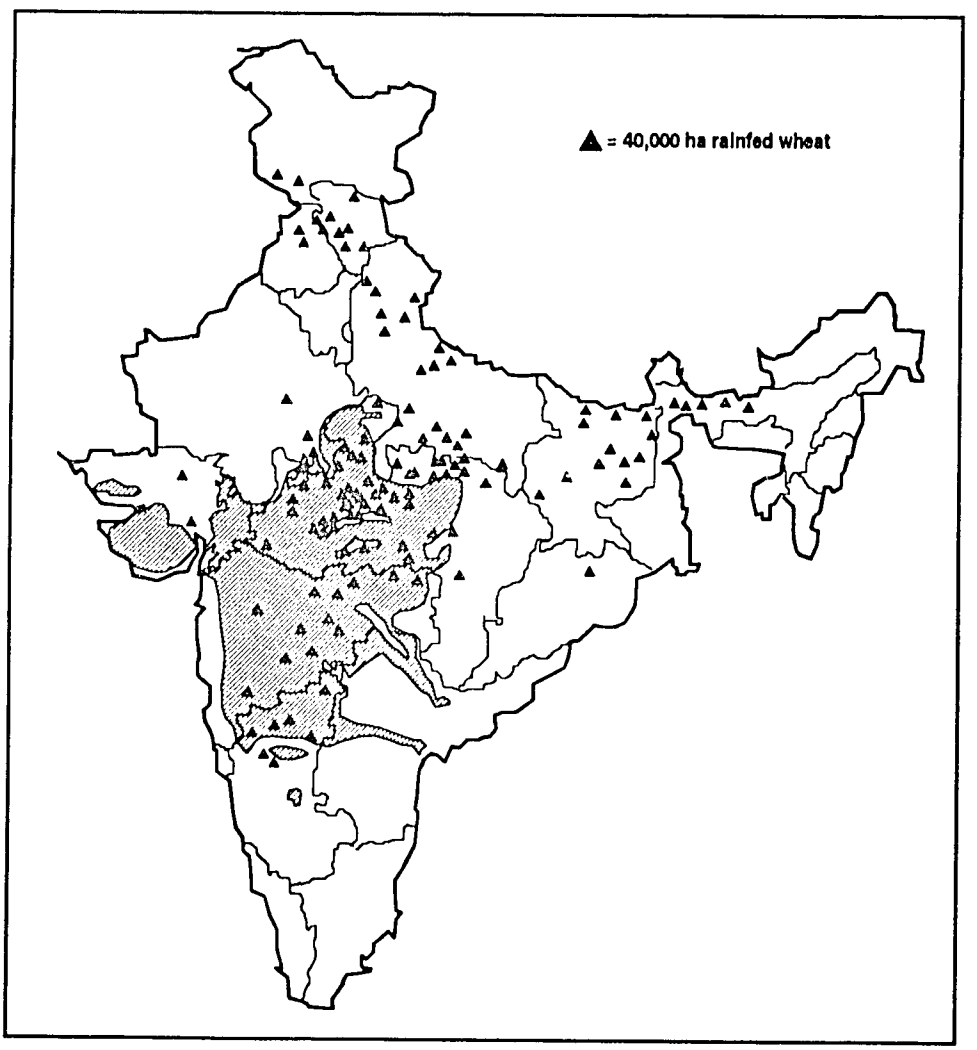

Figure 1. Map of India showing area of black vertisols (shaded) in relation to the total rainfed wheat areas.

careful not to plant too late because with a rapidly receding soil moisture profile the crop will lose valuable water and could run into severe drought during flowering and grain fill. The problem is therefore very clear: to develop germplasm that will germinate at higher soil temperatures.

We describe a proven method of improving crop establishment under high soil temperatures in India and emphasize the importance of landrace material in the breeding program that was successfully developed using material identified with this method. We conclude by outlining what the future approach of physiologists and breeders could be at ICARDA for these hot marginal regions.

The Environmental Physiologist's Approach

Poor seedling establishment is one of the major factors limiting the production of cereal grain crops in the semi-arid and arid tropics. An example of this is pearl millet, grown extensively by farmers in the Indian state of Rajasthan, and in Sahelian and Southern Africa (O'Neill and Diaby 1987, Soman et al. 1987). High soil surface temperatures (>55°C) have been reported to reduce seed germination, emergence, and survival of pearl millet seedlings in these regions (Soman and Peacock 1985, Gupta 1986, Peacock et al. 1993). Similar effects of high soil temperatures on seedlings have been reported in sorghum (Wilson et al. 1982, Ougham et al. 1988) and wheat (Bagga et al. 1987, Acevedo et al. 1990).

A breeding program was initiated for Rajasthan to produce pearl millet genotypes combining the apparent high-temperature adaptability (thermotolerance) of the local landraces and the yield potential of improved genotypes from the Indian National Program and ICRISAT. We believe that this is most effectively done if specific screening methods are available to evaluate genotypes for thermotolerance to

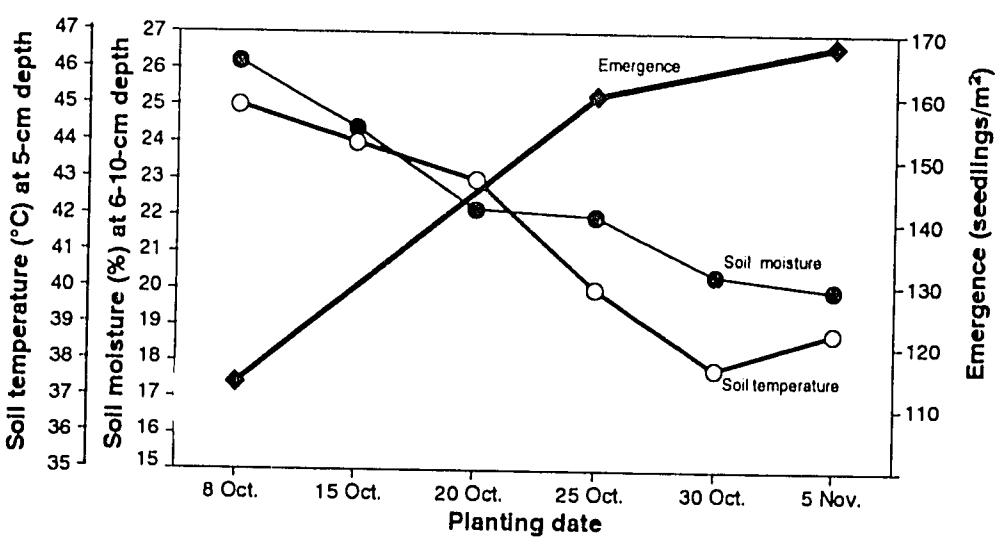

Figure 2. Effect of soil temperature and moisture on wheat germination (mean of 10 varieties). Indore, India, 1986-87.

supplement the conventional multilocational yield testing and breeding methods.

In this section, we describe techniques to examine the effect of high soil surface temperature on the survival of pearl millet seedlings in the field in Rajasthan and in the laboratory. The field technique demonstrates that 1) seedling mortality is largely due to high soil surface temperatures, and 2) there is genetic variation for seedling survival and thermotolerance. We also describe a laboratory method that simulates this field heat damage and can be used to verify the field performance of selected genotypes. The importance of an integrated approach (results are presented using techniques as diverse as field screening and molecular biology) in the understanding and improvement of crop response to environmental stress is emphasized.

Location and soil conditions of field experiments

The experiments were conducted at the Agricultural Research Station, Fatehpur, Rajasthan, India (Lat. 27° 37'N), during the dry summer months (April and May) of 1989 and 1990.

Seed material and experimental layout

Four experiments were conducted, two in both 1989 and 1990. In 1989, 76 genotypes [75 millet, *Pennisetum glaucum* (L.) R. Br., and one sorghum, *Sorghum bicolor* L. (Moench)], selected to cover a range of landrace, hybrid, and varietal variation, were tested, and in 1990, 26 genotypes representing a selection of the most susceptible and tolerant lines to high soil temperatures were tested. In all four experiments, each plot was a row, 2.5 m long, with 30 cm between rows. Plots were arranged in a randomized complete block design.

Experiments were sown in April and May. On the nights before sowing, 15 mm of water were uniformly applied to all plots from two parallel sprinkler lines to bring these soils to field capacity and to ensure that the soil profile did not dry out during the first 15 days of seedling growth. Eighty seeds were sown per plot at a depth of 50 mm.

Environmental measurements

Temperature—Soil and air temperatures at various depths and heights were measured using copper-constantan thermocouples and recorded at hourly intervals on the automatic datalogger (CR21X, Campbell Scientific Inc., Utah, USA). Air and soil temperatures often exceed 40°C, and soil surface temperatures around 60°C were frequently recorded. Figure 3 shows typical curves of the temperatures measured after sowing, at emergence and during seedling establishment (Peacock et al. 1993).

Soil moisture—Soil moisture was estimated gravimetrically from soil samples taken at numerous depths with a multiple-ring soil sampler immediately after sowing and then

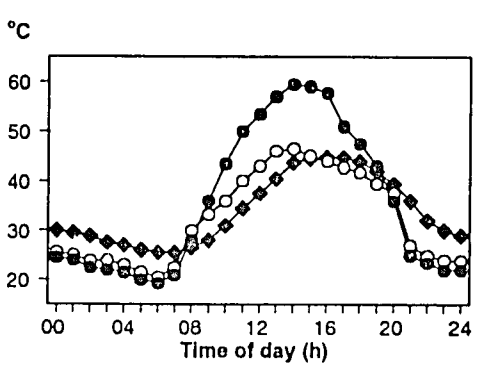

Figure 3. Diurnal temperature data recorded in Fatehpur, Rajasthan, India. Each measurement is the mean value from three thermocouples placed at soil depths of either 5 cm (◇) or 0.5 cm (●) or 150 cm above the soil surface (○).

daily at 0600 h until 10 days after sowing (DAS). In the root tip zone, soil moisture did not fall below 5% (which is well above the wilting point for these soils) confirming that subsequent seedling death was not due to low availability of moisture (Peacock et al. 1993).

Plant measurements

Seedling death—The number of live seedlings was counted daily (Peacock et al. 1993) and at the same time dead seedlings were marked with a wooden matchstick. Seedling death at this stage could be attributed largely to high soil surface temperature because there was still adequate moisture in the soil.

A "thermotolerance index" (TI) was calculated as the ratio of seedlings surviving to the total number of seedlings emerged and these data are shown in Table 1.

Laboratory heat-girdling apparatus and plant materials

In all experiments, millet seeds were germinated in vermiculite in a glasshouse. After a seven-day germination period,

Table 1. Thermotolerance index for pearl millet and sorghum genotypes (Ranking order of each experiment in parentheses).

Genotype	1989		1990		Mean
	Expt. 1	Expt. 2	Expt. 3	Expt. 4	
HHB 67	0.91 (6)	0.76 (6)	0.83 (1)	0.94 (1)	0.86
IP 3201	0.97 (1)	0.82 (2)	0.78 (3)	0.84 (8)	0.85
IP 3173	0.80 (11)	0.81 (3)	0.71 (4)	0.83 (10)	0.79
HiTip 88	0.72 (18)	0.80 (4)	0.78 (2)	0.80 (13)	0.78
NC D2	0.95 (2)	0.76 (9)	0.46 (16)	0.89 (4)	0.77
ICMH 451	0.92 (3)	0.70 (13)	0.58 (7)	0.79 (16)	0.75
RCB 2	0.76 (16)	0.79 (5)	0.61 (5)	0.82 (12)	0.75
IP 3188	0.91 (5)	0.76 (9)	0.46 (15)	0.83 (11)	0.74
CZMP 84	0.77 (14)	0.63 (15)	0.61 (6)	0.90 (3)	0.73
Sadore Local	0.75 (17)	0.76 (9)	0.55 (8)	0.85 (7)	0.73
LaGraP 88	0.78 (13)	0.76 (9)	0.52 (10)	0.79 (16)	0.71
WRajPop	0.85 (8)	0.61 (16)	0.48 (14)	0.87 (5)	0.70
IP 3273	0.84 (9)	0.75 (11)	0.27 (24)	0.90 (2)	0.69
IP 3258	0.90 (7)	0.82 (1)	0.36 (20)	0.64 (21)	0.68
LaGraP 87	0.84 (10)	0.74 (12)	0.53 (9)	0.55 (23)	0.67
IP 3228	0.79 (12)	0.66 (14)	0.51 (11)	0.69 (18)	0.66
IP 3342	0.92 (4)	0.55 (18)	0.29 (23)	0.80 (14)	0.64
IP 11145	0.69 (19)	0.50 (21)	0.43 (18)	0.84 (9)	0.62
ICMH 423	0.67 (20)	0.53 (20)	0.50 (12)	0.75 (17)	0.61
ICTP 8203	0.66 (21)	0.48 (22)	0.48 (14)	0.66 (19)	0.57
EC 87	0.62 (22)	0.46 (23)	0.33 (21)	0.85 (6)	0.57
IP 3218	0.77 (15)	0.31 (25)	0.45 (17)	0.60 (22)	0.53
CIVT	0.53 (23)	0.37 (24)	0.36 (19)	0.65 (20)	0.48
ICMV 84400	0.48 (24)	0.54 (19)	0.31 (22)	0.53 (24)	0.47
BSEC C4	0.42 (25)	0.55 (17)	0.13 (25)	0.38 (26)	0.37
Sorghum	0.42 (26)	0.26 (26)	0.12 (26)	0.40 (25)	0.30
Mean	0.75	0.63	0.48	0.75	
S.E.	0.057	0.054	0.051	0.044	

vermiculite was carefully washed from the roots. Seedlings were then transferred to wooden racks as described by Matsuda and Riazi (1981). The seedlings were grown in plastic trays containing an aerated Hoagland's solution (Hoagland and Arnold 1938) supplemented with an iron chelate. Each tray contained 90 plants (six racks of 15 plants each). Healthy and similar seedlings were transferred to the heat treatments when the plants were 10 days old.

Opaque plexiglass racks identical in size to those described above were modified to allow temperature control of the leaf intercalary meristem (Peacock et al. 1990). Meristem temperature modification was achieved by circulating water through a brass tube inserted into a longitudinal groove cut into each piece of plexiglass. Meristem temperatures were measured with fine thermocouples coupled with a datalogger (CR21X, Campbell Scientific Inc., Utah, USA). For these studies, six racks were placed in each tray of Hoagland's solution. There were three heated and three control racks in each tray, ensuring that the root and shoot temperatures were the same for both treatments (see Peacock et al. 1990). In heat-girdling experiments, meristem temperatures were set to 52°C, which represents the average maximum temperature at which seedlings died in the field. Elongation of the youngest leaf was measured with a plastic ruler using the method described by Peacock (1975). Measurements were made at the beginning and end of each daylight period and leaf extension rate per day was calculated.

Results and Discussion

There was considerable genotypic variation in TI (Table 1). Genotypes BSEC C4 and ICMV 84400 have consistently low TI values, whereas a number of genotypes including the hybrid HHB 67 and the local landrace material IP 3201 have high values. The superior performance of the first 10 genotypes, based on the mean of TI, is explained to a large extent by examining their background (Peacock et al. 1993).

The consistently poor performance of sorghum both for emergence and seedling survival supports the hypothesis that pearl millet is more thermotolerant than sorghum (Sullivan et al. 1977) and therefore provides an excellent susceptible check.

A dendrogram of log semipartial R^2 for the 25 genotypes calculated using Ward's Minimum Variance Cluster Analysis (not shown), in general, reflects the rankings of TI (Table 1). Three major subgroups of 4, 13, and 8 genotypes are formed, clearly separating genotypes with high and low TI values (see Peacock et al. 1993 for details). Most important to note is that with the exception of IP 3218, all the landraces (IP numbers) collected in the dry regions are clustered together in subgroups 1 and 2. This is similar to what happened with wheat in central southern India where landrace lines like Hindu 62 and Kathia both established and yielded better than the improved recommended varieties for the area (Byerlee 1992).

Our field screening method is found to be repeatable as evidenced from a lack of significant interaction between genotype and experiment. The broad sense heritability of the TI trait is high ($h^2 = 0.82$) and therefore of considerable interest to the breeders. In addition, the preliminary data on pearl millet using the laboratory method confirm field data and this is encouraging.

Mechanisms and genetics of plant responses to high temperature stresses

We recognize that the variation in seedling survival between genotypes of pearl millet and sorghum may arise from different

causes. Seedling death in sorghum and pearl millet is related to the injury to the meristem of the seedlings, which is located near the soil surface where temperatures can be very high. Recently, Peacock et al. (1990) showed that injury of the meristem retards subsequent leaf growth and restricts the movement of carbohydrates to the roots, which leads ultimately to seedling death in susceptible genotypes. Figure 4 shows that, in the shoots of the heated sorghum plants, the concentration of total carbohydrate (TSC, primarily sucrose, glucose, and fructose; see Peacock et al. 1990) increased substantially during the experiment (Figure 4—left). After 173 hours of heat, both TSC and starch concentration were at least 3-fold greater than in the unheated seedlings (Figure 4—right). In contrast, meristem heating reduced root TSC to very low concentrations, with a five-fold decrease seen in 173 hours (Figure 4—right). With millet, in our laboratory experiment (data not shown), after one heat shock the leaf expansion of ICMH 423 was reduced to less than 5 mm/h whereas IP 3201 continued at over 15 mm/h. If these heat shocks were continued over three days, then all the ICMH 423 seedlings died, whereas fewer than 10% of the landrace seedlings IP 3201 died.

The role of specific proteins, the heat shock proteins (HSPs), in survival at high temperature is currently being investigated in several laboratories (Nguyen et al. 1992). Howarth (1989, 1990a,b) has clearly shown that HSPs are produced in pearl millet and sorghum above temperatures of 35°C and that at 50°C normal proteins no longer occur (Howarth 1991; Figure 2). However, if a pretreatment at 45°C is given, the seedlings synthesize HSPs and continue to grow and survive a temperature of 50°C. Similar results in cereals have been shown for barley and wheat (Stanca et al. 1987, Zivy 1987, Krishnan et al. 1989, Hendershot et al. 1992).

The precise function of HSPs in thermotolerance is still not understood (for reviews see Lindquist 1986, Ougham and Howarth 1988, Nagao et al. 1990, Nguyen et al. 1992). The denaturation of normal cellular proteins at high temperature and the protective response associated with HSP synthesis has been suggested (Pelham 1986,

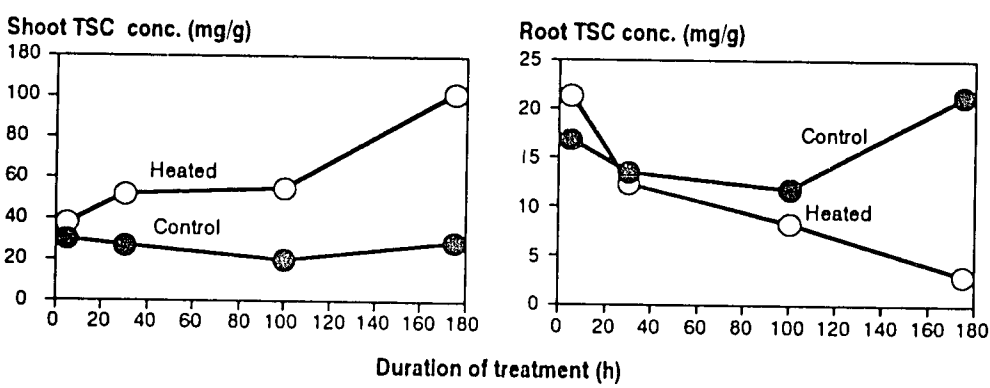

Figure 4. Effects of meristem temperature on (left) shoot total soluble carbohydrate (TSC) concentration (sum of sucrose, glucose, and fructose, as determined by HPLC) and (right) root total soluble carbohydrate concentration, each on a dry-weight basis. Seedlings were heat-girdled with 52°C meristem temperatures or nongirdled with 31°C. Data points are the means of three replications of three seedlings each.

Ellis 1991). A similar mechanism is possible in plant tissues and it may be precipitated, denatured proteins that restrict the flow of carbohydrates to the root when a seedling is "heat girdled" by high soil and meristem temperatures. HSPs may be important in protecting meristematic tissue during the sudden daily fluctuations in temperature. Current research is investigating the involvement of HSPs in genotypes showing differential thermotolerance. Recent data (Howarth 1991) with two pearl millet lines, HHB 67 and BSEC 4, showed that the thermotolerant HHB 67 was able to synthesize HSPs each time it encountered a heat shock, whereas the susceptible BSEC C4 failed after the first heat shock synthesis. Likewise, in our field experiments, the thermosensitive genotype BSEC C4 did not die immediately when it experienced extremes of temperature, but, when high midday temperatures persisted for a number of days in succession, death occurred.

There are limited studies on the genetics of heat tolerance in cereals (Blum 1988) and most of these have utilized solute leakage as a measure of membrane stability (Sadalla et al. 1990, Shanahan et al. 1990) or chlorophyll fluorescence (Moffat et al. 1990) to indicate relative acclimation to exposure to heat.

Similarly, very little has been done on the inheritance of HSPs in plants. Marmiroli et al. (1986) showed that in barley the F1 progeny had some HSPs common to both parents, some common to one and a large number appeared to be F1-specific. However, no measurements of heat tolerance were conducted.

The possibility of using a rapid screening method using specific antibodies or nucleic acid probes to proteins such as HSPs to screen for seedling survival at high temperatures is of great value to a breeding program, and the identification of the relevant proteins is currently being investigated by the Institute of Grassland and Environmental Research (UK) and others (Nguyen et al. 1992). Such proteins could be used to measure rapidly and precisely the abundance of a given gene or set of genes. Even if a given gene is not directly involved in the mechanism of acquired thermotolerance, this does not mean that a given gene or its product cannot be used for a screening technique if a close correlation exists between its presence and the ability to survive high temperatures. Such a screening technique could then be used to assess the thermosensitivity of a given genotype.

If the processes of plant acclimation and survival can be understood, and thus manipulated, the tolerance of plant species can be further improved.

Present and future research at ICARDA on developing heat-tolerant wheat lines

At ICARDA, the physiologists have adapted the laboratory method described above for a wider range of temperatures and species, by replacing the temperature-controlled water with a silicone oil (which is a liquid between -75 and +60°C). They have also replaced the water culture with soil, in order to improve their understanding of the effects of high soil surface temperature on root function growth and development. By identifying parents with distinct differences in heat tolerance they hope to assist in the development of biparental progenies that will aid in determining the role of HSP genes in heritable heat tolerance.

The work in identifying appropriate material will be greatly assisted by the ICARDA/CIMMYT breeders located at ICARDA, who have already developed a breeding methodology for heat tolerance in both bread and durum wheat genotypes. Breeding material is selected at Tel Hadya in

northern Syria in late June-July when maximum soil temperatures reach 44°C. These temperatures are similar to those in India in September at the start of the *rabi* season, but are higher than those (42°C) experienced at Wadi Halea and Wad Medani in Sudan. For more details, see earlier works (Nachit and Ketata 1991a,b; Ortiz Ferrara et al. 1994; Acevedo et al. 1990). In durum wheat, this strategy has generated several promising lines, viz., Wadalmez, Omtel 16, Omrabi 3, Omlahn, and Genil 2 that have high levels of heat tolerance and outyielded the checks Cham 3 and Stork by as much as twice in some cases (Nachit 1993).

In addition to working closely with the breeders, we hope to develop collaborative projects with molecular biologists at other institutes.

In conclusion, we believe that by focusing our attention on this specific problem in India, we will provide useful germplasm for rainfed situations in other countries in West Asia and North Africa, notably at Jebbel Marra and Abdu Naama in Sudan. We believe that wheat scientists at ICARDA, in conjunction with CIMMYT and our respective partners in the national programs and advanced institutes in the developed world, should be able to develop high yielding wheats that are adapted to high temperatures.

Acknowledgments

We would like to thank Dr. P.C. Gupta, Associate Director of Research, Rajasthan Agricultural University, for providing facilities at Fatehpur and Kesri Singh for maintaining our sanity in Shekhevati and the freedom of Mandawa Castle. The editorial assistance of Linda Sears at ICARDA is appreciated.

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Questions/Discussion

Dr. Peacock was asked if root growth was currently being studied at ICARDA. He replied that work was currently being conducted, but as yet, methodology was not available for large-scale germplasm screening.

Genotype Differences in Heat Stress in Wheat in the Irrigated Gezira Scheme

H.M. Ishag
Agricultural Research Corporation, Wad Medani, Sudan

Abstract

Five cultivars of bread wheat were sown on 9 and 23 November and 14 December 1991. Detailed sampling was conducted during the growing cycle and at maturity. The latest sowing date produced yields some 33% lower than the earliest date. Sowing date affected most yield components with the exception of spikelets per spike. Accumulated thermal units for the growth stage terminal spikelet to anthesis was markedly affected, reducing from 96°C at the earliest to 41°C at the latest sowing date. El Nielen had the highest grain yield at all dates, perhaps associated with heavy awns and greater amounts of epicuticular wax.

Introduction

Wheat (*Triticum aestivum* L.) is best adapted to cool environments, but now its cultivation has expanded into the lower latitudes to less than 15° as a winter crop (Khalifa et al. 1977).

With adequate supplies of water and nutrients in Sudan's Gezira Scheme, yield potential of 7.6 t/ha under farmers' conditions has been obtained. Temperature, the main limiting factor, is responsible for seasonal yield variation.

The effect of temperature on wheat has been extensively studied in Australia and Mexico. Wheat grown in the irrigated Gezira Scheme can experience high temperatures in either the early or late parts of the growing season. Hot environments reduce the length of all development stages and high grain yield can only be obtained when anthesis coincides with the coolest period (Ishag and Ageeb 1991).

The objectives of the present study were to study the effects of temperatures (sowing date variation) on growth, yield, and yield components of cultivars differing in phasic development.

Materials and Methods

Growing conditions

Five cultivars (Condor, Debeira, Wadi El Neil, El Neilen, and Veery'S') were sown on three dates (9 and 23 November and 14 December 1991) at the Gezira Research Farm (14°44'N). The experimental design was split plot with the sowing dates as main plots and the genotypes as sub-plots. Sub-plot size was 10 x 1.6 m, eight rows each and spaced 20 cm apart. Yield was obtained from a net area of 6 m². Treatments were replicated five times. At sowing, 78 kg N/ha as urea and 39 kg P/ha as superphosphate were applied. The crop was irrigated at two-week intervals. The experiment was kept free from weeds and aphids.

Measurements

Eight randomly selected plants were removed three times a week during the vegetative phase to determine the

primordial development with a microscope. Thermal units for each developmental phase were calculated as the sum of mean daily air temperature above 1°C based on data from a meteorological station situated 1.2 km from the site.

Weekly plant samples from an area of 1000 cm^2 were taken to determine number of shoots, number of leaves in the main stem, and spikes/m^2. Number of spikelets per spike, grains per spike, grains per spikelet, and 100-grain weight were recorded

Results

Grain yield

Differences between sowing dates were highly significant. Late sowing (14 Dec.) decreased the grain yield of all cultivars by about 33%. However, Condor outyielded El Neilen by 9% and Veery'S' and Debeira by 23%. El Neilen and Veery'S' significantly outyielded the other three cultivars sown at the early dates (Table 1).

No significant differences were detected between Condor, Debeira, and Wadi El Neil. El Neilen and Veery'S' had the highest grain yields, which were not significantly different from each other. Interaction between genotypes and sowing dates was significant. Condor as an early maturing genotype was less sensitive to late sowing date.

Straw yield

Early sowing dates produced similar straw yields of about 7.6 t/ha and the difference was not significant. Late sowing resulted in a 32% decrease in yield. Wadi El Neil, a late maturing genotype, gave the highest straw yield, particularly at the 9 Nov. sowing date (Table 2).

Yield components

Table 3 shows the effects of sowing dates and cultivars on some yield components. Sowing dates significantly affected number of spikes per plant, number of grains per spikelet, number of grains per plant, and 100-grain weight. There were also considerable differences between cultivars in grains per spikelet, grains/plant, and 100-grain weight. El Neilen and Wadi El Neil had the highest grain weights and Condor the lowest.

Table 1. Effects of sowing dates on grain yield of wheat cultivars (kg/ha).

	Sowing dates				
Cultivars	9 Nov.	23 Nov.	14 Dec.	Mean	
		± 113.3**			
Condor	2132	2412	1939	2161	
Debeira	2440	2309	1573	2107	
Wadi El Neil	2419	2559	1673	2207	± 65.4**
El Neilen	2749	2866	1783	2466	
Veery'S'	2699	2914	1573	2395	
Mean	2488	2606	1708	2267	
S.E.		± 79.7***			

Table 2. Effects of sowing dates on straw yield of wheat cultivars.

	Sowing dates				
Cultivars	9 Nov.	23 Nov.	14 Dec.	Mean	
		± 350.4***			
Condor	5804	7860	5564	6417	
Debeira	7430	7647	5065	6714	
Wadi El Neil	9130	7114	5731	7325	± 202.3*
El Neilen	7447	5198	6907	-	
Veery'S'	7734	7480	5178	6907	
Mean	7634	7480	5178	6459	
S.E.		± 289.9***			

Table 3. Effects of sowing dates and cultivars on some yield components.

	Spikes/ plant	Spikelets/ spike	Grains/ spikelet	Grains/ plant	100-grain wt. (g)
Sowing date					
9 Nov.	2.0	19.8	2.0	60.8	3.8
23 Nov.	1.8	19.6	1.4	46.3	3.5
14 Dec.	2.0	19.2	1.7	47.4	2.6
Mean	1.9	19.5	1.7	51.5	3.3
SE ±	0.05*	0.67NS	0.11*	0.04**	0.06**
Cultivars					
Condor	2.1	18.6	1.7	50.2	3.1
Debeira	1.8	19.5	1.5	45.4	3.2
W/El Neil	1.9	20.0	1.6	50.2	3.4
El Neilen	2.0	19.9	1.7	54.6	3.6
Veery'S'	1.9	19.9	1.8	57.0	3.3
Mean	1.9	19.6	1.7	51.5	3.3
SE ±	0.07NS	0.38NS	0.06*	2.56*	0.07**

Table 4. Mean duration and range of wheat developmental phases in different sowing dates averaged over five cultivars.

Developmental phase	Mean (days)	Range (days)	T°C	Tu
		9 Nov.		
GS1 (E-DR)	26.6	21-35	28.0	775
GS2 (DR-TS)	14.4	10-21	28.9	390
GS3 (TS-Anth.)	19.0	11-24	25.0	96
GS4 (Anth-Mat.)	35.0	-	22.1	311
GS1+GS2+GS3+GS4	95.0	91-105		1572
		23 Nov.		
GS1 (E-DR)	29.8	28-31	28.9	862
GS2 (DR-TS)	16.8	14-21	24.2	430
GS3 (TS-Anth.)	21.2	20-24	22.8	67
GS4 (Anth-Mat.)	33.6	27-42	22.4	283
GS1+GS2+GS3+GS4	101.4	91-106		1642
		14 Dec.		
GS1 (E-DR)	32.6	31-35	25.0	810
GS2 (DR-TS)	14.4	10-19	23.2	357
GS3 (TS-Anth.)	17.6	13-22	21.3	41
GS4 (Anth-Mat.)	27.8	21-97	24.3	303
GS1+GS2+GS3+GS4	92.4	91-97		1511

GS1 = Emergence to double ridge.
GS2 = Double ridge to terminal spikelet initiation.
GS3 = Terminal spikelet initiation to anthesis.
GS4 = Anthesis to physiological maturity, Zadoks (DC = 92).
T = mean daily temperature.
Tu = Thermal units above 1°C.

Phasic development

Table 4 shows the durations of all four development phases as affected by sowing dates (mean of five cultivars). Thermal units during the developmental phases are also included. Duration from emergence to double ridge was longer with the late sowing, 27 compared to 33 days. The mean rate of reduction for number of days from anthesis to maturity between the 9 Nov. and 14 Dec. sowings was 20% (Table 4).

GS2, i.e., from double ridge to terminal spikelet, was the shortest phase followed by GS3, terminal spikelet to anthesis. Accumulated thermal units between terminal spikelet and anthesis was reduced markedly from 96°C for 9 Nov. to only 41°C for the 4 Dec. sowing.

Discussion

The 1991-92 season was characterized with cooler weather for the whole growing season, with the exception of seven days from 28 Jan. to 4 Feb. when mean air temperature exceeded that of the 1990-91 for the same period.

High temperature shortened the developmental phase from anthesis to maturity and this shortened the grain-filling period, which is in agreement with Fischer and Maurer (1976) and Midmore et al. (1982). Sofield et al. (1977) reported that higher grain weight is associated with a longer grain-filling period. High temperature also decreased the number of grains per plant due to fewer grains per spikelet.

Early genotypes planted on early sowing dates resulted in low yield due to fewer grains per plant.

El Neilen produced the highest grain yield in all environments. The yield advantage of El Neilen in comparison with other cultivars may be associated with heavy awns, greater amounts of epicuticular wax, and larger grains. Groundbacher (1962) pointed out the value of awns as assimilatory organs under warm, dry conditions. Awn area was also found to be associated with yield (Terare and Peterson 1971). The importance of glaucousness, which is the waxy covering on wheat leaves, was suggested by Fischer and Wood (1979). These waxes reduce heat input to the tissues and consequently lowers leaf temperature.

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Questions/Discussion

On the subject of whether increasing seed rate may reduce the effect of late seeding, Dr. Ishag said that previous results with older varieties showed no effect on yield over a wide range. He indicated that his present thinking is to research the effect of narrower rows (15-18 cm).

Variation and Adaptation of Wheat Varieties for Heat Tolerance in Peninsular India

R.R. Hanchinal
All India Coordinated Wheat Improvement Project, Dharwad
J.P. Tandon
Project Director, Directorate of Wheat Research, Karnal
P.M. Salimath
IARI Regional Station, Dharwad, India

Abstract
In peninsular India, high temperature stress has a strong influence on wheat growth and yield. The stress intensity is severe under late planting causing the reduction in the duration of GS2 and GS3 growth phases. The genetic variability and association analysis indicated grain test weight, spikelets/spike, and grains/spike under hot (normal planting) environments and spike length and spikes/m² under very hot (late planting) environments may serve as valuable selection criteria. The stability analysis for yield under normal planting over 10 locations showed the superiority of improved varieties with regards to adaptation and better response to both favorable and poor environments. Under late planting, the better adaptation of the variety HD2501 was evident in all the environments when tested over nine locations. The exploitation of landraces of durums and emmer wheats in evolving heat tolerant cultivars is suggested.

Introduction

Peninsular India is geographically located between 8°N and 21° N latitude and between 73°E and 85°E longitude (Figure 1). Though maximum and minimum temperatures during the wheat growing season are high (Figure 2), wheat cultivation is traditionally important in the region both for grain and fodder. Until the introduction of semidwarf bread wheats, this region was dominated by tall durums and dicoccums under rainfed and irrigated conditions, respectively. With the introduction of semidwarf wheats and the implementation of new irrigation projects, the area under irrigated wheat is increasing tremendously. However, yield levels are not high, possibly due to greater susceptibility of semidwarf wheats to heat stress (Fischer and Maurer 1978). This is a major factor limiting the productivity and adaptation of wheat, particularly when higher temperatures coincide with critical stages of plant development.

It is difficult to adequately define heat stress in plants because plants' response to heat stress depends on the thermal adaptation, the duration of the exposure, and the growth stage (McWilliam 1980). The rate of change of temperature, the duration, and the degree of high temperature all contribute to the intensity of heat stress. Where heat stress occurs, it is important that crops possess a certain degree of heat tolerance to survive the stress period.

Metabolic stress and changes induced by high temperature have long been considered to be important contributing factors in plant growth and yield depression (Sullivan et al. 1979). Yield reduction can occur at temperatures above a mean of 15°C, spike

and grain growth being especially sensitive. Very hot conditions during stand establishment and lack of full ground cover will further contribute to yield loss (Fischer 1989).

Fischer and Byerlee (1991) broadly categorized the high temperature stress environments into four categories: hot dry, hot humid, very hot dry, and very hot humid. Hot and very hot climates are those where the mean temperatures for the coolest month of the cycle is greater than 17.5°C and 22.5°C., respectively. Thus, the strong influence of heat on wheat growth and yield raises an important question regarding the availability of genetic variability for adaptation to the high temperature environments.

The parameters related to metabolic changes that indicate tolerance to heat stress are difficult to record as the heat tolerance mechanism itself needs to be understood before subjecting the genotypes for screening. Under these conditions, the guiding factors are morphological and biomass features that can be assessed easily. Such morphological and biomass features and their consistency in the high temperature regions indirectly help to evaluate the genotypes as tolerant to heat stress or otherwise. A timely planted (second week of November) crop is considered to pass through normal climatic conditions in peninsular India although the temperatures are quite hot (20°C). Early (third week of October) and late (second week of December) planted crops obviously

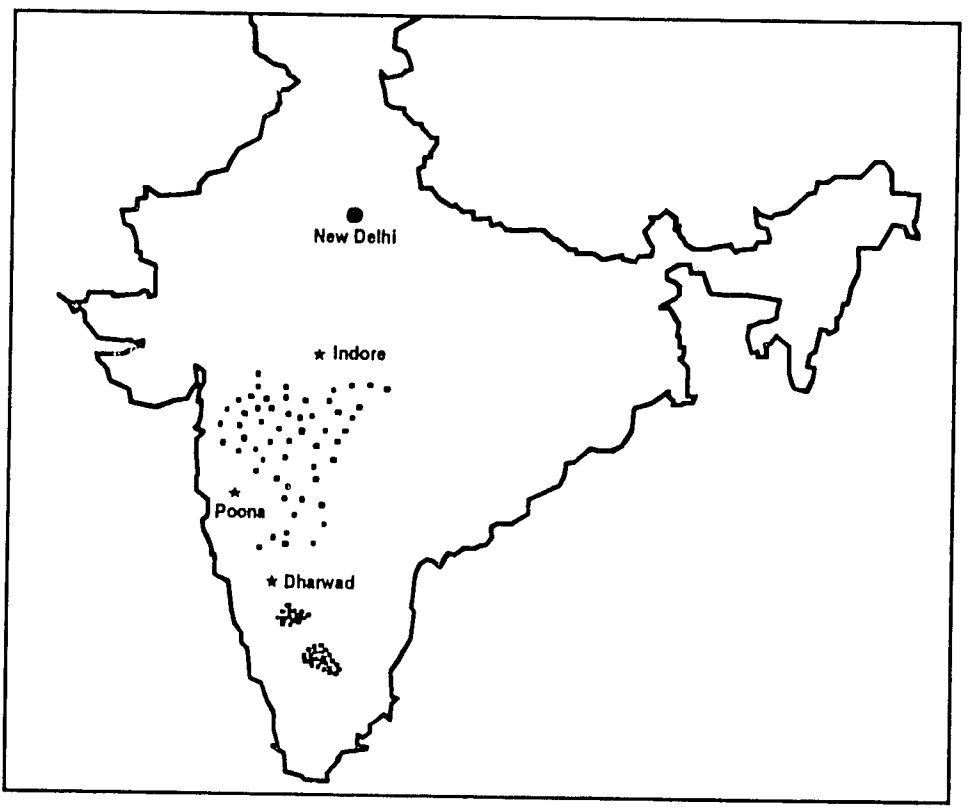

Figure 1. Approximate distribution of irrigated wheat in Peninsular India.

pass through relatively hotter periods in the early (emergence to double ridge) and later (double ridge to maturity) stages of crop growth respectively (Figure 3). The yield reduction is greater under late planted crops due to reduced spike number per plant and grain weight. The more apparent and striking effect of high temperatures on wheat growth is in the acceleration of plant development and the overall reduction in plant size (Shpiler and Blum 1991). The reduction in the duration of GS1 (emergence to double ridge) and GS2 (double ridge to anthesis) is associated with reduced spike number per plant and grain number per spike. The reduction in the duration of GS3 (anthesis to physiological maturity) is often associated with a reduction in grain weight (Warrington et al. 1977).

Genetic Variation and Association Analysis

The existence of genetic variation for heat tolerance in wheat, measured mostly as reduction in yield, and its components has received limited attention. The present study has been performed to examine genotypic variation for heat tolerance in terms of yield components and their subsequent effect on yield. Nine standard and experimental varieties were planted under three temperature regimes (Table 1). This clearly indicates higher yield under early planting as evident from the low stres intensity (relative yield loss) of 0.11 compared to late planting (0.35). According to Warrington et al. (1977), of the three major developmental phases, the most important thermo-sensitive stage was founc to be GS2. Reduction of the duration of GS2 under the influence of high temperature resulted in a reduction in spikes per plant (Fischer and Maurer 1976) and spikelets anc or grains/spike (Halse and Weir 1970, Warrington et al. 1977, Johnson and Kanemasu 1983). Temperature during GS1 does not affect spike size, but higher temperature at this phase decreases tillering and the spikes/plant (Warrington et al. 1977). Of the genotypes tested, var. HD-250 showed a low (0.69) heat susceptibility index for yield under late-sown conditions, indicating heat tolerance for GS2 and GS3 phases as clearly evident from low reductions in spikes/m and grain weight. However, other varieties (AKW-1071, HD-2380, and NI-9406) were better yielders under timely sown conditions.

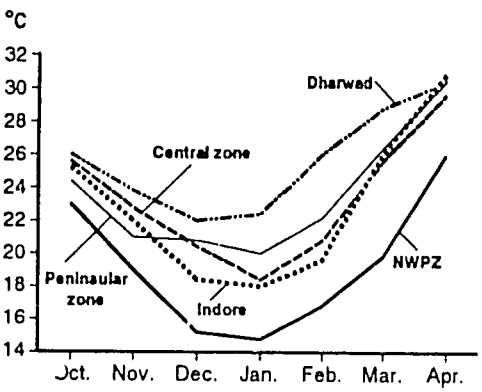

Figure 2. Comparison of mean monthly temperatures of wheat producing zones (India).

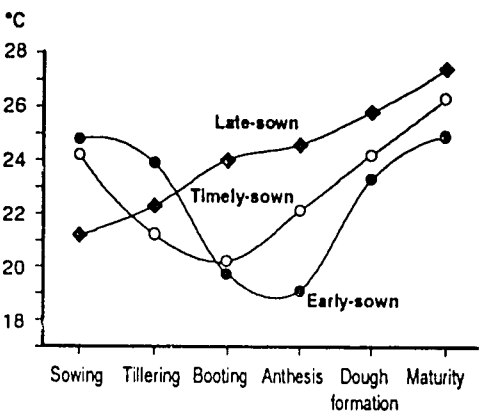

Figure 3. Average temperature during wheat crop under early, timely, and late-sown conditions in the Peninsular Zone.

Table 1. Performance of irrigated wheat genotypes under three temperature regimes at Ugar during 1991-92.

Varieties	Early planting				Normal planting				Late planting			
	Grain yield (t/ha)	Days to anthesis	Spikes/ m of row	TGW (g)	Grain yield (t/ha)	Days to anthesis	Spikes/ m of row	TGW (g)	Grain yield (t/ha)	Days to anthesis	Spikes/ m of row	TGW (g)
CPAN-3004	4.71 (0.63)[a]	75	73	42.5	5.05	76	90	39.6	3.45 (0.92)[a]	70	77	32.7
NI-9406	3.97 (2.50)	67	91	42.5	5.42	70	116	36.8	3.35 (1.10)	68	83	31.2
AKW-1071	5.40 (0.59)	71	98	47.3	5.76	74	99	38.9	3.62 (1.07)	71	69	35.5
HD-2189 (c)	4.05 (1.36)	67	53	45.5	4.74	68	70	39.4	2.53 (1.35)	65	65	37.6
HD-2380 (c)	3.97 (2.66)	62	71	52.0	5.55	62	116	50.7	3.14 (1.26)	60	82	43.0
MACS-2496 (c)	4.45 (0.36)	72	83	45.1	4.63	73	81	40.7	3.34 (0.81)	70	58	32.7
DWR-162 (c)	5.09 (0.16)	70	86	46.7	5.18	72	88	42.5	3.52 (0.93)	69	76	34.0
HI-977[b]	4.98 (0.09)	66	100	49.0	5.03	70	115	41.0	3.60 (0.82)	68	97	38.2
HD-2501[b]	4.80 (0.37)	47	50	43.0	5.00	51	55	40.1	3.80 (0.69)	49	54	39.9
Mean	4.60 (0.11)[c]	66.3	78.3	45.9	5.15	68.4	92.2	41.1	3.37 (0.35)[c]	65.6	73.4	36.1
S.E.±	0.09	0.69	3.15	1.12	0.08	1.12	5.24	0.73	0.04	0.82	3.75	0.16

[a] Figures in parentheses indicate heat susceptibility index (S) compared to normal planting. This is calculated by using the equation: $S=(1-Y/Y_p)/(1-X/X_p)$ where Y is yield under stress, Y_p is yield without stress and X and X_p represent mean yields over all cultivars under stress and nonstress conditions, respectively. The term $(1-X/X_p)$ is defined as stress intensity.

[b] Varieties recommended for late planting.

[c] Values indicate heat stress intensity.

Such genotypic variation to warm and cool temperatures was also observed by Bagga and Rawson (1977). Hence, to decide upon the selection criteria for hot (timely) and very hot (late planting) environments, the data from Advanced Varietal Trials conducted for timely sown conditions with 17 adapted genotypes and late-sown conditions with 12 genotypes adapted for late planting in the Peninsular Zone during 1991-92 were subjected to genetic variability studies.

From Table 2, it is evident that there was considerable reduction in the means for all the traits under late planting. The most affected traits being spike length (20.26%), spikes/m² (28.67%), grains/spike (28.17%), and grain yield (29.76%). This study further confirms the findings of Warrington et al. (1977) that the growth stage GS2 is the most thermo-sensitive. Fischer and Maurer (1976) showed that a 1°C rise in the temperature between the end of tillering and the beginning of grain-filling reduced the yield by 4% under their test conditions. Yield reduction was associated with reduced spikes/plant and grains/spike.

The variability studies showed relatively high phenotypic (PCV) and genotypic (GCV) coefficients of variation accompanied by high heritability coupled with high genetic advance for test grain weight, spikelets/spike, and grains/spike under timely sown conditions, which is indicative of additive gene action. These traits can be relied upon for further improvements

Table 2. Influence of temperature regimes on the estimates of genetic parameters in irrigated wheat.

Character		Mean± S.E.	Coefficient of variability Phenotypic (PCV)	Coefficient of variability Genotypic (GCV)	Heritability (%)	Genetic advance (% of mean)	Genotypic correlations with yield
1. Days to anthesis	T	63.88± 0.62	9.19	8.87	93.29	17.65	0.1970
	L	62.04± 0.57 (2.88)	7.08	6.72	90.09	13.12	0.0132
2. Days to maturity	T	112.99± 0.51	4.16	4.01	92.89	7.96	0.2607
	L	100.33± 0.38 (11.20)	3.63	3.51	93.53	7.00	-0.0496
3. Test grain weight (g)	T	38.70± 0.72	8.82	7.55	73.28	11.40	0.6376
	L	36.30± 0.09 (6.20)	4.04	4.00	98.14	8.17	0.1148
4. Spike length (cm)	T	10.41± 0.08	16.89	16.78	98.70	34.35	0.2898
	L	8.30± 0.07 (20.26)	11.05	10.71	94.05	21.40	0.6672
5. Spikelets/ spike	T	19.97± 0.05	18.55	18.53	99.85	38.15	0.6760
	L	17.03± 0.17 (14.72)	7.72	7.36	90.75	14.44	0.0607
6. Spikes/m²	T	406.57±11.14	10.86	8.55	61.96	10.91	0.9990
	L	290.003±11.42 (28.67)	15.04	11.54	58.84	18.23	0.8497
7. Grains/ spike	T	43.60± 1.43	23.74	22.33	88.44	43.26	0.9720
	L	31.36± 0.92 (28.17)	10.41	7.53	52.25	11.20	-0.3719
8. Grain yield (kg)	T	4699.28± 0.57	22.80	20.56	88.76	32.48	
	L	3300.71± 0.64 (29.76)	16.35	14.86	65.37	15.04	

T = Timely sown.
L = Late-sown.
Figures in parentheses correspond to percentage decrease.

through selection under this environment. Relatively high phenotypic (PCV) and genotypic (GCV) coefficients of variation coupled with high genetic advance indicating additive genetic variance was observed for spike length and spikes/m² under late-sown conditions. Hence, considerable improvement in these two traits may be achieved through selection in very hot environments.

Correlation studies also showed strong positive associations of grain test weight, spikelets/spike, grain/spike, and spikes/m² with yield under timely sown environments indicating selection for these traits is expected to result in yield improvement. Further, in this environment, although days to maturity had strong positive association with spike length, spikelets/spike, and grains/spike, it had weak positive association with grain yield and spikes/m². This indicated that genetic variability for a longer life cycle is not the key trait conferring yield potential (Reynolds et al. 1991). Under late-sown conditions, only spike length and spikes/m² showed high correlations with yield. This would suggest that, in very hot environments, these are the two key traits to be considered as selection criteria in yield improvement.

Further, resolution of correlation coefficients (Table 3) into direct and indirect effects clearly brings out the important yield attributes that should be looked for as selection criteria under timely and late-sown conditions. It is evident that the characters, grain test weight, spikelets/spike, and grains/spike have not only shown high correlations but also high positive direct effects on yield, thus emphasizing their

Table 3. Direct and indirect effects of different traits on grain yield under two temperature regimes in irrigated wheat.

Characters		Days to anthesis	Days to maturity	Grain test weight	Spike length	Spikelets/ spike	Grains/ spike	Spikes/ m²	Genotypic correlation with yield
1. Days to anthesis	T	-1.4140	1.0651	-0.0964	-0.0298	0.6155	0.1982	-0.1416	0.1976
	L	-0.2149	0.4380	-0.1058	-0.1253	-0.0418	-0.0647	-0.0016	0.0132
2. Days to maturity	T	-1.3644	1.1038	-0.0616	-0.0212	0.5132	0.2229	-0.1321	0.2607
	L	-0.1805	0.5216	-0.1306	0.1928	-0.0478	-0.0209	0.0014	-0.0496
3. Test grain weight	T	-0.3442	-0.1719	0.3959	0.0072	-0.0657	0.2115	-0.0835	0.6376
	L	-0.1322	-0.3989	0.1708	0.1179	0.1246	-0.0352	0.0025	0.1148
4. Spike length	T	-0.1705	0.0945	-0.0114	-0.2474	0.5535	0.2137	-0.1426	0.2898
	L	-0.0341	-0.1274	0.0256	0.7893	0.1683	-0.2282	0.0055	0.6672
5. Spikelets/ spike	T	-0.8600	0.5596	-0.0657	-0.1353	1.0122	0.3776	-0.2527	0.6760
	L	-0.0277	-0.0769	0.0657	0.4102	0.3289	-0.6919	0.0021	0.0627
6. Grains/ spike	T	-0.3881	0.3363	0.1144	-0.723	0.5244	0.7317	-0.2505	0.9720
	L	-0.0159	0.0125	0.0069	0.2066	0.2572	-0.8715	0.0010	-0.3713
7. Spikes/m²	T	-0.6664	0.4851	0.1100	-0.1174	0.8512	0.6100	-0.0067	0.9990
	L	-0.0525	0.1092	0.0632	0.6473	0.1011	-0.1305	0.3005	0.8497

T = Timely sown condition.
L = Late-sown condition.
Underlined values represent direct effects

value as selection criteria under timely sown conditions. They were also the means through which other characters related to the spike contributed to yield. Interestingly, the situation is entirely different when we consider late-sown conditions. Spikes/m² and spike length stand out as important yield traits by virtue of their high correlation accompanied by high positive direct effects on yield. Thus, the selection criteria will have to be different for timely and late-sown conditions.

Shpiler and Blum (1991) suggested that grains/spike may correlate best with yield in their hot environment. However, their environment is different from the present, where, under late-sown conditions, the temperatures increased from planting (21.5° C) to maturity (27.5° C).

The present study has clearly indicated that, under a hot environment (normal planting), grain test weight, spikelets/spike, and grains/spike, while in a very hot environment (late planting), spike length and spikes/m² would serve as valuable selection criteria as considerable variation was observed for these traits with limited material that we have studied. It would therefore suggest that there could be ample scope for improving yield under hot and very hot environments specifically looking for such important traits in a large diverse range of material, which could be further utilized in breeding programs.

Adaptation of Wheat Varieties

The combination of higher yields and wider adaptation is most important and guarantees maximum spatial, temporal, and system independent yield stability. Hence, it is suggested that conducting yield trials and screening of nurseries are likely to be better indicators of performance under heat stress environments than that of heat stress trials specifically designed to measure the tolerance of germplasm. Therefore, to study the nature of adaptation of new wheat varieties developed for two temperature regimes separately, two sets of data were used. Timely sown trials (hot environments) were conducted with 17 standard and experimental varieties at 10 locations and late-sown trials (very hot environments) with 12 standard and experimental varieties at nine locations. Under timely sown conditions (Table 4), the experimental varieties DWR-187, DWR-188, CPAN-3004, and recently released variety MACS-2496 in the bread wheat group and DWR-185(d) in the durum wheat group were found significantly superior and the standard varieties HD-2189, DWR-39, HD-2380, and HD-4502(d) were found stable. The superiority of these new varieties with

Table 4. Yield perfomance of wheat varieties over locations and their rating according to cultivar perfomance index under timely sown irrigated conditons.

Varieties		Grain yield (t/ha)	Over sites (Py)	Rank
1.	DWR-187	4.95	37.53	3
2.	CPAN/3004	4.95	38.77	2
3.	DWR-188	4.94	40.00	1
4.	MACS/2496 (C)	4.85	28.77	6
5.	HD-2615	4.83	32.55	4
6.	DWR-185 (d)	4.78	25.65	7
7.	AKW-1071	4.74	30.68	5
8.	HD-2380 (C)	4.74	25.65	7
9.	HD-2616	4.63	25.65	7
10.	DWR-162 (C)	4.61	20.62	10
11.	AKW-1811	4.56	15.03	12
12.	DL-802-3	4.56	12.50	13
13.	DL-788-02	4.42	10.00	14
14.	NI-9406	4.39	8.73	15
15.	DWR-39 (C)	4.27	16.87	11
16.	HD-4502 (D)	4.19	2.50	16
17.	HD-2189	4.18	1.93	17
	Mean	4.62		
	C.D.	0.16		

regards to adaptation and their response to favorable as well as poor environments is evident from Figure 4. The cultivar performance index suggested by Fasoulas (1983) also indicated the superiority of these new varieties. Similarly under late-sown conditions (Table 5 and Figure 5), the significant superiority of AKW-1071 and HD-2501 over Sonalika under favorable and poor environments is evident.

Future Strategies

Local durums and dicoccums are well adapted to warm and dry climates with very short, moderately cool winter and high temperature during the grain-filling period prevalent in most tropical areas. This seems to be due to natural selection over the centuries. Physiological investigations have shown that both emmer types and local durums tend to have lower stomatal conductance, transpiration rate, and leaf temperature than other forms of wheat. These features are reported to confer heat tolerance to the plant. These wheats have also been found to show good grain-filling capacity even under very high temperatures. The grains show little shrivelling under such conditions. Emmer types also possess a very high degree of resistance to stem rust and leaf rust, the major wheat diseases of the region. Hence, there is a need to improve these wheats.

Table 5. Yield performance of wheat varieties over locations and their rating according to cultivar perfomance index under late-sown irrigated conditions.

Varieties	Grain yield (t/ha)	Over sites (Py)	Rank
1. NI-9406	3.58	16.16	6
2. DWR-193	3.58	13.13	7
3. DWR-194	3.59	6.06	9
4. DWR-195	3.77	18.18	4
5. AKW-1071	3.85	27.27	1
6. HD-2590	3.73	16.16	6
7. HD-1610	3.71	18.18	3
8. HD-2615	3.54	6.06	9
9. HD-2616	3.63	8.08	8
10. HD-2501 (C)	3.88	35.25	2
11. HI-977 (C)	3.52	5.05	10
12. Sonalika (C)	3.49	16.16	5
Mean	3.66		
C.D.	0.18		

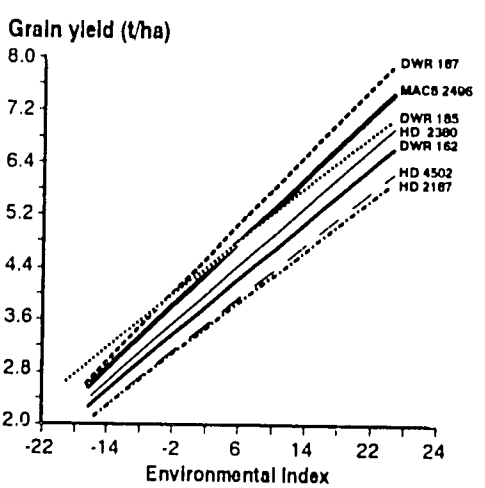

Figure 4. Stability parameters of timely sown wheat varieties.

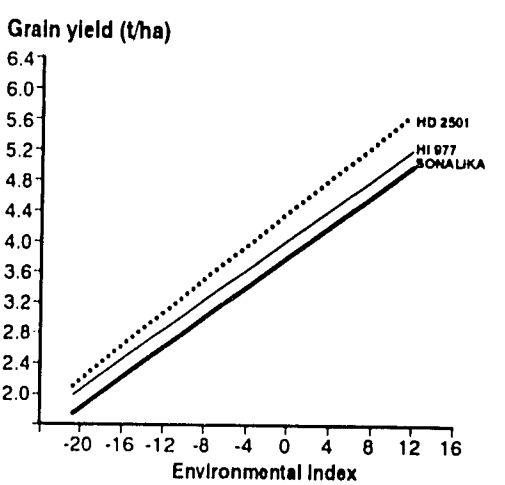

Figure 5. Stability parameters of late-sown wheat varieties.

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Summary of Data from the 1st and 2nd International Heat Stress Genotype Experiments

M.P. Reynolds
International Maize and Wheat Improvement Center (CIMMYT), El Batan, Mexico

Abstract

The International Heat Stress Genotype Experiment (IHSGE) is designed to look closely at a small number of traits that seem to have potential value as predictors of yield at high temperature. The main objectives of the IHSGE include: 1) basic studies on plant characteristics, 2) developing faster screening methodologies for heat tolerance, and 3) increasing international cooperation. The target environment includes 50 countries currently importing more than 20 million tons of wheat per year. The hot environments studied seem to show some grouping. In particular, a number of sites show reasonable yield correlations with CIMMYT's hot dry environment at Tlaltizapan, Mexico. These are Sudan, India, and Brazil, while Syria and Thailand are clearly the environments most unlike the rest. Two physiological traits, canopy temperature and membrane thermostability, look promising and require further investigation and protocol development if they are to be incorporated into breeding programs.

Introduction

Wheat has an important place in the crop rotations of many tropical cropping systems. It is grown as the winter season crop in rotation with a number of other species, for example with maize in Africa, rice in Asia, and soybeans in Latin America. There are many advantages to cultivating wheat in this niche, among them being it is a staple food and it is drought and cold tolerant, relatively high yielding, and easy to transport and store. CIMMYT has been involved in the production of heat-tolerant germplasm since the 1960s. Nonetheless, in a recent review of wheat breeding for hot environments, among the important areas identified for future work were: 1) basic studies on plant characteristics, 2) developing faster screening methodologies, and 3) more international cooperation (Kohli et al. 1991). These are among the main objectives of this project.

Target Environment

Probably the greatest challenge to understanding the physiological problems associated with high temperature stress is to encompass the diversity of hot environments that exist. Our target environment includes 50 countries currently importing more than 20 million tons of wheat per year (Fischer and Byerlee 1991). Since the experiments described in this report have been conducted on a multilocational basis as a collaboration between CIMMYT and national programs in warm wheat growing environments (Table 1), we anticipate that our results will be representative of the range of warm climates that exist. The International Heat Stress Genotype Experiment (IHSGE) is designed to look closely at a small number of traits that seem to have potential value as predictors of yield at high temperature. Another objective of the experiment is to assess the degree of genotype by

environment interaction that exists between environments. The range of environments encompassed by the experiment is most easily appreciated by comparing some of the climatic data and main effects of crop performance between environments. For the 1st IHSGE, the yields ranged from 1.3 t/ha in Thailand to 4.1 t/ha in Sudan, while life cycles ranged from 11 to 17 weeks. Mean daily temperature for the cycle was lowest in Brazil at 18°C and highest in the Sudan at 26°C (Reynolds et al. 1992)

Table 1. Countries with scientists currently participating in the IHSGE.

Country	Type of heat stress
Bangladesh	hot, humid
Brazil	hot, humid
Egypt	hot, dry
India	hot, dry
Mexico	hot, dry (very hot, dry summer)
Nigeria	very hot, dry
Sudan	very hot, dry
Syria (summer planting)	hot, dry
Thailand	hot, humid

Genotype by Environment Interaction

While the ANOVA for yield indicated a highly significant genotype by location interaction term in both years, perhaps a better indication of the variability is to correlate the yields of genotypes at one location with those at all others. It is clear when comparing these correlations that yields in some locations are much better correlated than in others. For example in the 1st IHSGE, correlations between environments for yield were significant between Tlaltizapan (Mexico) and three other environments (Reynolds et al. 1992): Sudan (r=0.82), India (r=0.66), and Brazil (r=0.46). On the other hand, Syria and

Table 2. Correlation coefficients for yield at each location with all other locations for the 2nd IHSGE.

Country	Bangla-desh	Brazil	India	Mexico Tlal. 5/12	Mexico Tlal. 26/2	Sudan	Syria	Thailand	Obg. Dec.	Nigeria
Bangladesh	-	0.21	-0.49	0.02	-0.43	0.13	-0.16	-0.02	-0.10	-0.22
Brazil	0.21	0.00	0.22	0.46	-0.04	0.72	-0.07	-0.38	0.31	-0.02
India	-0.49	-0.21	-	0.20	0.39	0.22	-0.11	-0.19	0.21	-0.18
Tlal. 5/12	0.01	0.46	0.20	-	0.32	0.83	-0.21	-0.71	0.66	-0.01
Tlal. 26/2	-0.43	-0.04	0.39	0.32	-	0.32	0.33	0.02	0.29	0.43
Sudan	-0.13	0.72	0.22	0.83	0.32	-	0.09	-0.72	0.43	0.07
Syria	-0.16	-0.07	-0.11	-0.21	0.33	-0.09	-	0.43	-0.15	0.46
Thailand	0.02	-0.039	-0.19	-0.71	-0.02	-0.72	0.43	-	-0.33	0.26
Obg. Dec.	-0.10	0.31	0.21	0.66	0.29	0.43	-0.15	-0.33	-	-0.25
Nigeria	-0.22	0.02	-0.18	0.01	0.43	0.07	0.46	0.26	-0.25	-
Mean 91-92	-0.14	0.11	-0.02	0.23	0.19	0.18	-0.12	-0.18	0.12	0.07
Mean 90-91	0.06	0.39	0.44	0.49	0.34	0.30	0.12	0.00	0.47	-

Tlal. 5/12 and Tlal. 26/2 = 5 Dec. and 26 Feb. plantings at Tlaltizapan, Mexico; Obg. Dec. = Ciudad Obregón, Mexico, Dec. planting.

Thailand, also the lowest yielding environments, appeared to be unrepresentative of other locations, or each other. Results from the 2nd IHSGE (Table 2) show, over all, much lower correlations between environments. Nonetheless, some of the same patterns emerge. Sudan and the warm Mexican environments appear to be the best correlated with all other environments. Thailand and Syria appear to be unrepresentative of most other environments, but somewhat related to each other in the 2nd IHSGE. A comparison of the correlation between the 1st and 2nd IHSGEs for each location (Table 3) reveals that in most cases year to year variability was not high. Most locations show significant correlations from one year to the next for yield, biomass, and phenology. Differences from one year to the next in the main effects of yield components and phenology were, in most cases, fairly consistent within each location (Table 4).

Table 3. Correlation coefficients between the 1st and 2nd IHSGEs for yield, biomass, and phenology at each experimental location.

	Correlation coefficient between 2 years data:			
Location	Yield	Biomass	Days to anthesis	Days to maturity
Sudan	.84	.64	.92	.88
Mexico I	.80	.67	.80	.94
Mexico II	.56	.63	.90	.91
Syria	.42	—	.75	.86
Thailand	.38	.10	.85	.84
Brazil	.57	.86	.10	.00
Bangladesh	.53	.72	.00	.69
India	.32	.23	.30	.51

Table 4. Comparison of two years of data from the IHSGE.

Environment	Yield (t/ha)	Days to maturity	HI	GR/M² (x10³)	TGW (g)	Yield (Day)	Biomass (Day)
Sudan 1	3.7	83	0.38	11.8	32	45	119
Sudan 2	4.8	99	0.44	13.3	36	48	113
Tlaltizapan 1	3.8	99	0.41	11.1	34	38	93
Tlaltizapan 2	3.8	100	0.39	10.9	35	38	98
Tlaltizapan 1	2.4	78	0.37	8.8	28	31	87
Tlaltizapan 2	2.5	83	0.45	8.3	30	30	67
Tlaltizapan 1	1.3	82	0.47	4.8	28	17	38
Tlaltizapan 2	1.7	81	0.29	5.8	29	21	71
India 1	2.7	82	0.30	8.6	32	33	107
India 2	3.9	87	0.36	11.7	34	45	125
Bangladesh 1	4.1	105	0.42	-	39	39	-
Bangladesh 2	3.0	108	0.27	9.2	33	27	102
Syria 1	1.6	86	-	-	-	18	-
Syria 2	0.8	70	0.29	-	40	12	39
Brazil 1	3.4	117	0.38	10.4	33	28	75
Brazil 2	2.7	81	0.33	8.6	32	34	102
Nigeria 2	1.6	89	0.31	4.1	39	18	60
Average 1	2.9	92	0.39	9.2	33	28	87
Average 2	2.7	89	0.35	9.0	33	30	86

1 = 1990-1991 cycle.
2 = 1991-1992 cycle.

One problem with interpreting correlations of yield between environments is that the correlation puts equal weight on superior and poor performing genotypes. A pragmatic breeder may be interested only in which genotypes rank highly in the majority of environments. If we consider the top four ranking genotypes in the 1st IHSGE at Tlaltizapan, we find that a favorable number of them also appear among the top four performers in the other locations of the 1st IHSGE (Table 5). If the same comparison is made for the four top yielding genotypes from the temperate environment Obregon, the four are less well represented in the other warm locations.

Table 5. Number of the top four yielding genotypes from Tlaltizapan or Obregon also among the top four ranking genotypes in other locations of the 1st IHSGE.

Target environment	Selection environment	
	Tlaltizapan	Obregon
Sudan	3	1
Thailand	3	1
Brazil	2	2
India	2	1
Bangladesh	1	2
Syria	1	1

With data from the 1992-93 cycle (3rd IHSGE) and further data analysis of GxE between environments, we should be in a position to define two or three sub-environments for the warm countries for which breeding can be targeted.

Correlation of Morphological Traits with Yield

With the target environments defined, breeders need confirmation of which selection traits to use for germplasm improvement. In the 1st IHSGE, the most promising morphological characteristic in most of these environments appeared to relate to biomass, especially final biomass, nongrain biomass, spikes/m², and groundcover at anthesis. There is also a tendency in several locations for later flowering and maturing genotypes to yield better. In the 2nd IHSGE, the correlation coefficients with yield for traits analyzed so far (Table 6) were generally lower than in

Table 6. Correlation coefficients for yield with plant characteristics across varieties for the 2nd IHSGE.

Country	Biomass maturity	Straw biomass	Harvest index	Spikes/ m²	Grains/ spike	Thousand grain wt.	Grains/ m²	Days to maturity	Days to anthesis
Bangladesh	0.52	0.18	0.73	-0.10	0.76	-0.12	0.83	-0.14	0.00
Brazil	0.59	0.22	0.58	0.26	0.73	-0.30	0.83	0.09	0.34
India	0.82	0.69	-0.20	-0.23	0.56	-0.13	0.76	0.00	0.00
Mex., Tlal. 5/12	0.87	0.44	0.88	0.16	0.73	0.00	0.91	0.61	0.89
Mex., Tlal. 26/2	0.85	0.69	-0.17	0.44	0.00	0.39	0.72	0.12	0.00
Sudan	0.48	-0.16	0.75	0.32	0.78	0.33	0.93	0.60	0.54
Syria	0.21	-0.15	0.66	0.00	0.61	-	-	-0.43	-0.52
Thailand	0.81	0.24	0.92	0.46	0.61	0.55	0.89	-0.72	-0.52
Nigeria	0.63	0.39	0.45	0.47	0.58	0.29	0.97	0.09	-0.20
Obregon, Dec.	0.79	0.36	0.66	0.21	0.77	-0.64	0.87	-	-
Mean 2nd IHSGE	0.64	0.28	0.51	0.20	0.59	0.10	0.85	0.03	0.08
Mean 1st IHSGE	0.78	0.50	0.49	0.39	0.39	0.22	0.90	0.32	0.25

Tlal.= Tlaltizapan.

the 1st IHSGE. Nonetheless, the correlations seemed to show more or less the same trend. As we get a better feel for which environments group together, the correlation with yield of various traits can be expressed more meaningfully in relation to the specific target environment(s).

One important consideration for a breeding program, having decided on the selection traits that are useful, is deciding upon a selection environment. That is to say in which environment(s) is the desired trait expressed best. For example, can high biomass or high numbers of spikes/m² be selected for in a temperate cycle in Obregon and still be expressed in a hotter location. When traits are correlated between two environments in Mexico and other similar warm locations in the first IHSGE, it is clear that the warmer (Tlaltizapan) of the two Mexican sites is a much better predictor of trait expression than the temperate Obregon cycle (Table 7).

Correlation of Physiological Traits with Yield

One trait that was well correlated with yield in Tlaltizapan (Table 8) and Sudan was canopy temperature, which can be measured very quickly using an infrared canopy thermometer. Canopy temperatures as much as 5°C below air temperature have been reported for wheat in dry environments, when soil moisture was plentiful (Idso et al. 1984). We are currently trying to better characterize genetic variability in canopy temperature in wheat in Tlaltizapan, Mexico, where we routinely measure temperatures up to 10°C below air temperature in some genotypes. The influence of factors such as stage of development and climatic conditions are being studied in terms of their effect on the interaction between genotype and canopy temperature. We hope that this will lead to the development of a rigorous protocol for screening germplasm for this trait. To support our findings, we have initiated a divergent selection study in collaboration with CIMMYT breeders to establish the contribution of crop canopy cooling to yield under hot, dry conditions.

Another physiological trait that we have been testing is membrane thermostability, in collaboration with Romanian wheat researchers. Membrane thermostability (MT), which is measured by electrolyte leakage from leaf tissue after a heat shock, has shown correlations with grain yield of

Table 7. Comparison of two environments in Mexico (Obregon and Tlaltizapan, both with a December sowing date) for their ability to predict genotypic traits in the similar warm locations of the IHSGE.

Correlated with:	Obregon				Tlaltizapan			
	Spearman correlation coefficients							
Location	Biom.	Straw	Sp./m²	Mat.	Biom.	Straw	Sp./m²	Mat.
Sudan	.28	.19	.42	.46	.65	.56	.55	.63
India	.39	.19	.55	.63	.53	.38	.23	.48
Brazil	.40	.30	.13	.68	.63	.62	.52	.64
Mean	.36	.23	.30	.59	.60	.52	.43	.58

Biom. = biomass; Sp.= spikes; Mat. = maturity.

field-grown plants in hot environments (Shanahan et al. 1990). Measurements made on leaf tissue from the 2nd IHSGE at Tlaltizapan show a high correlation between injury and yield loss for similar environments in the 1st IHSGE (Table 9). Studies with seedlings of the same genotypes showed a similar but weaker correlation.

"Stay green" or leaf chlorophyll content is a trait that has been used to indicate heat tolerance in the hot environment (Acevedo et al. 1991, Kohli et al. 1991). Flag leaf chlorophyll content measured two weeks after anthesis showed a significant correlation (r=0.4) with yield in the second planting date of the 2nd IHSGE in Tlaltizapan. One study, conducted in collaboration with Chapingo University, Mexico, was aimed at a better understanding of genetic variability in photosynthesis under heat stress and constituted an MSc. thesis. The data showed the decline in photosynthesis of low yielding genotypes to be related to declining leaf chlorophyll concentration.

Many mechanisms for heat stress in wheat have been reported in the literature. Not many have been tested in the field. We have

Table 9. Correlations between membrane thermal injury measured on leaf tissue at Tlaltizapan and yield and biomass for the IHSGE.

IHSGE site	Correlation Yield	Coefficient Biomass
Brazil	-.52	-.87
India	-.66	-.70
Sudan	-.58	-.63
Tlaltizapan, 1990-91	-.51	-.54
Tlaltizapan, 1991	-.45	-.59
Tlaltizapan, 1991-92	-.75	-.79
Mean	-.60	-.71

Table 8. Correlations between yield and canopy temperature depression in Tlaltizapan, 1992.

Stage of development	Days after irrigation	Air temperature (°C)	Time of day	Mean temperature depression (°C)	Correlation with yield
Cycle1					
2nd node	-	27	2pm	3.9	0.47
Booting	4	28	2pm	5.4	0.42
Heading	8	27.5	3pm	4.4	0.35
Anthesis	12	30	3pm	4.6	0.67
Anthesis	12	27	noon	2.8	0.38
Early grain-fill	3	30	3pm	4.4	0.73
Grain-fill	10	32	2pm	3.9	0.75
2w before maturity	3	31	1pm	2.8	0.75
1w before maturity	-	30	-	7.7	0.45
Cycle 2					
2nd Node	-	35	3pm	8.1	0.47
Booting	-	34	1pm	6.9	0.43
Heading	-	33	1pm	8.2	0.57
Anthesis	-	36	1pm	5.3	0.53
2w before maturity	-	36	3pm	4.0	0.44

Source: Reynolds et al. (1992).

tried to compare our data to the previous observations in order to develop a conceptual model for heat stress of wheat in the field. Table 10 shows the reported heat stress mechanism in the left hand column and on the right whether it seemed to account for the genetic variation in heat tolerance in studies in Tlaltizapan and the IHSGE. In considering these mechanisms, it must be kept in mind that the processes accounting for heat tolerance of a wheat crop will depend upon the particular heat stress environment in question.

Conclusions

Although still a little tentative at this stage, the hot environments studied seem to show some grouping. In particular, a number of sites show reasonable yield correlations with CIMMYT's hot dry environment at Tlaltizapan. These are Sudan, India, and Brazil, while Syria and Thailand are clearly the environments most unlike the rest.

We have some leads already on potential selection traits. Genetic variability in biomass accumulation in the hot

Table 10. Summary of heat stress mechanisms previously reported for wheat and whether they appeared to account for observed genetic variability in the IHSGE.

Reported heat stress mechanism	Accounting for genetic variation in heat tolerance (IHSGE)
Accelerated development (Midmore et al. 1984)	Yes, in some environments
Poor stand/canopy establishment (Rawson 1988)	No, poor correlation early growth and yield
Evaporative cooling (Idso et al. 1984)	Yes, IR thermometry data
Inhibition of meiosis (Saini et al. 1983, Zeng et al. 1985)	Nc grain:spikelet ratio not correlated
Sensitive growth phase (Fischer 1985, Shpiler and Blum 1991)	Checking (correlate PTQ during sensitive stage with yield)
Photosynthesis/chlorosis (Al-Khatib and Paulsen 1990, Shpiler and Blum 1991)	Yes, due to chlorosis
Thylakoid thermostability (Moffatt et al. 1990)	MSc. thesis project in progress measuring chlorophyll fluorescence
Membrane thermostability (Shanahan et al. 1990)	Yes
Inhibition of starch synthase (Bhullar and Jenner 1986, Rijven 1986)	No association between yield and TGW

environment seems to be more important than it is in temperate environments. Our data lend some support the notion that this trait can be selected for using a number of morphological traits.

Two physiological traits, canopy temperature and membrane thermostability, look promising and require further investigation and protocol development if they are to be incorporated into breeding programs.

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On-farm Trials to Investigate Seeding Methods for Wheat

E.A. Babikir
Agricultural Research Corporation, Wad Medani, Sudan
A. Ali Elhassan
Agricultural Engineering Dept., Rahad Scheme, Sudan

Wheat in Rahad has mainly been sown by the wide level disc drill introduced from nearby areas that cultivate rainfed sorghum. However, in the Rahad Scheme, there are many Vicon spreaders used for broadcasting fertilizers, especially urea. It was suggested that these could be used for broadcasting wheat seed. This operation has been followed by a passage of disc harrows to incorporate the seed. The farmer would usually then use a 40-cm ridger to facilitate the regulation of irrigation water.

This study sought to evaluate a system, in comparison to those described above, in which the ridger was used directly after the Vicon spreader, to both incorporate the seed and regulate irrigation applications. This would reduce the cost of wheat production.

Results from on-farm trials in three blocks within the Rahad Scheme are shown in Table 1. The use of the wide level disc drill resulted in yields some 10-11% higher than the Vicon broadcasting systems. There was no difference between these latter treatments and thus the cost of seeding with the Vicon spreader can be reduced by using the 40-cm ridger to cover the seed and shape the land for irrigation in one operation.

Table 1. Yield (kg/ha) comparisons of three wheat seeding methods in the Rahad Scheme.

Machine	Block 1	Block 2	Block 7	Treatment mean
Vicon spreader + 40-cm ridger	1688	1818	1645	1717
Vicon spreader + disc harrow	1688	1802	1558	1682
Wide level disc seeder	1947	2004	1644	1865

Response of Wheat to Nitrogen and Phosphorus Fertilizers in Farmers' Fields in the Rahad Scheme

E.A. Babikir and H.H. Abdalla
Agricultural Research Corporation, Wad Medani, Sudan

The Rahad Scheme is a newly developed project in which wheat was first sown in 1989-90. At that time, the fertilizer recommendations were those formulated for the Gezira Scheme, due to no prior research on wheat in the new area.

Subsequently, on-farm research experiments, ranging from microplots to large fields, have been conducted in the northern and southern groups of the Scheme. Some results are shown in Figure 1.

The addition of the recommended 2N rate (86 kg N/ha) increased wheat yields (over zero fertilizer) by 66 and 45% for the northern and southern groups, respectively. The addition of phosphorus (43 kg P_2O_5/ha) to the 2N rate substantially increased yield, although phosphorus application alone had no effect on yield at either location.

Generally, the response to N and P fertilizers followed the same trend in both locations and mean yield differences between treatments are summarized in Table 1. The results show that the interaction of NP fertilizers is very high. Thus, the application of the 2N + 1P combination was superior to the 2N application, while the 1P application alone was simply a waste. Accordingly, a recommendation of 2N + 1P has been passed by the ARC Husbandry Committee as the recommendation for the Rahad Scheme.

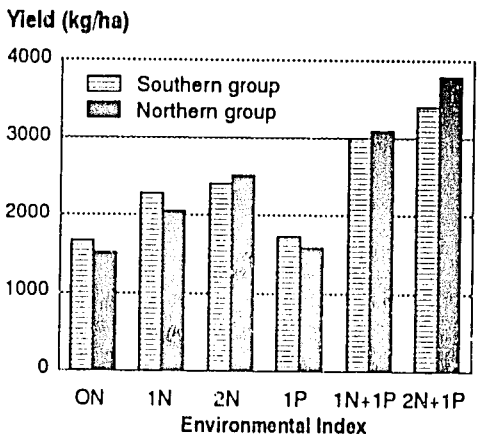

Figure 1. Effect of NP fertilizers on grain yield in the Rahad Scheme.

Table 1. Mean yields (kg/ha) across sites in the Rahad Scheme and yield differences between treatments.

Treatment	Yield (kg/ha)	2N+1P (3643)	1N+1P (3044.7)	2N (2466.1)	1N (2169.7)	1P (1659)
0N	1591.1	2051.9	1453.6	875.0	578.6	67.9
1P	1659.0	1983.0	1385.7	807.1	510.7	
1N	2169.7	1473.3	875.0	296.4		
2N	2466.1	1176.9	578.6			
1N+1P	3044.7	598.3				
2N+1P	3643					

Transfer of Wheat Management Technology Using Demonstration Plots in the Rahad Scheme

E.A. Babikir and A.O. Mohamed
Agricultural Research Corporation (ARC), Wad Medani, Sudan

Wheat is a new crop in the Rahad Scheme, introduced only in 1989-90. Its introduction has been accompanied by a strong research-extension linkage making use of demonstration plots, field days, training and visits to transfer new wheat cultivation technologies to farmers.

In the demonstration plots, a package of technology developed by ARC research was applied that highlighted variety, seedbed preparation, seeding date, fertilizer application, and irrigation scheduling. Yields in the demonstration plots were 74, 107, and 19% higher than the Scheme averages for the last three seasons (Table 1).

In 1990-91, the average temperatures in November and December were 3 and 4°C higher than the long-term average, and are presumably responsible for reduced yields, particularly shown by the Scheme average which fell by 33% compared to a drop in the demonstration yields of 21%. Thus, the detrimental effect of the high temperature could be substantially modified by good management.

In 1991-92 however, the yield gain using the technology package was low. That growing season was unusually cool for an extended period and consequently heat stress, particularly on late-sown wheat, was minimized. In addition, infestations of Sudan grass were lower, again due to low temperature. However, even in this highly favorable season, the recommended package of practices resulted in significant yield increases.

Table 1. Average wheat yields (kg/ha) of the Rahad farmers' fields and demonstration plots.

Season	Scheme average	Demonstration plot average	Yield difference (%)
1989-90	1569	2720	74
1990-91	1041	2153	107
1991-92	2274	2710	19

Determination of the Economic Threshold Levels of the Wheat Aphid (*Schizaphis graminum*)

H.O. Kannan
Rahad Research Station, Elfau, Sudan

Aphid infestations are more serious in Sudan's newer areas of wheat production and economic losses can be high if the insect is not controlled.

Five levels of infestation (15, 25, 35, 45, and 55% of plants infested), compared to an untreated control, were evaluated to determine the level of infestation where economic damage to the crop was incurred.

Low infestation levels (15 and 25%) were required to be sprayed earlier and consequently more sprays were necessary to control the aphids during the crop cycle (Table 1). No responses were obtained from control at these early stages. However, Table 1 indicates that at the 35% level of plant infestation, spraying the insects significantly increased yield. It may be concluded that spraying may be effective only after a 35% level of plant infestation is reached.

Table 1. The effect of insecticide control of *S. graminum* at different levels of infestation.

Infestation level (%)	No. of sprays	No. of aphids/ 100 plants	Yield (t/ha)
15	4	7.9	2.48
25	3	7.1	2.56
35	2	9.3	3.71
45	2	9.5	2.26
55	2	9.8	2.26
Control	0	17.8	2.02
S.E.		1.5	0.22

Bionomics and Seasonal Abundance of Wheat Aphids (*Schizaphis graminum*) in the Rahad Scheme

H.O. Kannan
Rahad Research Station, Elfau, Sudan

This investigation was initiated in 1990-91 at Rahad to quantify the population and fate of the wheat aphid, *S. graminum*, and its host plants during the off-season. The sampling area was about 5 km around the Research Farm where regular periodical counts were carried out at two-week intervals.

The study showed that the pest was observed in some crops grown within the sampled area during April-October (Table 1). *S. graminum* was recorded on alfalfa, grass weeds, and Sudan grass, but were more abundant on grass weeds, particularly with early showers of May and June. Lower intensity of the pest during August and September was quite apparent and this could be due to heavy rains at that time, in addition to increasing populations of predators, mainly chrysopids.

Coccinellids were reported during April-July mostly in cucurbits, whereas chrysopids and syrphids were observed to be abundant in cotton from August onwards.

This study helped identify the most important alternative host plants of the aphid during the off-season. A pest control strategy could involve eradication of the alternative hosts.

Table 1. Off-season sampling of the wheat aphid (*S. graminum*) in the Rahad Scheme, Sudan.

Time	Aphid host plant	Predator species	Host plant where predators reported	No. of aphids/plant
April	Grass weeds, alfalfa, Sudan grass, eggplant	Coccinellids	Cucurbits	1.1
May	Grass weeds, alfalfa	Coccinellids	Cucurbits	4.3
June	Grass weeds alfalfa	Coccinellids	Cucurbits, alfalfa	5.6
August	Grass weeds	Coccinellids, syrphids, chrysopids	Cucurbits, cotton	0.2
Sept.	Grass weeds	Syrphids, chrysopids	Cotton	0.2
Oct.	Grass weeds	Syrphids, chrysopids	Cotton	0.6

Performance of Three Sowing Methods under Two Tillage Systems for Wheat Production

A.O. Mohamed
Rahad Research Station, Elfau, Sudan

An experiment on sowing machines was conducted over two seasons. In 1990-91, two seed drills, one with a tine furrow opener and the other with a single disc opener, were compared to broadcasting and incorporating the seed under two tillage systems: 1) chisel plowing + disc harrowing and 2) disc harrowing alone.

The tine-furrow opener drill (Drill A) resulted in significantly higher yield than the other two seeding methods (Table 1) regardless of tillage method (which were not significantly different).

However, Drill A applied urea as a banded application in rows adjacent to the seed row and it was felt that this, and not the furrow opening/seed placement aspects of the machine, may have been the reason for higher yield. Thus, in the second season, Drill A was used as a seed drill only (with the urea broadcast and incorporated, as with Drill B and the broadcast seed methods) or as the combined seed and urea drill (Drill AF).

As there was again no difference between tillage treatments, mean performances of the seeding methods in 1991-92 are shown in Table 2. With the combined seed plus urea method, Drill AF gave the highest yield; the differences between the treatments were not statistically different. Yields were radically higher than the previous year due to an abnormally long, cool growing season.

Table 1. The effect of seedbed tillage and seeding methods on wheat crop performance, Rahad, 1990-91.

Tillage method	Seeding method	Yield (kg/ha)	Plant pop. (10^3/ha)	1000-grain weight (g)
CH	Drill A	1152.0	1928	23.0
CH	Drill B	882.2	1902	31.2
CH	B/caster	744.2	1965	27.2
DH	Drill A	1116.7	1900	25.0
DH	Drill B	854.0	1788	30.5
DH	B/caster	896.0	1852	23.8

CH = chisel plowing + disc harrowing + leveling.
DH = disc harrowing.

Table 2. The effect of different seeding methods (means of two seedbed tillage systems) on grain yield, Rahad, Sudan 1991-92.

Treatment	Grain yield (kg/ha)
Drill AF	3100
Drill A	2920
Drill B	2760
Broadcasting	2970
S.E.	±69.1

Wheat Tillage Systems in the Gezira Scheme

M.I. Dawelbeit and A.A. Salih
Gezira Research Station, Wad Medani, Sudan

Various tillage systems are being adopted in the Gezira Scheme depending on the availability of machines. The data were collected from the 14 groups of the Gezira Scheme. Selected sites representing the different systems were studied. Four different tillage systems were identified (Table 1). Some 231,600 ha were cultivated in the 1991-92 season. The distribution of the area by tillage system is shown in Figure 1 and the mean yields of the four systems are shown in Figure 2. System D gave the highest yield followed by system A. Systems B and C were similar.

It seems that ridging, split-ridging, and harrowing (A and D) had beneficial effects compared to the other two systems. Systems A and D resulted in a finer seedbed because of the extra manipulation. Shallow soil inversion could be advantageous to the wheat crop. System B had the lowest cost followed by system C. Systems A and D were more expensive.

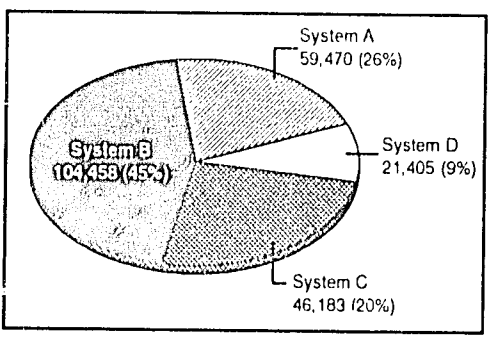

Figure 1. Area (ha) of wheat tillage systems in the Gezira Scheme in 1991-92.

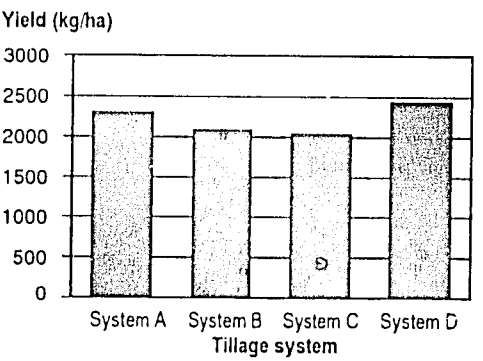

Figure 2. Mean grain yields of tillage systems in the Gezira Scheme in 1991-92.

Table 1. Tillage systems in the Gezira Scheme during 1991-92.

Feature	Tillage system A	B	C	D
System operations				
One	Ridging	Ridging	Ridging	Ridging
Two	Split ridge	Split ridge	Harrow	Split ridge
Three	Harrow	Level	-	Harrow
Tractor				
Horsepower	75-130	70-80	120	75-150
Type	Wheeled	Wheeled	Clawler	Wheeled
Harrow type	Tandom & offset	-	Offset	Offset
Cost (Ls/ha)	797.3	464.0	725.9	797.3

Ls= Sudanese pound.

On-Farm Evaluation of Harrow Packing on Wheat Yield in the Gezira Scheme

M.I. Dawelbeit
Gezira Research Station, Wad Medani, Sudan

This was an on-farm researcher/farmer-managed trial conducted during the 1991-92 growing season. The objective was to investigate the effect of harrow packing (HP) on wheat yield. Currently used seed drills in the Gezira Scheme use tine covering devices. It seems that compacting the soil after seed placement and covering could help improve crop establishment and consequently yields.

The study was conducted at two locations, each with 12 cooperating farmers, with a total area of 25.2 ha at each location.

Farmers reported that harrow-packed areas were easier to irrigate, especially the first critical irrigation. It took less time to irrigate harrow-packed areas, mainly because the harrow packer coil makes small furrows, which facilitate water flow. No differences were observed in the time of emergence. Figure 1 shows the yield data. Harrow-packed areas outyielded the unpacked. The percent increase in yield due to harrow packing was 5.3 and 9.4% for the first and the second locations, respectively. Mean yields in harrow-packed and unharrow-packed areas were 1,924 and 1,797 kg/ha, respectively. Statistical analysis showed that there is no significant difference (P = 0.05) in yield.

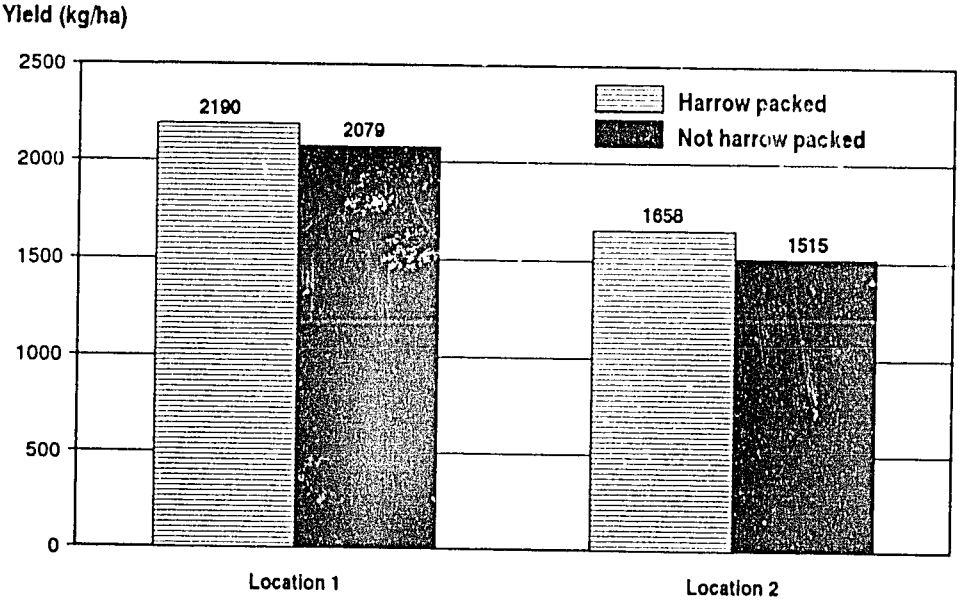

Figure 1. On-farm evaluation of harrow packing on wheat yield in the Gezira Scheme.

Summary Session

G. Varughese
Associate Director, CIMMYT Wheat Program, El Batan, Mexico

Over the last three days, we have had a very productive dialogue as we covered a wide variety of topics. Our discussions on the expansion of wheat production in the hot environments were particularly relevant since we have been fortunate to meet here in Sudan, which is one of the extremes for wheat production in such environments. We have seen that, in the last few years, annual wheat production has gone from 150,000 to almost 890,000 tons—a remarkable achievement for the Sudanese.

Other countries in the warm areas are also making progress. In Nigeria, close to 200,000 tons of wheat are being produced annually. Egypt probably has one of the highest average yields among developing countries—although we do recognize that Egypt has a range of production environments, from fairly favorable to hot environments.

In India, there is also great diversity of environments, from extremely hot to very favorable production conditions. The report from India indicated that there is still enormous potential for increasing productivity—there are about 24 million hectares sown to wheat, about 78% of which is irrigated and the national yield is still less than 2.5 t/ha. Also, there is potential for increase in the hotter, less favorable conditions, through the use of local varieties in the hybridization programs—the landraces Hindi 62, Kharchia 65, and the tall improved variety C306 having very good early growth stage tolerance, as well as many other varieties with heat resistance in later growth stages. In addition, the dicoccums show excellent tolerance to heat stress indicating again the tremendous potential for improvement to heat stress in the warm environments.

General discussions during the meeting revealed that scientists should work at better defining their target environments (minimum, maximum, or mean temperatures are not enough), and that breeders and physiologists should better differentiate between heat tolerance and heat avoidance mechanisms. In addition, more work should be conducted on the relative lengths of vegetative and reproductive phases to optimize the use of target environments.

It seems we have made fairly good progress in heat stress screening. However, our current procedures tend to identify tolerance or susceptibility to heat at a relatively late stage in germplasm development. We appear to be still far from applying methodologies in the early generations. From general discussions, I believe it was observed that no single character or even set of characters could be used as an index for selection of materials tolerant to heat stress. However, the physiologists in our audience came up with some agronomic practices that can alleviate the effects of heat stress. These included timing and frequency of irrigation, good seedbed preparation to promote root growth that will bring water from lower depths to cool the meristem, and straw mulch, which in Mexico has been shown to reduce daily maximum soil temperatures. This possibly affects root growth and hence

enhances water uptake when the topsoil dries. This is supported by canopy temperature data. Also in Mexico, the addition of animal manure has been effective, much more so than the equivalent rates of inorganic fertilizer. This may also be an effect on root growth.

Finally, I noticed that in the plant protection session, the major emphasis was on insect pests. One has to presume that diseases are of very minor importance and that is true of this region. However, we have to be ever vigilant in watching the disease situation, and keep in mind that it is not insects alone that we have to worry about.

As I close this conference, I want to thank, on behalf of CIMMYT, Dr. Osman Ageeb and his energetic staff for the very successful meeting they have orchestrated. As the papers to be published in the proceedings will show, it has been a very informative and useful get together. I was very impressed with the large number of active participants among our Sudanese hosts, including representatives from the Agricultural Research Corporation; the Ministry of Agriculture, Animal Wealth, and Natural Resources; the Agricultural Production Corporations (i.e., Gezira, Rahad, New Halfa, and Blue Nile); the University of Gezira; Sudan University of Science and Technology; Wadi El Neil University; the Arab Organization for Agricultural Development; and the Arab Authority for Agricultural Investment and Development.

Sincere thanks also goes to the United Nations Development Programme (UNDP) for co-sponsoring this conference with CIMMYT.

Participants, Wheat in Hot, Dry, Irrigated Environments, Wad Medani, Sudan, 1-4 February 1993

Australia
D.A. Saunders
Interag Pty. Ltd.
Victor Harbor

Egypt
A.M. AbdElGhani
Field Crops Research Inst.
Agricultural Research Council
Giza

A.M. AbdElShafi Ali
Wheat Research Dept.
Agricultural Research Council
Giza

Enayat Ghanem
Wheat Research Station
Agricultural Research Council
Giza

India
R.R. Hanchinal
All-India Coordinated Wheat Project
Dharwad

J.P. Tandon
Directorate of Wheat Research
Karnal, Haryana

Kenya
Rashid Hassan
CIMMYT
Nairobi

Mexico
Norman E. Borlaug
CIMMYT
El Batan

Gene P. Hettel
CIMMYT
El Batan

Matthew Reynolds
CIMMYT
El Batan

George Varughese
CIMMYT
El Batan

Nigeria
B.K. Kaigama
Lake Chad Research Inst.
Maiduguri

L.B. Olugbemi
Institute of Agricultural Research
Ahmadu Bello University
Samaru, Zaria

J.A. Valencia
Global 2000
Kano

Sudan
Omer Abdel Wahad Abdalla
Sudan Gezira Board
Barakat

Hassan Hag Abdalla
Soil Science
Sudan Gezira Board
Barakat

Badr Eldin Abdelrahman
Statistics
Agricultural Research Corporation
Wad Medani

Hamed Warrag Abdelrahman
Ministry of Agric. Planning Administration
Khartoum

Hussein S. Adam
University of Gezira
Neisheshiba

Fathi A. Agabawi
Plant Protection
Agricultural Research Corporation
Wad Medani

Osman A.A. Ageeb
Administration
Agricultural Research Corporation
Wad Medani

Abdel Moneim B. El Ahmadi
United Nations Development Programme
Khartoum

Abdelmoneim M. Ahmed
Agricultural Research Corporation
Wad Medani

Mohamed Osman Mohamed Ahmed
Abu Haraz College of Agric.
University of Gezira
Wad Medani

Mohamed Sid Ahmed
Extension Dept.
Sudan Gezira Board
Barakat

Muddathir Ali Ahmed
University of Gezira
Wad Medani

M.S. Ahmed
New Halfa Research Station
Agricultural Research Corporation
New Halfa

Radwan Mohamed Ahmed
Blue Nile Agric. Corporation
Wad Medani

Sirelkhatim Hassan Ahmed
Hudeiba Research Station
Agricultural Research Corporation
Ed Damer

Faisal M. Ali
Agricultural Research Corporation
Wad Medani

Naiem A. Ali
Gezira Research Station
Agricultural Research Corporation
Wad Medani

Zakia Ibrahim Ali
Agricultural Research Corporation
Wad Medani

Yousif H. El Ani
Arab Authority for Agricultural Development
Khartoum

Elfadil A. Babiker
Rahad Research Station
El Fau

El Tayeb El Obeid Badr
Farmers' Union
Gezira Scheme
Wad Medani

Abdel Razig El Bashir
Economics Administration
Ministry of Agriculture
Khartoum

Dafalli Ahmed Dafalla
Agric. Res. Extension & Training Project
Khartoum

Gasim A. Dafalla
Faculty of Agriculture
University of Gezira
Wad Medani

Mamoun Ibrahim Dawelbeit
Agricultural Enginering
Agricultural Research Corporation
Wad Medani

Abdalla B. Elahmadi
Plant Breeding Section
Gezira Research Station
Agricultural Research Corporation
Wad Medani

Abd Elmonim B. Elahmadi
Sorghum-Millet Research
UNDP
Khartoum

Eltigani M. Elamin
Agricultural Research Corporation
Wad Medani

Nasr Sharaf Eldin
Agricultural Research Corporation
Wad Medani

Mohamed Elkashif
Faculty of Agricultural Sciences
University of Gezira
Wad Medani

Hashim Elobeid
Sudan Commercial Bank
Khartoum

Hamid H.M. Faki
Economics
Agricultural Research Corporation
Wad Medani

Osman Gameel
Agricultural Research Corp.
Wad Medani

Ahmed Ali Geneif
Ministry of Agriculture, Natural Resources, and Animal Wealth
Khartoum

Ahmed Mohamed Gorashi
New Halfa Research Station
Agricultural Research Corporation
New Halfa

Abelrahman El Tayib Abdel Hafiz
Arab Organization for Agric. Development
Khartoum

Hamed Ali Hamed
Dept. of Biochem & Soil Science
University of Khartoum
Khartoum

Sami Ali Mohd Hamid
Sudan Univ. of Science & Technology
Khartoum

Abdalla Mohamed Hamdoun
Agricultural Research Corporation
Wad Medani

Desougi Ahmed Hashim
Ministry of Irrigation
Wad Medani

Mohamed Ali Hashim
Extension Dept.
Sudan Gezira Board
Barakat

Ahmed Abdalla Hussain
Abu Haraz College of Agric.
University of Gezira
Wad Medani

Ahmed Ali El Hassan
New Halfa Scheme
New Halfa

Babiker A. Ibrahim
New Halfa Research Station
Agricultural Research Corporation
New Halfa

Hassan Suliman Ibrahim
Hudeiba Research Station
Agricultural Research Corporation
Ed Damer

H.M. Ishag
Agricultural Research Corporation
Wad Medani

Mohamed A. Ismail
Planning Unit
Sudan Gezira Board
Barakat

Ahmed Dafalla El Kabashi
Information and Public Relations Dept.
Sudan Gezira Board
Barakat

Hassan Omer Kannan
Rahad Research Station
El Fau

M.G. Khatib
Water Management
Sudan Gezira Board
Barakat

Leodtios Leontiades
FAO Representative
Khartoum

Abdalla Ibrahim Sheikh Mohamed
Hudeiba Research Station
Agricultural Research Corporation
Ed Damer

Abdel Aziz Ahmed Mohamed
National Seed Administration
Khartoum

Abdel Ilah B. Mohamed
University of Gezira
Faculty of Agricultural Sciences
Neisheshiba

Ali Omer Mohamed
Rahad Research Station
El Fau

Ali Sidahmed Mohamed
Faculty of Agric. Sciences
Wadi El Neil Univ.
Dongla

Elsadig Suliman Mohamed
Hudeiba Research Station
Agricultural Research Corporation
Ed Damer

Gaafar El Sarrag Mohamed
Shendi Research Station
Agricultural Research Corporation
Shendi

Habib Alla Hafiz Mohamed
Faculty of Agricultural Sciences
University of Gezira
Wad Medani

Mohamed Salih Mohamed
New Halfa Research Station
Agricultural Research Corporation
New Halfa

Osman Abdel-Shakour Mohamed
Rahad Research Station
El Fau

Samira Abuelgasim Mohamed
Hudeiba Research Station
Agricultural Research Corporation
Ed Damer

Yousif Fadlalla Mohamed
Faculty of Agricultural Sciences
University of Gezira
Wad Medani

Laila Y. Monawar
Food Research Centre
Agricultural Research Corporation
Shambat

Nuri Osman Mukhtar
Gezira Research Station
Agricultural Research Corporation
Wad Medani

Badar Munir
Agricultural Research Corporation
Wad Medani

Ahmed M.A. Musa
Agricultural Engineering
Sudan Gezira Board
Barakat

Musa M. Musa
Ministry of Agriculture
Khartoum

Mohamed Mustafa Omer
Sennar Research Station
Agricultural Research Station
Sennar

Dick Nauta
Royal Netherlands Embassy
Khartoum

Aldirdiery G. Osman
New Halfa Research Station
Agricultural Research Corporation
New Halfa

Ahmed A. Salih
Soil Science
Agricultural Research Corporation
Wad Medani

Ahmed El Badawi Mohamed Salih
Sudan Gezira Board
Wad Medani

F.M. Salih
Wadi El Neil University
Dongla

Wageeh Samuel
Sudan Gezira Board
Bakarat

Osman Abdul Shakur
Rahad Corporation
Rahad

Osman Ali Sidahmed
Faculty of Agric. Sciences
University of Gezira
Neisheshiba

Suleiman M. El Tayeb
Ministry of Agriculture
Central State

Abdel Hadu Abdel Wahab
Agricultural Engineering
Agricultural Research Corporation
Wad Medani

A.M. Yassin
Agricultural Research Corporation
Wad Medani

Omer Abdel Fadeel Yousif
Ministry of Agriculture
Khartoum

Syria
R.H. Miller
ICARDA
Aleppo

M.G. Mosaad
ICARDA
Aleppo

G. Ortiz Ferrara
CIMMYT/ICARDA
Aleppo

V. Mahalakshmi
ICARDA
Aleppo

J.M. Peacock
ICARDA
Aleppo

Tanzania
Marco Quiñones
Global 2000
Dar Es Salaam

Thailand
Christoph E. Mann
CIMMYT
Bangkok

Uganda
W.W. Wagoire
Uganda Grain Milling Co.
Jinja

United Kingdom
D.W. Lawlor
Institute of Arable Crops Research
Rothamsted Experiment Station
Harpenden, Herts.

Participants, Wheat in Warm Area, Rice-Wheat Farming Systems.

Opening Address

Majid-Ul-Haq
Minister of Agriculture and Irrigation, Water Resources, and Flood Control, Government of The People's Republic of Bangladesh

It is a great pleasure for me to be with you at this Conference on Wheat in Warm Area, Rice-Farming Systems. I understand that delegates from China, India, Nepal, Thailand, Vietnam, Myanmar, and Bangladesh are participating in this conference. Additionally, CIMMYT scientists from Mexico, Thailand, Nepal, and Bangladesh are also present. I welcome you all. I am sure the papers that will be presented and discussions that will follow will contribute towards improved and better production of wheat in nontraditional, warmer environments.

The Wheat Research Centre of the Bangladesh Agricultural Research Institute is located in the northern region of Bangladesh, on the eastern boarder of West Bengal of India and near the southern boarder of Nepal. This area represents the warmer and drier area of these countries. Wheat is the second most important cereal crop after rice in our country. In the early 1970s, wheat was cultivated only on 50,000 ha. Currently, 700,000 ha are covered with wheat. Production has increased from 115,000 to 1.5 million tons in this short period.

The major contribution made by the wheat breeders was selection of the high yielding variety Sonalika. Farmers of Nepal, India, Bangladesh, and some other countries of the region are well acquainted with this variety.

We expect that here at the Wheat Research Centre the distinguished scientists will have a chance to share experiences with each other concerning wheat breeding, growing wheat in different climates and environments as well as the latest seed technology that will help us in our "Grow More Food Program". A short tour of our wheat research plots and farmers' fields may give you an idea of the wheat crop's condition as well as the condition of our farmers. These farmers will be happy to show their crops and discuss their problems. I am aware of the growers' needs and their commitment to grow wheat. I would like to request the scientists from similar environments present at this conference to extend their technical help to our workers to find out the problems of spike sterility of wheat, premature yellowing of leaves, leaf spot disease, leaf rust, poor stands, heat-forced maturity, and delayed planting. Discussions here will surely benefit all of us and surely be profitable for each of the participating countries' wheat research programs.

Finally, I would like to thank BARI and CIMMYT as the co-hosts of this conference and the financial assistance of the United Nations Development Programme (UNDP). I wish you a happy stay here in Dinajpur during the next three days.

I now declare the conference open. Thank you all.

KEYNOTE

Wheat in Warmer Areas: An Overview of CIMMYT's Involvement

R.A. Fischer
Director, CIMMYT Wheat Program, El Batan, Mexico

Abstract

This paper reviews developments in wheat in warmer areas over the last decade or so during which CIMMYT has been explicitly involved in the UNDP-supported project. Also briefly reviewed is the general situation with respect to wheat in developing countries to provide a background against which to view warmer area progress and prospects. The CIMMYT/UNDP project demonstrated the potential of wheat in nontraditional climates and has accumulated a substantial body of research findings on wheat in these climates. As to the future, CIMMYT will maintain a modest commitment to selection for tolerance to hot conditions in the CIMMYT-Mexico breeding program. The Warmer Areas Wheat Screening Nursery (WAWSN) commenced in 1987 and the Heat Tolerance Wheat Yield Trial (HTWYT) started in 1992 will continue to be distributed upon request to collaborators in warmer areas. The greatest contributions in the future may come from spillovers from the CIMMYT-IRRI-national program research on the rice-wheat system under way in South Asia.

Introduction

This conference was foreshadowed within the United Nations Development Programme (UNDP) Global Project 90/001, entitled Increasing Wheat Production in Warmer and Stressed Environments, which supports CIMMYT's work on wheat in warmer, nontraditional areas and continues until mid-1993. Location of the conference in Bangladesh, on the fringe of the warmer areas as we define them, derives from a fortunate coincidence of interests. We needed to have a regional meeting to wrap up achievements under the UNDP project in Asia at the same time as CIMMYT's bilateral involvement in wheat in Bangladesh had been refinanced by the Canadian International Development Agency (CIDA) and as the Bangladesh Agricultural Research Institutes 's Wheat Research Centre here in Nashipur had become fully operational. One player is exiting the scene at the same time as others are taking over.

However, before discussing developments in wheat in warmer areas over the last decade or so during which CIMMYT has been explicitly involved in the subject, it is useful to review briefly the general situation with respect to wheat in developing countries. This provides a background against which to view warmer area progress and prospects.

Wheat in Developing Countries

Growth in wheat yields in developing countries slowed somewhat in the 1980s, dropping from 3.3%/year in the 1970s to 2.8%. Wheat area growth also slowed, to around 0.5%/year, meaning that production growth was about 3.3%/year in the 1980s. All rates are undoubtedly even lower now. Nevertheless, production records continue to be broken, with 220 million tons (mt) produced in developing countries in 1991-92, including 55 mt for India and almost 100 mt for China.

The last decade saw a continuation of the long-term downward trend in the real price of wheat on world export markets (Figure 1). This has been because of continuing production growth, along with export subsidies on the part of the European Community, USA, and Canada, combined with disruption in some major importing countries such as the former USSR and Iraq. Wheat is cheaper than ever before: the wheat consumer is the major beneficiary of this, but productivity gains have also generally benefitted wheat farmers.

Developing countries confronted by cheap wheat on world markets and under pressure to free up domestic markets and to balance budgets have moved to reduce input subsidies for grain production (e.g., fertilizer subsidies in India and Bangladesh) as well as bread price subsidies to consumers. The economic climate for wheat producers has thus become noticeably less attractive over the last decade. The possible gradual elimination of export subsidies should a new General Agreement on Tariffs and Trade (GATT) be negotiated and the growing restrictions that environmentalists seek to place on high-input agriculture in developed countries are the only bullish factors for developing country wheat producers in the short-term.

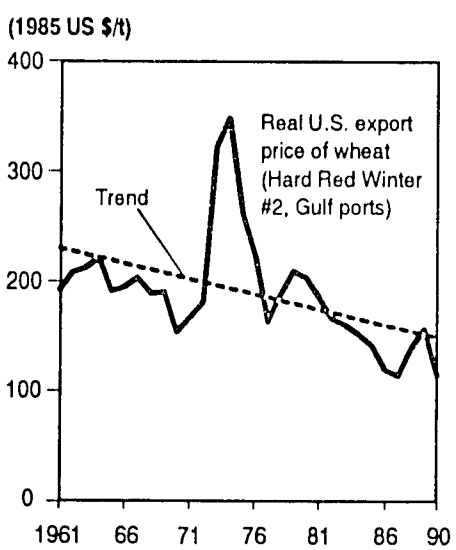

Figure 1. Evolution of real world wheat prices, 1961-90.

In the longer term, however, the world must meet growing wheat demand, preferably at reasonable prices, and definitely in a sustainable manner. Crosson and Anderson (1992), in a comprehensive look at the future for the World Bank, estimate that wheat demand in developing countries will grow at 3%/year for at least the next 15 years or so as a result of growing population and increased per capita income. This is faster than the estimated growth in rice demand (2.4%/year). They also examined ways by which this demand growth could be met. Since I agree with their reasoning, I will give some space to them here.

At the outset, Crosson and Anderson excluded the possibility of a major role for increased exports from the world's few wheat surplus countries. Also, they argued that growth in crop area through development of new arable lands and through intensification of cropping during seasons when the land is idle offer little prospect, particularly in Asia where new land resources are scarce. Similarly, growth in irrigation, a major source of production growth in the past, has slowed markedly: major potential irrigable lands in some regions may prove too expensive to develop. At the same time, the authors pointed to deterioration in the land resource for grain production, as existing area is irreversibly lost through salinization, overexploitation of water reserves, erosion, and urbanization.

Another potential negative factor in future agriculture lies with the climate and atmospheric resources for agriculture. Climate change as a result of greenhouse gas build-up is predicted to adversely affect developing countries in particular, although the increase in atmospheric CO_2 concentration, which largely drives this change, will tend to counter the negative effects on crop yield. Stratospheric ozone thinning and consequent increases in UV radiation levels may also become significant, although I would suggest that atmospheric pollution from industry and automobiles (e.g., ozone, SO_2, NO_2, heavy metals, and smoke) are likely to have a greater negative effect. Interestingly, Crosson and Anderson did not consider that shortage of fossil fuel would be a serious limitation on meeting the need for expanding grain production, largely because of the huge reserves still available globally.

Having concluded that new land and water resources for agriculture in developing countries offer little scope and that possible changes in climate and atmosphere could have negative implications, Crosson and Anderson pointed to new knowledge and technology as a major driving force needed for further production growth, and the only resource that can be expanded without limit. This can be considered in two parts, first application by farmers of existing technology, a closing of the station to farm yield gap, and second, generation of new technology through further research. The former will be an important element in the future, but in some situations at least (e.g., the Indian Punjab), we have already seen a closing of this gap in the last decade. Crosson and Anderson place their greatest emphasis on continuing investment in research to generate new technology. And that is what our conference is about this week.

Wheat Research in Developing Countries

Clearly, there is a need for continuing, or even increasing, investment in wheat research in developing countries. Given this imperative, it is interesting to ask what has happened to the strength of the national agricultural research systems (NARSs) in wheat over the last decade. The number of wheat scientists has continued to increase and has probably reached adequate levels; however, training and self-reliance are often inadequate. Besides, NARS budgets are generally more constrained than before and operational support frequently quite insufficient. Overall, CIMMYT estimates that the capabilities of NARS wheat programs have increased on average only marginally since the mid-1980s: some programs have gone ahead, notably that of our hosts Bangladesh, while others have slipped.

What about the role CIMMYT sees for itself in future wheat research? Our mission statement has evolved, although the NARSs and through them, the developing world wheat farmers, remain our clients. What is new is the explicit inclusion as objectives for CIMMYT, of resource-use efficiency and sustainability in wheat production. This change will lead us into more research on the natural resource issues, primarily soil ones, in major wheat cropping systems, as we see for example in the collaborative project we have with the International Rice Research Institute (IRRI) and NARSs on the rice-wheat cropping system in the Indo-Gangetic Plain. At the same time, CIMMYT is becoming involved in more strategic research as demanded by new problems and challenges facing our breeders, pathologists, and agronomists. Modest investment in molecular biology is one such move. These new activities are, however,

arising at a time when CIMMYT's real budget has contracted significantly. Some traditional activities will have to be shed in order to take up new ones unless a very substantial increase occurs in special project funding.

New elements outside of CIMMYT and of the NARSs will influence our wheat research in the future. Concern for the environment, expressed most clearly at the United Nations Conference on the Environment and Development (UNCED) in Rio de Janeiro last year, is one such element. While preservation of tropical rain forests and of biodiversity seem to be the major environmental preoccupations, agriculture and rural poverty in developing countries have inevitably come in for critical attention. Agricultural research with an environmental or sustainability perspective may be the only solution to many perceived environmental problems in agriculture and I believe that traditional agricultural research structures are largely appropriate and relevant to this challenge. However, we have a lot of work ahead to convince many outsiders and funders of research that this is the case, and at the least we must be seen to be environmentally sensitive and concerned with the natural resource base of our agriculture.

A second new element derives from the wave of privatization presently sweeping the world. For some administrators, this wave should be allowed to wash away publicly-funded research in agriculture. But many research issues in agriculture are not attractive to private researchers because money cannot be made out of solving the problem— breeding better wheats or solving environmental issues like soil erosion are examples. The very countries urging privatization often seem to forget the huge role played historically by public-funded agricultural research in their own rural development. Public research could become more efficient with proper reward systems, decentralized decision making and budgets, etc., but wholesale privatization must be resisted.

A third new element revolves around genetic resources, molecular biology, and intellectual property rights (IPR). The developed world is investing heavily in crop-related molecular biological research. Much of this investment is in the private sector where companies will rely on patenting and/or plant variety rights (PVR) to derive profit from successful innovations. Much uncertainty surrounds the IPR issue. Some observers warn that useful new technologies and even naturally occurring genes will be locked up by patents and available only at an improper price. Others have reacted by refusing to share germplasm. In the case of wheat, I believe these are over-reactions to an admittedly uncertain future. Much wheat molecular biology will remain in the public sector and CIMMYT and its backers intend to see that any useful new tools for breeders will be freely available. In addition, deals can be worked out with the private sector. In all of this, however, we must fiercely hold on to the policy of free exchange of wheat germplasm among all breeders and countries, a policy that has been so fruitful throughout the history of modern wheat breeding. Registered varieties can be accommodated in this scheme with proper acknowledgment and, if necessary, through transfer agreements. This is a new scenario, especially for CIMMYT and developing world breeders, but it should certainly not be seen as the end of our successful collaboration on wheat improvement.

Achievements of the UNDP Project

In the early 1980s, in response to demand from a number of nontraditional wheat countries, CIMMYT began paying special attention to wheat possibilities in these countries. This effort gathered momentum with the commencement of a UNDP-funded Global project to support CIMMYT's work specifically in this environment. The UNDP project has now run for 10 years, under various titles, and will end in June of this year. It is therefore appropriate to review briefly progress achieved by the project. Under this project, the CIMMYT Wheat Program had an agronomist and breeder and, finally only a breeder, based in Bangkok, and for much of the project, a breeder and an agronomist in Asuncion, Paraguay. Besides, for the last 2 years a physiologist in Mexico has been studying heat tolerance.

In a recent external review of the UNDP project (Persley et al. 1992), the project was complimented for demonstrating the potential of wheat in nontraditional climates, for accumulating a substantial body of research findings on wheat in these climates—see the most recent conference proceedings (Saunders 1991)—and for the collaboration with the strengthening of wheat researchers in relevant NARSs. This doesn't mean that wheat production has changed dramatically in all target countries, but in Paraguay, tropical Bolivia, and central Brazil, for example, there have been substantial increases. Also in Thailand, production has more than doubled from a tiny base, and Bangladesh is well positioned to resume rapid production growth. Finally Sudan, not nontraditional nor a specific target country, but nevertheless a country where wheat is grown under the world's hottest conditions, has recently shown dramatic wheat production increases. In assessing these changes in production, we should not lose sight of the impact of economic factors mentioned earlier. The economic changes amount to less incentive for wheat production in nontraditional areas of developing countries than 10 years ago.

On the biological front, a great deal has been achieved under the UNDP project. We now have a clear idea of the warmer area physical environments seen by wheat. We started considering well watered, usually irrigated, hot winter environments (> 17.5°C coolest month), divided into humid foliar disease-prone ones (like Bangladesh or Paraguay) and dry disease-free ones (like Sudan or most parts of Thailand). We soon learned that we needed to include hot water-stressed situations, where wheat grows largely on residual soil moisture (like central India, Myanmar, and parts of Thailand where winter irrigation is not possible). Wheat is one of the few food crops suited to this latter situation. Later the possible relevance of the project to the substantial areas of late-sown, heat-stressed irrigated wheat in temperate latitudes of Pakistan and northern India, such as wheat after long-cycle rice, became evident.

Results have accumulated to suggest that the temperature constraint in hot environments operates both via shortening the life cycle and interfering directly with physiological processes. Thus, a certain degree of lateness seems desirable for best performance, and on the physiological front, high membrane and photosynthetic thermostability are consistently associated with high yield in hot environments. Also, variation in canopy temperature seems to be related negatively to performance, a relationship that may reflect underlying physiological differences in thermostability. Potential selection criteria have been identified (Reynolds et al. 1992).

However when we look at the water-stressed hot environments, little progress in understanding adaptation or breeding for yield has been made in this harsh environment.

On the disease front, spot blotch (*Helminthosporium sativum*) has been identified as the number one threat to wheat in warm and hot humid areas, followed by leaf rust (*Puccinia recondita*), head scab (*Fusarium* spp.), stem rust (*P. graminis*), and tan spot (*H. tritici-repentis*) (Dubin and van Ginkel 1991). *Sclerotium rolfsii*, powdery mildew (*Erysiphe graminis*), and bacterial leaf streak (*Xanthomonas campestris*) are also constraints in certain areas. For stem rust, existing host plant resistance is still holding up, while in the case of leaf rust notable advances in understanding and exploitation of durable resistance have been made in the general CIMMYT program (Singh and Rajaram 1992). With the exception of *S. rolfsii*, sources of resistance have been located for the other diseases mentioned above, and more resistant advanced lines developed with a few varieties already released. Particularly promising is the progress in spot blotch and scab resistance, in both cases using predominantly Chinese sources of resistance. The prospect for much reduced losses through the host plant resistance mechanism looks good, but more research is needed to complete the job. In the meantime, seed dressing which is currently hardly practiced in nontraditional areas, offers good prospects for reducing losses due to certain of the above diseases, and fungicide spraying will continue as a widespread control measure in Brazil, Paraguay and tropical Bolivia.

At first, the management or agronomy of wheat in warmer areas received little attention under the UNDP project, but it soon became evident that understanding agronomic problems and improving agronomy offered much scope for increasing yield. One example arising from work, not by the UNDP project but by Global 2000, is the demonstration in the very hot conditions of Sudan that irrigated wheat yields of 5 and even 6 t/ha could be reached in farmers' fields if proper attention is given to soil, fertilizer, and water management. The warmer area wheat crop, since it develops and grows so rapidly, appears more sensitive to the proper timing of management interventions, and especially adequate nutrition. An example of a common nutritional problem in warmer areas and receiving attention in Thailand is that of boron-induced sterility: the effect appears greater under humid conditions, and genetic as well as agronomic solutions appear feasible (Mann and Rerkasem 1992). Besides, the high soil temperatures place a premium on agronomic techniques such as surface mulching, which can cool the young wheat plants. High soil temperatures also stimulate organic matter breakdown, and consequent soil degradation. For this and other reasons, reduced and zero tillage for wheat becomes even more desirable than in temperate latitudes.

Future Role of CIMMYT

Unfortunately, CIMMYT resources directed towards the warmer wheat areas of Southeast Asia and elsewhere will be substantially reduced after mid-1993. What will CIMMYT have to offer in the future? As a result of the UNDP project, there is a modest commitment to selection for tolerance to hot conditions in the CIMMYT-Mexico breeding program: the Warmer Areas Wheat Screening Nursery (WAWSN) commenced in 1987, and the Heat Tolerance Wheat Yield Trial (HTWYT) begun in 1992,

will continue to be distributed upon request to collaborators in warmer areas. But it is not entirely clear whether very effective selection for heat tolerance can be made in the Mexican program, which relies largely on late planting in northwestern Mexico to achieve this goal. Some results from Thailand suggest selecting segregating populations in Thailand gives faster progress. An alternative for CIMMYT in Mexico might be to use more intensively the higher temperature mid-altitude site of Tlaltizapan, the site used over the last 2 years of the UNDP project (Reynolds et al. 1992). Results indicate that performance at Tlaltizapan (January mean temperature of 20°C) correlates better with most hot sites round the world (e.g., Sudan) than does performance in late planting in Obregon. As more sophisticated analytical techniques are brought to bear on the results of CIMMYT's international trials (e.g., DeLacy et al. 1994), it is likely that test sites that group more closely with warmer area locations in client countries will be identified.

On the disease front, CIMMYT will continue to push for better resistance to *Helminthosporium* and *Fusarium*. We have good sites for screening in Mexico (Poza Rica and Toluca, respectively) and in certain collaborating NARSs (e.g., Brazil, Bangladesh). We have reasonable support to continue this work. In the case of *Helminthosporium*, a CIMMYT pathologist will be heading this thrust and we can anticipate progress although we need to understand better the question of pathogen variation. Special *Helminthosporium* and *Fusarium* nurseries will continue to be sent out. Bangladesh, Nepal, Brazil, and possibly tropical Bolivia will be key NARS collaborators. It is in the area of host plant resistance that CIMMYT expects that its new investments in molecular biology will give their first payoff. These techniques and products will be made available to NARSs.

Work by CIMMYT on wheat management in warmer areas barely got started before it had to be cut. The last effort under UNDP, the International Heat Stress Management Experiment (IHSME), is an ambitious attempt to elucidate principles and stimulate NARS research—it's a start but clearly not enough. The greatest contributions in the future may come from spillovers from CIMMYT-IRRI-NARSs collaborative research on the rice-wheat system under way in South Asia. The work will extend into Bangladesh, where in addition a bilateral project supports CIMMYT and NARS work on wheat management. Large challenges in technology transfer or extension face wheat agronomists in warmer nontraditional areas where farmers have little experience with the wheat crop.

Training and visiting scientist opportunities for wheat researchers from nontraditional wheat countries in Asia to come to Mexico will be considerably reduced, as will visits from CIMMYT wheat scientists to the region. Given the input in these areas over the last 10 years, with good support and organization, some of new wheat countries are fully capable of meeting the research needs of wheat into the future. Some are not. I urge wheat programs in the region to not spread themselves too thinly and scientists to collaborate as much as possible, for wheat areas and prospects are not enough to justify many separate wheat research initiatives. I also urge careful targeting of the most suited production zones and close collaboration with agricultural extension in these areas.

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Wheat Breeding Objectives In Nepal: The National Testing System and Recent Progress

R.N. Devkota
National Wheat Research Program, Bhairahawa, Nepal

Abstract

At present, foliar blight caused by Helminthosporium *spp. and post-anthesis heat and drought stresses are the major constraints in wheat production in Nepal, particularly in the terai belt. Specific breeding objectives and strategies to overcome such problems are discussed. Recent progress in terms of area and production of wheat and adoption of modern varieties to different agro-ecological regions of the country are also discussed.*

Introduction

Nepal can be divided into two distinct wheat production zones. One belt, containing the terai, tars, and lower valleys up to 600 masl, experiences a subtropical climate and has the most fertile soil. This is, by far, the best and the largest wheat production zone comprising the plains area of the terai running east-west in the extreme south as well as other areas of similar environment, i.e., inner terai, foothills, lower valleys, and river basins. The rice-wheat rotation is the predominant system of this zone. The second belt, containing the mid- and high hills and running east-west between the terai and the Himalayas, experiences a warm to cool temperate climate. The rice-wheat rotation is common in the mid-hills (600-1700 masl) while maize-wheat is common in the high hills (above 1700 masl).

Status of the wheat crop

Wheat, which ranks third in both area and production after rice and maize, contributes about 19% to the cereal area and 14% to the cereal production of the country. Spring wheat is planted during the winter season, however, the naturally existing agro-ecological diversity within the country does not totally preclude the possibility of cultivating some winter or facultative wheats in areas yet to be explored.

Wheat is a relatively new crop in the country. Until about 30 years ago, it was a traditional crop limited to hill areas in the mid- and far-western regions. However, after the introduction of Mexican photo-insensitive, semi-dwarf/dwarf, lodging-resistant, and input-responsive wheat genotypes from India during mid-1960s, wheat production was expanded to other nontraditional areas where a monocrop of rice was the only predominant practice. These photo-insensitive varieties are grown commercially even during the summer season in a wheat-potato rotation in some high mountain areas. Today, wheat is grown on approximately 600,000 ha and has become a vital component both in farms and kitchens of Nepalese farmers.

Objectives

National Wheat Research Program (NWRP)

During the early 1970s, increasing population pressure in the country compelled the government to realize that stronger research programs, particularly on major food crops (rice, maize, and wheat),

were required for increased production. The inception of the National Wheat Development Program (NWDP) in 1972 under the special Crop Commodity Development Program marked the beginning of an era of systematic and meaningful research and production programs on wheat. The original NWDP was recently renamed as the National Wheat Research Program (NWRP) with the following broad objectives:

- To increase wheat production and productivity in the country by coordinating a multi-disciplinary, multilocational, applied research and testing system on wheat at the national level.
- To identify the major wheat production constraints at the farm level, particularly under the rice-wheat system by conducting diagnostic surveys and then planning research programs accordingly both on crop improvement and crop management aspects.
- To produce and supply the required quantity of source seed (breeder seed) for further multiplication.
- To collaborate with various national and international agencies or institutions for wheat improvement.

Breeding and varietal development

Breeding objectives for the rice-wheat areas of the subcontinent include heat tolerance, earliness, leaf rust resistance, and in certain places *Helminthosporium* spp. resistance (Rajaram 1988). Wheat in Nepal, being grown predominantly under a rice-wheat system, does not differ much from the objectives mentioned above. However, in recent years, foliar blight caused by *Helminthosporium* spp. has posed a threat to wheat cultivation and now has priority over leaf rust in the breeding program. Specific objectives include the following.

Heat stress tolerance—Under the rice-wheat system, late planting of wheat is common, although optimum planting dates have been identified. The main reasons for this are the late harvest of rice varieties that have longer maturity durations and residual moisture in the rice field that makes land preparation impossible immediately after rice harvest. Usually under late planting, wheat is exposed to increasingly high temperatures combined with hot-westerly winds during grain-filling. Consequently, major yield components such as 1000-kernel weight, number of spikes per unit area, and number of grains per spike and hence grain yield are reduced. Therefore, breeding aimed at selecting genotypes with heat stress tolerance is one of the most vital objectives.

Disease resistance—Leaf rust (*Puccinia recondita*) and yellow or stripe rust (*P. striiformis*) resistance in the past was the main breeding objective. The program is now considered strong enough in this regard. However in recent years, foliar blights caused by *Helminthosporium* spp. have become important diseases. Two major species of *Helminthosporium*, i.e., *tritici-repentis* and *sativum*, are known to cause serious problems in wheat, particularly in the terai. Predominance of the two species, however, has changed over the years. The principal foliar blight organism in 1987-88 was *H. tritici-repentis* while in 1989-90, it was *H. sativum* (Dubin and Bimb 1991). Helminthosporium leaf blight combined with heat stress during grain-filling is causing significant yield losses. Yield loss assessment studies conducted at the Bhairahawa research station have shown losses as high as 27%. Similar studies elsewhere have shown that under the most favorable conditions yield loss can be up to

80% and under certain field conditions, it can go even up to 100% (Mehta 1985). Hence, breeding for foliar blight resistance is of high priority.

Drought stress tolerance—Significant areas of wheat in Nepal are either rainfed or partially irrigated as less than 25% of the sown area has assured water supplies. Winters are relatively dry and the wheat crop planted into the residual soil moisture from the late monsoon, in most cases, is exposed to post-anthesis moisture stress. This causes considerable yield loss and hence breeding and selection for drought stress tolerance is another important objective of high priority.

Breeding for appropriate maturity to fit in the rice-wheat pattern—Although this is more or less related to heat stress tolerance, breeding for the appropriate maturity class particularly for the rice-wheat pattern is important. In general, earliness and high yield potential in wheat seem to be negatively associated and hence genotypes that have medium maturity (usually judged on the basis of heading/flowering) with a high degree of heat tolerance are best suited for rice-wheat rotations (Rajaram 1988). Usually, early to very early maturing wheat varieties are planted in late December or early January following late maturing rice varieties. This may not be a good combination in itself as the early maturing wheat varieties, though they have potential to escape post-anthesis heat stress, they yield much lower. So the objectives should be to manipulate the maturities of both crops in order to find a suitable combination that realizes the optimum yield in both the cases. Breeding wheat varieties of medium maturity class and rice varieties of medium to early maturity class may provide a better combination to realize higher yields from the rice-wheat system.

National Testing System

The multidisciplinary and multilocational testing network, established for varietal development in wheat, is approached through a bi-directional system.

Direct introductions

Direct introductions of wheat materials of wider genetic base from abroad (CIMMYT/Mexico, CIMMYT Bangkok, national programs such as India and Pakistan) have helped to broaden the genetic variability in the program. Materials received every year in the form of segregating populations, observation/screening nurseries, and yield trials are tested and evaluated for adaptability and diseases under local environments. The best genotypes selected out of these nurseries are either directly released as cultivars for commercial cultivation or utilized as a parent for specific traits in the hybridization program.

Hybridization and varietal development

Hybridization was initiated during the late-1970s. A crossing block consisting of eight or nine groups of specific traits is planted on two or three dates of 10- to 15-day intervals to synchronize pollen availability. About 100-150 crosses between selected exotic and locally adapted Nepalese genotypes/cultivars of specific traits are made annually. Depending on the objectives, simple, double, triple, multiple, and back crosses are made.

Segregating populations are handled following a modified pedigree-bulk method (space planting and individual plant selection in F2 and F5, bulk selection in F3, F4, and F6) with heavy artificial disease epidemics. Shuttling is done with some of the stations located at higher altitudes.

Homozygous lines selected and bulked at later generations (F6 or F7) and other promising lines selected out of international observation/screening nurseries are included in multilocation screening nurseries, i.e., the Nepal Advanced Lines (irrigated) and Nepal Rainfed Nurseries. These are also subjected to heavy epidemic conditions. Level of resistance to various biotic and abiotic stresses, earliness, plant type, and grain type are the major traits considered during selection. Promising entries selected out of these nurseries form the basis for national yield trials.

National preliminary yield trials (Initial Evaluation Trials) and advanced yield trials (Coordinated Varietal Trials) are organized for both terai and hill conditions to have a complete yield assessment on a multilocation basis. These trials are conducted under different environments, i.e., optimum sowing date/rainfed, optimum sowing/irrigated, and late-sowing/irrigated. Stability of yield over environments, besides disease reaction and agronomic traits, have been the major thrusts of such trials.

Finally, before proposing for release, the best entries are extensively tested under farmers' field trials and in the varietal minikit program. Crop management trials are also conducted to determine adaptability to a wide range of cultural practices.

Breeding Strategies

Based on the objectives, specific breeding strategies have been executed to develop genotypes with resistance/tolerance to different diseases (foliar blight in particular), heat stress, drought stress, etc.

Helminthosporium leaf blight (HLB)
Breeding for HLB resistance has been given priority in present in the program. Starting in 1989, steady progress has been made with respect to HLB resistance. The following methodologies are being used:

- Screening and identification of resistant lines from different sources—The best materials identified so far come from China, Brazil, Zambia, and alien gene lines (mostly *Agropyron curvifolium* derivatives from the CIMMYT Wide Crosses Program).

- As a first step, some simple crosses are made using the identified resistant lines as well as other introduced genotypes.

- In the next step, these F1s are triple-crossed with the best adapted Nepalese cultivar (Nepal 297 in this case) so as to incorporate earliness and desirable types into the progenies. Nepal 297 (HD 2320) is as early as RR 21 (Sonalika) and on the basis of studies done at Bhairahawa, it also has a significant level of HLB resistance.

- Not much work regarding the genetics of resistance has been done so far, but it is presumed to be polygenic. Therefore, relatively larger populations (between 1500-2000 in the F2) have been maintained to provide better chances for isolating tolerant/resistant plants from the segregating populations. Moderate selection pressure will be exerted in earlier generations (F2-F4). F3 and F4 generations will be handled in bulks and exposed to late planting and hence to post-anthesis heat stress. Grain plumpness and HLB resistance will be the major selection criteria.

- Apart from the crosses made at the NWRP, Bhairahawa, some F2 segregating populations specifically bred for warmer areas are also received regularly from CIMMYT. Shuttling with CIMMYT is underway. A little over 2500 F3 progenies and about 600 F4 progenies bred for ME5 (tropical environment) were received from CIMMYT, Mexico during 1991. These progenies were planted at NWRP, Bhairahawa in late December. Foliar blight incidence, earliness, and grain plumpness were considered during selection. Part of the seed of the best progenies selected were again sent back to CIMMYT, Mexico and CIMMYT, Bangkok in 1992.

Rusts

Since the inception of the NWRP, a constant endeavor to breed lines resistant to the two important rust diseases (*P. recondita* and *P. striiformis*) has greatly minimized their severity in the country. Nevertheless, hybridization, screening, and selection against these two rusts are ongoing. As both leaf and stripe rusts are severe in the hilly regions, "shuttle breeding" initiated during the mid-1980s still continues with the stations located at the mid- and high-hill areas, i.e., Pakhribas (1750 masl), Lumle (1700 masl), Jumla (2200 masl), and Khumaltar (1360 masl). In addition, some specific F2 populations of spring x winter crosses and other important nurseries received regularly from CIMMYT have increased the variability in the germplasm for selection.

Loose smut

Although not a problem of the warmer areas, loose smut of wheat (*Ustilago tritici*) assumes importance in the hilly regions. A small backcross program particularly on RR21 and Nepal 297 has been initiated.

Heat stress

Late-maturing wheat varieties usually suffer from heat stress, while early-maturing ones escape to some extent. Regardless of what particular attribute, the crosses have been made for HLB, or rust, or loose smut, heat, drought, etc., earliness is one of the most vital characters to incorporate into all progenies. The strategy is to use at least one parent with an early-maturing background in the crosses made for any specific objective. In all segregating populations, screening nurseries, and field trials, earliness as well as grain plumpness are major characters considered during selection, particularly for the warmer rice-wheat areas. The Warmer Area Wheat Screening Nursery (WAWSN) from CIMMYT, Mexico and the Hot Climate Wheat Screening Nursery (HCWSN) from CIMMYT, Bangkok also provide material for selection against heat stress.

Drought stress

Drought stress tolerance has been observed in some genotypes such as Triveni (HD2189), Nepal 251 (HUW 251), C306, and BL 1249. Some of the local landraces collected mainly from the mid- and far-western hills are also observed to have a high degree of drought stress tolerance. Compared to improved genotypes, even germination has been observed to be faster in the local landraces. Utilizing these improved and local sources, a crossing program has already been started. In addition, specific F2 populations for semi-arid areas, the Semi-Arid Wheat Screening Nursery (SAWSN) and the Semi-Arid Wheat Yield Nursery (SAWYT) received regularly from CIMMYT are screened and genotypes with better tolerance are selected and advanced for multilocation testing. About 40% of the wheat breeding and varietal development activities in the program are focused on drought tolerance.

Recent Progress

The impact of wheat research, particularly the breeding program, can be clearly measured in terms of increased area and production, development, dissemination of high yielding improved varieties, self-sufficiency in quality seed production, and technical collaboration with wheat programs in neighboring countries and other international institutions.

Area and production

One of the most spectacular impacts of wheat research has been the rapid extension in wheat area and production over the last 25-30 years, particularly during the period after the inception of the NWRP (Figure 1). From a mere 118,000 ha in 1965-66 (when improved varieties were first introduced), the area sown to wheat has gone up to just over 600,000 ha in 1989-90, the highest so far. Simultaneously, the total production during the same period increased tremendously from 147,000 t to just over 850,000 t, also the highest so far. However, yield has increased much slower than expected from around 1 to 1.4 t/ha during the same period.

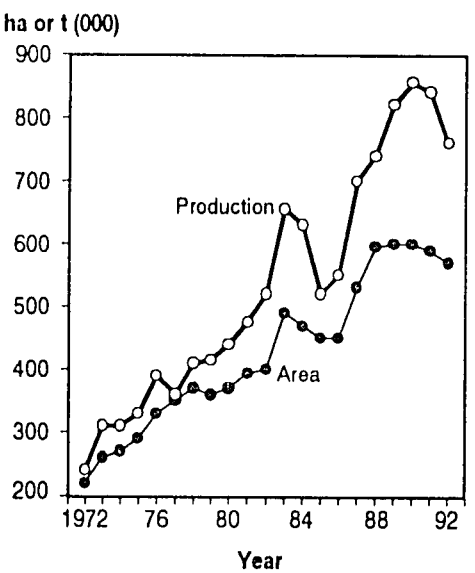

Figure 1. Wheat area and production trends in Nepal, 1972-92.

Development and dissemination of improved varieties

Lerma 52, a tall wheat, was released in the early 1960s for the hills. However, after introduction of the Mexican wheats from India in the mid-1960s, a series of cultivars—Pitic 62, Lerma Rojo 64, Kalyansona, and RR 21 (Sonalika), the latter possessing extremely wide adaptation—were recommended in the late 1960s. Since the inception of the NWRP in 1972, 14 more new cultivars have been released for various agro-ecological regions (Table 1). Some of the cultivars such as UP 262, Triveni, Vinayak, Nepal 297, Nepal 251, and BL 1022 have become quite popular in the terai. RR 21 is no longer a predominant variety in the terai as its yield is decreasing due to its susceptibility to leaf rust and HLB. The annual rate of yield decline in this particular variety has been estimated to be 6.8% over the past 15 years (Morris et al. 1992). As a result of this, UP 262 released in 1978 has replaced RR 21 in many areas. Nepal 297 released in 1985 has become increasingly popular and is being adopted very rapidly. It is as early as RR21 and therefore suitable for the rice-wheat pattern, has larger grains, and has resistances to major diseases (rusts and HLB). Farmers utilize Vinayak for late-sowing conditions, while Triveni is being adopted under rainfed conditions. Nepal 251, with wide adaptation, performs comparatively well under suboptimal conditions and performs even better when conditions are optimal.

Varieties for the hills are lacking. After the recommendation of Lerma Rojo 64 and RR 21 during the late-1960s, it took more than 15 years for the NWRP to develop and release its first two varieties for the hills. Consequently, RR 21, despite its

susceptibility to various diseases, is still the predominant wheat variety in the hills. However, the successful releases of Annapurna-1 and Annapurna-2 in 1988 and Annapurna-3 in 1991 have provided alternatives to RR 21. Farmers are adopting these new releases mainly because of their higher yield and better disease resistance.

With the successive release of new cultivars, the rate of adoption of these cultivars has also increased. Well over 90% of the terai belt is now sown to improved varieties (Morris et al. 1992). One of the reasons for quicker adoption of the newer cultivars is presumed to be the effective outreach activities organized by NWRP in the form of on-farm trials and the varietal minikit program. The latter has been one of the most effective tools for dissemination of newly released cultivars.

Seed production

NWRP has the responsibility of producing the required quantity of breeders' seed. Through the substantial emphasis on maintenance breeding, following "head to row" progeny, high quality breeder seed of different varieties is produced every year depending on demand. This seed is utilized by various farms/stations to produce foundation seed required by the Agriculture Input Corporation, which handles further multiplication and distribution of certified seed. As a result, self-sufficiency in wheat seed production has been achieved and no more seed is imported from abroad.

International collaboration

Technical collaboration, mainly in terms of germplasm exchange with wheat programs of neighboring countries such as AICWIP (India), PARC (Pakistan), and international

Table 1. Wheat varieties released in Nepal after the start of the National Wheat Development Program in 1972.

Variety	Cross	Origin	Year of release	Recommended agroecological region
NL30	HD832-5-5-0Y/BB	India	1975	Western terai
HD 1982	E5557/HD845	India	1975	Western and midwestern terai
UP 262	S 308/Bajio 66	India	1978	Terai
Lumbini	E 4871/Pj 62	India	1981	Terai
Triveni	HD 1963/HD 1931	India	1982	Terai
Vinayak	Unknown	India	1983	Terai
Siddhartha	HD 2902/HD 1962 //E4870/K 65	India	1983	Terai
Vaskar	Tzpp/P1/TC	Mexico	1983	Midwestern terai
Nepal 297	HD 2137/HD 2186 //HD 2160	India	1985	Terai
Nepal 251	WH147/HD2160// WH147	India	1988	Terai
Annapurna-1	Kyz'S'/Buho// Kal/Bb	Mexico	1988	Hills
Annapurna-2	Npo/Tob'S'// 8156/3/Kal/Bb	India	1988	Hills
Annapurna-3	Kvz'S'/Buho//Kal/Bb	Mexico	1991	Eastern and western hills
BL 1022	CM 58794-1B-2B-5N-1B-0B	Nepal	1991	Western, midwestern, and far-western terai

institutions like CIMMYT and the International Center for Agricultural Research in the Dry Areas (ICARDA), has been active since NWRP's inception. This has been further strengthened after the establishment of the CIMMYT regional office for South Asia in Kathmandu in 1985. Shuttle breeding currently underway with CIMMYT (Mexico) is one of the best examples of collaborative research.

Other benefits

The returns to wheat research in Nepal have been studied recently by Morris et al. (1992). The overall benefits in terms of internal rate of return (IRR) from wheat research as a whole during the 1960-1990 period, is estimated to be 75%. IRR from wheat breeding alone is still higher (84%). The average annual rate of increase of potential yield through the development of new varieties released since 1978 has been estimated at 1.25% per year (Figure 2). This may be interpreted as the potential future rate of national yield gains as the newer varieties become more widely adapted.

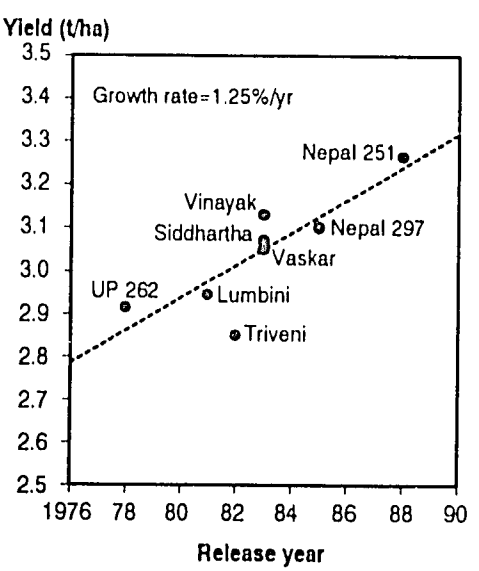

Figure 2. Yield gains in wheat varieties released in Nepal, 1978-88 (Source: Morris et al. 1992).

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Questions/Discussion

Mr. Devkota was asked about a possible rice-wheat conflict by selecting for medium-maturity wheat while recommending that rice varieties should be selected for shorter maturity. He explained the short maturity wheats do not yield sufficiently well in his experience. On the other hand, late-maturing lines suffer extreme heat stress at the end of the growing season. Therefore, he is concentrating on medium maturity. In the case of rice, the relative yield loss in going towards earlier varieties is less than the loss when earlier wheat varieties are selected (compared to medium maturities). He feels confident of overall rice-wheat yield benefit from the system utilizing early to medium maturity rice followed by medium maturity wheat.

Wheat Breeding Objectives, Yield Testing System, and Recent Progress in Southern China

S. Changjian
Guangdong Academy of Agricultural Sciences, Guangzhou, Peoples Republic of China

Abstract
Southern China, comprising the provinces of Guangdong, Guangxi, Fujian, and Hainan, is one of 10 agroecological wheat production zones in the country. It is climatically tropical to subtropical. Wheat breeding objectives include early maturity, high yield, good quality, and resistance to diseases, lodging, and sprouting. Since 1972, promising wheat lines have undergone multi-location testing throughout the four provinces. Twenty-eight varieties, which have been released from the program, have increased production in the region by 600,000 t. Lines have been introduced from CIMMYT, Italy, and other wheat areas in China.

Introduction

China's wheat area is divided into 10 major agroecological zones differing in temperature, rainfall, wheat growing duration, and cropping systems.

Southern China, comprising the provinces of Guangdong, Guangxi, Fujian, and Hainan, is situated between 104° 5'E and 122° E longitude and between 17° 5'N and 28° 2'N latitude. The topography of the three mainland provinces slopes from northwest to southeast and hills, generally less than 500 masl cover 90% of the area. There are wide sedimentary plains in the lower reaches of the rivers. The Wuyi and Nanling Mountains in the north prevent cold air from moving southward. In addition, there is a warm, humid ocean airflow from the southeast. In January, the coolest month, the average temperature ranges between 6 and 19°C, gradually increasing from north to south. During the wheat growing season, 250 to 650 mm of rainfall are received, with about 600 to 900 hours of sunshine during that period. Only spring wheats are grown on the red soils and paddy soils derived from the red soils. Early-maturing varieties are required on the coastal plains while in the inland hills, types with a longer life cycle are more adapted.

Temperatures are high and relative humidity is low during the early growth stages, resulting in poor plant development and premature heading. Frosts occur during flowering and continual rain and low light intensity during grain-filling result in epidemics of leaf rust, powdery mildew, head scab, and septoria.

Breeding Objectives

Early maturity

The most common crop rotation in the area is rice-rice-wheat. Only 110 to 140 days are available for the growth of the wheat crop.

High yield

While the vegetative period is short due to high temperatures, the period for spike development is relatively long (about 30 days for the early varieties and 40-50 days for the longer growth duration types),

resulting in large spikes. The grain-filling period is 50-60 days resulting in large grains (1000-grain weight greater than 42 g). Selection emphasis is placed on large spikes and grains. Mean yield of released varieties is 4-5t/ha.

Resistance to high humidity

The rainfall during the wheat crop is not well distributed. About 15-20% falls during the seedling stage, 20-30% falls between tillering to flowering, and the remaining 50% falls during grain-filling. Selected lines must have some degree of waterlogging tolerance since waterlogging, particularly on the paddy soils, is common. In addition, the humid conditions during grain-filling can result in grains germinating in the ear. Sprouting resistance is therefore important.

Disease resistance

The warm, humid climate after flowering is ideal for the disease development, particularly leaf and stem rust, powdery mildew, scab, and septoria. These can reduce yields by up to 30%. Starting in the 1970s, lines from CIMMYT (beginning with Potam S70, Inia 66, Tanori F70, etc.), and Italy (Funo, Abbondanza) have been introduced and varieties are now available with good resistance to leaf and stem rust and septoria, and reasonable resistance to powdery mildew. However, progress in selection for scab resistance has been less successful.

Quality

The climatic conditions during grain-filling are not conducive to the production of high quality grain. However, large differences have been found between lines in grain quality and great efforts have been made to ensure that the quality of the released varieties is as high as possible.

Multi-Location Testing

To ensure that the released varieties are widely adapted and have stable yield, multi-location testing is essential. The Southern China Wheat Yield Testing System (presided over by the Guangdong Academy of Agricultural Sciences) was established in 1972 for the testing and promotion of new wheat varieties. Sites for the experiments are selected to represent all wheat agro-environments in southern China. Up to 15 sites have been used per year. Varieties selected for the yield trials are those which have proved best in the regional yield trials in Guangdong Province.

The multi-location testing system is a vehicle for the exchange of germplasm and academic exchange, and provides an opportunity for the scientists to see the reaction of their varieties in other locations.

During the last 20 years, 90 lines, including 47 early and 43 mid-maturing lines, have been tested in these experiments. Twenty-eight lines were promoted to recommended varieties. Today these varieties cover an area of about 4 million hectares and have resulted in an increase in production of 600,000 tons. The most popular varieties resulting from the program are Yeomay 6148, Yeomay 6024, Anmay, and Longxi 35, all of which have high yield, early maturity, strong disease resistance, and resistance to high temperature and humidity.

Wheat Breeding Objectives and the Provincial Yield Testing System in Guangxi, China

Huang Jiayong and Zhu Guojin
Guangxi Maize Research Institute, Nanning, Guangxi, China

Abstract
Wheat growing in the double cropping system of rice in Guangxi Zhang Autonomous Region of southern China is described. Due to the conditions being warm, humid, and cloudy, the breeding objectives are for short stature, early maturity, powdery mildew and Bipolaris sorokiniana *resistance (or tolerance), and high yield with large spikes and grain. It is emphasized that the female parent in a cross should be a disease-resistant line and the male, a high yielding one, in order for a high proportion of the progeny to have the disease resistance. The provincial testing system in Guangxi is also outlined.*

Introduction

Guangxi is situated in Southern China between 21°54' and 26°30'N latitude and 104°30'-112°5'E longitude. The climate is subtropical. The largest area sown to wheat was 300,000 hectares in 1956, but in recent years about 30,000 to 40,000 hectares have been grown annually, distributed through Yulin, Wuzhou, Liuzhou, Heqi, and Baise prefectures, in a rice-rice-wheat cropping system.

The growing season for wheat is from November to March. Mean temperatures for November and December are 17.5 and 15.0°C respectively; the total rainfall for these months is 47.5 mm with 273 hours of sunshine. Under these conditions, the plant has rapid seedling growth, early differentiation, a short vegetative period and a low number of ear-bearing tillers.

January is the coldest month (about 6°C) and temperatures increase again during February (9°C) and March (14°C). During January and February, about 20-30 days of drizzle can be expected with a resultant reduction in radiation. These conditions are ideal for the development of powdery mildew which is one of the major limiting factors for wheat production in Guangxi.

Breeding Objectives

More than 100 wheat varieties have been intensively studied to find the important yield determining factors. The results showed the following were the major factors, in descending order: diseases, length of the growing cycle, grains/spike, grain weight per spike, grain sprouting in the spike, plant height, leaf length, and tillering ability.

Consequently, our major breeding objectives are powdery mildew resistance, earlier maturity, and large spikes and grain. Secondary selection criteria are sprouting resistance, shorter stature, and shorter upright leaves. Other factors, i.e., tillering ability, plant shape, and leaf color, are not considered important for Guangxi.

Breeding for powdery mildew resistance has been conducted for many years. We believe that wheat varieties with powdery mildew resistance and good agronomic characteristics can be produced by complex crossing with more parents and gene

recombination. We have found the following crossing patterns to be effective: Q/A//B or Q/A//B/A, where Q = the disease-resistant line and A,B = resistant or slightly sensitive varieties with good agronomic characteristics.

We have analyzed the progeny from 25 crosses and have found that if the female is disease-resistant, whatever the male is, the progeny have a higher frequency of resistance than if the male is the resistant line, indicating that female selection is the key to powdery mildew resistance breeding.

There are two types of resistance to powdery mildew:

- A high resistance or immunity which is controlled by a major gene. This resistance breaks down easily because there are many physiologic races and high variability within the pathogen.

  "Slow mildewing" resistance, which is controlled by a major gene plus minor genes, or only by minor genes. This resistance is more durable.

Therefore, we select "slow mildewing" types with good agronomic characteristics. Varieties of this type include Guimai No. 1, No. 2, and No. 3. On these varieties, the disease does not appear before heading and only affects the lower half of the plant. These are now grown over very large areas and have yielded 20-30% higher than the older varieties, have earlier maturity and consequently better fit the rice farming system. In addition, they are more responsive to improvements in management.

Grain yield must be the ultimate objective for both breeders and farmers. An analysis of the Guangxi Wheat Regional Test from 1975 to 1980 has been conducted to determine important yield determining characters over time and location. The number of heads per unit area, grain number per head, and grain size all showed high correlations (r>0.7) with grain yield. There was a poor relationship (r=0.117) between heads/plant and yield.

The Provincial Testing System

Any promising line must pass a series of tests consisting of pre-testing, provincial regional trials, demonstrations, and appraisal by experts before release. All this testing work is financed by the provincial seed company, but conducted by the wheat breeding institutions.

After pre-testing for 1-2 years, a promising line will enter the Guangxi Regional Test for a three-year cycle at five-six locations, each of which is the responsibility of the local agricultural research station. All locations are sown to the same specifications and managed in the same manner, except that planting date may be varied slightly (always before mid-November) depending on the second rice crop harvest date in that location. All seed comes from the same source.

In this way, the adaptability and yield potential of the entries in different ecological conditions can be assessed and specific adaptabilities can be determined. The testing system provides a dependable base for the recommendations for release of a new variety.

Each year, the data from all locations are centrally analyzed. The varieties are judged on yield, stability, and agronomic characteristics. The selected lines are demonstrated in farmers' fields in comparison with existing varieties.

Finally, all data are submitted to the Guangxi Crop Seed Examining and Approving Committee for evaluation and varietal approval.

Wheat Production Zones and Breeding Objectives in Yunnan Province, China

Yang Yan-hua
Cereals Crop Institute of Yunnan Academy of Agricultural Sciences, Kunming, Peoples Republic of China

Abstract

This paper discusses the varied conditions for wheat-growing in Yunnan Province, and divides the wheat production into three great growing districts, on the basis of natural ecological conditions and historical growing habits. The conditions and problems existing in various growing districts are introduced and used to determine the breeding objectives.

Introduction

Yunnan Province lies in the southwestern part of the People's Republic of China and has terrain increasing in altitude from the northwest (76 masl) to the southwest (6740 masl). The total area of the province is 383,000 km^2, which are composed of 84% mountains, 10% plateaus, and 6% basins and river valleys. Due to the highly variable topography, the province has many climatic types—from cold-temperate, through temperate to subtropical and tropical zones. It is said of Yunnan Province that "there are four seasons within one mountain, and the weather here is different from that 5 km away".

The cultivable area is 2.8 million hectares, on which wheat ranks third in area and production after rice and maize and is grown in areas with altitudes between 1600 and 2000 masl.

In 1949, the wheat growing area was only 181,000 ha with a mean yield of 1065 kg/ha. By 1992, this had increased to 593,000 ha while yields had nearly doubled (2049 kg/ha).

During the long period over which wheat production has developed, divisions in the wheat area have occurred due to major climatic differences and growing systems. Among the climatic conditions affecting the divisions, rainfall and temperature are the most important.

Farming Systems

The annual rainfall over most of Yunnan Province is about 1000 mm with uneven distribution. More than 85% of the total falls from May to October. During the wheat growing season, from the last 10 days of September to the beginning of June, average rainfall amounts to 300 mm with January, February, and March being particularly dry with only 20-30 mm of rainfall. The low rainfall, combined with high evapo-transpiration caused by strong winds, results in drought conditions in winter and spring in nearly all years.

Wheat production can be divided into two main types on the basis of water availability:

- Dimai, which refers to rainfed (dryland) wheat, is distributed at the upper altitudes with maize as the preceding crop, and constitutes two thirds of the total wheat area of Yunnan Province.

- Tianmai, which is fully irrigated wheat sown following rice, utilizes spring or facultative varieties. Fertilizer application rates are higher in this production system and Tianmai produces 60% of the total wheat production of the province.

The wheat growing areas can be divided mainly on the basis of the temperature effects on the wheat growth cycle:

- Late-maturity district in the north,
- Medium-maturity district of the central areas, and
- Early-maturity district in the south.

In the central areas, the length of the wheat life cycle is variable due to the topography and climate differences and so the medium maturity district is further subdivided into two smaller regions, the late and early-medium maturity areas (Figure 1).

The Late-Maturity District

This district lies between 26 and 29° north latitude and contains 17 counties of northeast and northwest Yunnan, with a cold-temperate to temperate climate. It is characterized by adequate sunshine, high radiation, and large diurnal temperature fluctuations. The rainfall during the wheat crop is 190-440 mm and frosts can occur from mid-October to early May. The mean temperature is 10°C and wheat sown in mid-November matures in mid-June. There are only 20,000 hectares of rice-wheat in this district.

Climatic conditions here are such that high yields could be achieved although currently the yields are low due to poor management and low fertilizer rates.

As temperatures remain low from the beginning of winter until early spring, the spike differentiation stage is long, resulting in the formation of large spikes. The sunshine, radiation, and the large diurnal temperature fluctuations are conducive to the accumulation of dry matter. In 1977,

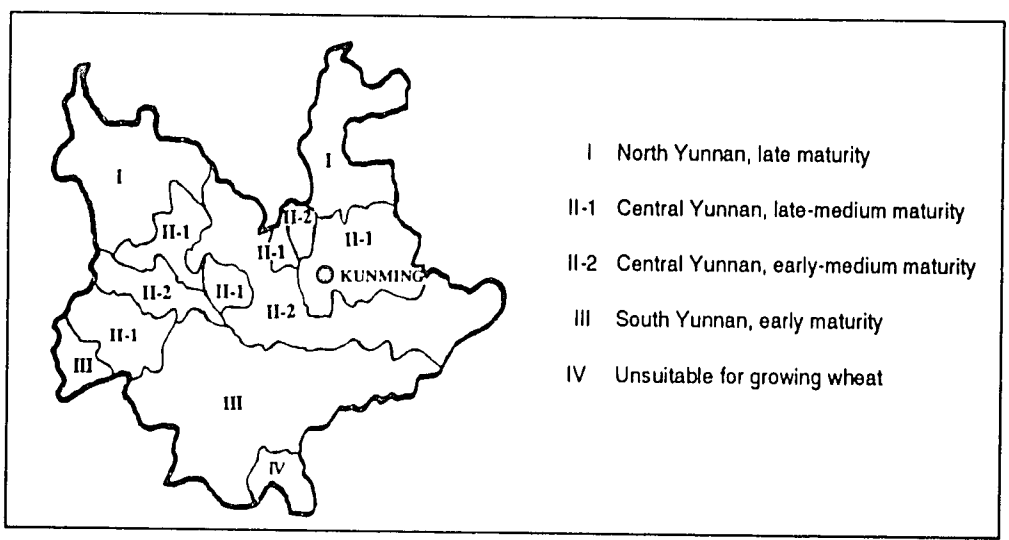

Figure 1. Wheat-growing areas of Yunnan Province, China.

"Fongmai", a variety grown in Lijiang County, set a record wheat yield for China of 12.38 t/ha.

In this district, the low temperature causes wheat to have a long life cycle (about 210 days), which causes conflicts with the crops grown before or following wheat. Thus, a breeding objective is to produce earlier maturing varieties that grow slowly in the vegetative stage but develop rapidly in later stages.

In addition, stripe rust (*Puccinia striiformis*) is a serious problem due to the abundant rainfall. Rainfall during harvest also causes sprouting in the ear. Thus, the breeding objective in this district is to select earlier maturity facultative lines with cold tolerance, stripe rust resistance, and a long dormancy period to minimize sprouting in the spike.

The Medium-Maturity District

Most of this district is between 24 and 26° north latitude, although some high-elevation south of 24° and some low elevation areas north of 26° latitude are also included. It contains 64 counties among which are Kunming, Chuxiong, Dali, Baoshan, Yuxi, and Qujing.

The climate is temperate with adequate sunshine and a frost period of 110-165 days (compared to 210 days in the Late-Maturity District), or even less in some river valleys. Although drought in winter and spring is severe, this district is the main crop production area in Yunnan as a large proportion of it consists of fertile basins with irrigation facilities. The rice-wheat production system occupies 150,000 hectares out of the total wheat area of 385,000 hectares.

The late-medium maturity region is at altitudes of 1900 m or more where the average temperature during the crop is about 11°C, and the life cycle of wheat is 185-200 days. Areas with an elevation of about 1600 m, an average temperature of about 13°C and a crop cycle of 160-185 days are included in the early-medium maturity region.

The temperatures are conducive to good spike development, but not so low as to excessively prolong the wheat life cycle which makes this district the most suitable for growing wheat in Yunnan Province. The farming techniques are advanced, irrigation can be controlled, and fertilizers are available such that their application can be made at the correct time according to the growth stages.

Consequently, yields are high and in the counties of Kunming, Yuxi, and Dali, average yield is now 6 t/ha. Wheat (rainfed and irrigated) in this region constitutes 65% of the total sown area in Yunnan but contributes 75% of the production.

Drought and frost are the climatic factors that most influence the yield level. In winter and spring, drought is severe and timely irrigation and fertilizer topdressing have an important effect in increasing yield.

On the other hand, the heavy frosts in January and February or the late frosts in March and April can severely restrict yields. In addition, the climate here promotes diseases (stripe rust, leaf rust, powdery mildew) and aphids.

In general, the breeding objectives in this district are to obtain relatively early maturing, disease resistant spring varieties of high yield potential. As this district has a long history of wheat production over a

large area, varieties grown here have tended to lose their rust resistance rapidly. Breeders should therefore select varieties with a range of resistance sources to check the spread of rust.

The Early-Maturity District

The majority of this district is south of 25°N latitude and includes 46 counties such as Dehong, Linchang, Simao, and Xishuangbanna. Temperatures are high (mean temperatures range from 12.5 to 16.8°C depending on location) and there is a short frost season or none at all.

In the southeast, the Karst mountainous regions have highly permeable soils where the topsoil moisture is rapidly depleted in rainfed crops. In the southwest of this district, there is adequate rainfall, friable soils with relatively high temperatures.

The rice-wheat cropping system has been increasing rapidly in recent years in this district. At present, out of a total wheat area of about 120,000 ha, 35,000 are rice-wheat, mostly in the southwest. The wheat growing cycle is short, about 160 days.

As wheat production is a relatively recent development in this district, there is a lack of farmer experience with the crop management practices for high yields. Fertilizers are generally used less than in other parts of Yunnan and the varieties have been introduced from other (cooler) parts of the province and consequently yields are low.

However, climatic conditions (temperature, rainfall, short frost season) are suitable for wheat and this district offers opportunities for further wheat area expansion.

In breeding, spring types with stem and stripe rust resistance, good quality and high yield are the objectives.

Conclusions

Most districts of Yunnan Province have climates suitable for wheat production, although each major districts has specific varietal requirements and management techniques.

In order to offer the farmers continually improved varieties, breeding centers have been established in all major wheat growing districts. Cooperation by groups throughout the province has strengthened the breeding and selection programs to produce new wheat varieties to progressively increase wheat production throughout the province.

Questions/Discussion

Mrs. Yang, in response to a question regarding sprouting in the ear, explained that in Yunnan Province, the wheat crop matures in May while the rainy season commences in mid-April. Consequently, sprouting is a very serious problem. In order to solve this, seed dormancy is used as an important selection criterion in the breeding program.

Suitable Wheat Varieties in the Rice-Based Cropping Systems in Northern Vietnam

Minh Ta Duy and Long Tran Dinh
Vietnam Agricultural Science Institute, Vandien, Hanoi, Vietnam

Abstract
Two triple cropping systems—late spring rice followed by early rainfed rice then wheat or full spring rice followed by early rainfed rice and wheat—have been proposed as the most convenient patterns to include wheat in the rice-based cropping systems in northern Vietnam. Five wheat varieties have been found suitable for these rotations and another 10 advanced lines are under test.

The Potential for Wheat

Vietnam imports between 100,000 and 300,000 t of wheat flour annually. There is no commercial wheat production in the country although in the Trungkhanh District in Caobang Province, there is a small traditional area (30-35 ha/year) where wheat has been planted after rice for many years with an old local variety yielding about 1.0 t/ha.

There is currently an interest in growing wheat in the northern mountainous areas as an alternative to opium and to decrease the food deficiency of these areas. In addition, there is considered to be substantial potential for growing wheat in the Red River Plain.

The temperatures from November to March are relatively suitable for wheat, but high relative humidity, particularly in the Red River Plain (Figure 1) promotes foliar disease development. Rainfall during the wheat growing season is low, varying between 0 and 100 mm.

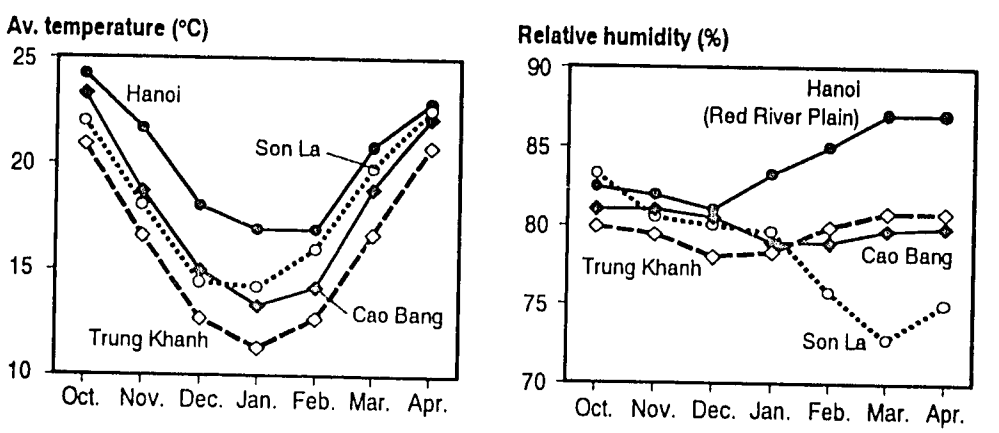

Figure 1. Average temperature and relative humidity data for northern Vietnam.

Cropping Systems

The cropping systems in northern Vietnam are generally rice-rice-upland crop, but the type of rice crops vary between locations, due mainly to the elevation (deep-water to highland areas) and climate. While nominally a three-crop system, only about 30% of the area (1.7 million hectares) are sown annually to the third crop.

For wheat to be most conveniently fitted into the cropping pattern, rice should be harvested early (end of September) or transplanted late (beginning of March). There are four proposed cropping systems into which wheat may fit (Figure 2) of which options 6 and 7 are preferred.

Thirteen long-maturation rice varieties are released as full spring or full rainfed season varieties with yield potentials of 5-7 t/ha. Twelve short-maturity rices (with yield potentials of 4.5-6.8 t/ha) are available for late spring or early rainfed seasons.

Wheat Diseases

Diseases are a significant problem for wheat production in northern Vietnam. Planting date studies on the Red River Plain have shown that when seeded early (October 1), wheat can escape three diseases (leaf rust, powdery mildew, and head scab). Plantings in early November are attacked by leaf rust (*Puccina recondita*) and powdery mildew (*Erysiphe graminis*), but escape head scab (*Fusarium* spp.), while late plantings (mid-December) suffer heavily from Helminthosporium leaf blight, leaf rust, powdery mildew, and head scab. However, late planting in the northern provinces (Cao Bang in the northeast and Son La in the northwest) are only slightly attacked by leaf blight and powdery mildew, but leaf rust and head scab cause more damage.

There has been some progress in selecting for disease resistance among nearly 1900 introductions from the CIMMYT (Mexico, Bangkok) and CIMMYT/ICARDA

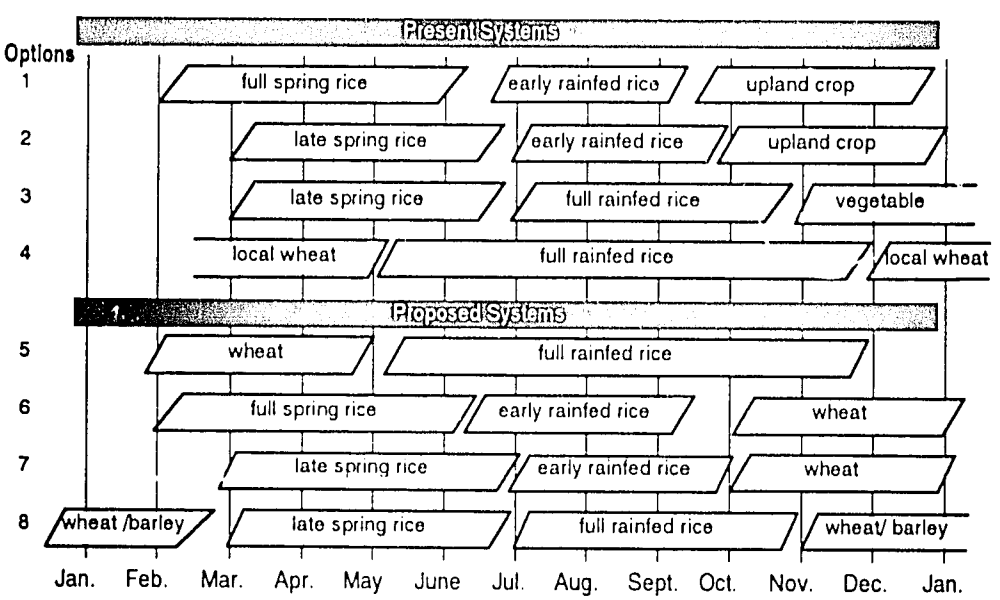

Figure 2. Present and proposed cropping systems in northern Vietnam.

programs. Good leaf blight tolerance has been identified in 162 lines, some of which also have leaf rust resistance and moderate resistance to powdery mildew (Table 1).

Wheat-Rice Cropping Pattern Trials

Cropping pattern trials were conducted at the Vandien Research Station over three years, beginning in 1989-90. The soil is medium-textured with 26-30% clay, pH(KCl) 6.5-7.0, organic matter 0.98-1.34%, and adequate phosphorus status.

Two early rice varieties (IRRI 8423 and IRRI 352) were used in the trials with 100 kg N/ha. Only 80 kg N/ha were applied to wheat. The five wheat varieties used were TU (Thanbuyen, a very old variety), D11 (Line 11), 49CM (Tuc'S'/Mon'S'//Vee'S'), 11CM (IAS 58/4/Kal/BB/CJ/3/Ald'S'), and Hel 65 (Mad'S'/Bjy'S').

The results (Table 2) showed that wheat could be successfully incorporated into the rice cropping system as the third crop in the Red River Plain of northern Vietnam. Table 2 also shows results obtained under farmers' conditions in two northern provinces in a two crop system (with lower inputs).

In the future, crop management research will be given more emphasis. Priorities of the breeding program will continue to be

Table 1. Disease response to sowing dates and locations of some disease-resistant lines in northern Vietnam.

	Spot blotch (*H. sativum*)					Powdery mildew (*E. graminis*)						
	Hanoi			Cao Bang		Hanoi		Cao Bang		Days to heading		
Line/variety	10 Oct.	1 Nov.	15 Nov.	1 Dec.	10 Oct.	1 Nov.	15 Nov.	1 Dec.	Leaf rust	Hanoi	Cao Bang	Yield (t/ha)
Long 83-3393	3	3	3	-	0	3	5	-	R	50	-	3.2
Yiu 83N-6148	3	3	5	0	0	3	5	0	20S	53	73	3.5
Punjab 81	3	3	5	0	0	5	5	0	R	53	71	3.0
COQ'S'/F61.70/...	-	3	5	0	0	3	0	-	R	53	-	2.8
Cook//Vee'S'Dove/Seri (check)	8	7	8	-	0	5	9	-	R	48	-	2.5
Long 82-2124-1	3	3	3	-	0	3	5	-	R	58	-	3.0
Long Mai 12	3	3	3	0	0	3	5	5	R	52	75	3.2
Long 83-3108	3	3	3	0	0	3	7	3	MR	58	78	2.8
Insee 1	3	3	5	0	0	3	5	3	R	62	78	3.3
Pgo/Fury//Slm/Aldans	3	3	3	-	0	3	3	-	R	62	-	2.9
Thanh Uyen, Local check	3	3	5	0	0	5-9	9	5	100S	60	78	2.2

Notes: Diseases recorded 85 and 115 days after sowing at Hanoi and Cao Bang, respectively. Spot blotch and powdery mildew, scale used 0-9, 0 = resistant, 9 = susceptible; Leaf rust: R = resistance, MR = moderate resistance, S = susceptible. Hanoi: 5 masl, latitude: 21°01 N, longitude: 105°48'E; Cao Bang: 320 masl, 22°50'N, 106°31'E. Missing data denote line not sown at that date/location.

early heat tolerance, suitability for late sowing (early maturity, late heat and drought tolerance), resistance to the disease complex, and yields of 2-3 t/ha under farmers' conditions.

Acknowledgment

The authors wish to thank Dr. Christoph Mann for his assistance in the preparation of this paper.

Table 2. Yields of rice-wheat cropping pattern trials at the Vandien Experiment Station, Hanoi and under farmers' conditions in the northern provinces of Son La and Cao Bang; means of three crop seasons.

				Average yield over 3 seasons (t/ha)		
	Late spring rice	Early rainfed rice	Wheat	Crop 1 (Rice)	Crop 2 (Rice)	Crop 3 (Wheat)
Van Dien, Hanoi (trial)						
Transplanting	25 Feb.-5 March	25 June-5 July	10 Oct.			
Variety	IRRI 8423	IRRI 8423	Thanh Uyen	4.78	5.04	2.75
	IRRI 352	IRRI 352	11CM	4.86	4.66	2.95
Moc Chau, Son La (farmers' pattern)						
Transplanting		15 June-5 July 7	30 Nov.			
Variety		Full rainfed rice	Thanh Uyen, 49CM		2.12	2.2
Trung Khanh, Cao Bang (farmers' pattern)						
Transplanting		15 May-15 June	Dec.			
Variety		Full rainfed rice	Local variety		1.65	1.2

Wheat Breeding Program in Northern Thailand

S. Moolsri
Samoeng Upland Rice and Temperate Cereal Experiment Station, Rice Research Institute, Chiang Mai, Thailand

Abstract

Wheat experiments were first conducted in northern Thailand in 1934. Research, particularly breeding, has continued until the present. Most materials, until recently, have been introduced from the CIMMYT and regional National Programs as advanced lines and segregating populations. In 1983, the Rice Research Institute released two bread wheat varieties for northern Thailand, Samoeng 1 and Samoeng 2. In 1987, the Rice Research Institute released two additional bread wheat varieties, Fang 60 and Phrae 60. Wheat yields in farmers' fields are low, about 0.6-0.7 t/ha, although the yields on experimental stations are higher. We have recognized that there are two distinct environments under which farmers may grow wheat in northern Thailand—rainfed upland and irrigated lowland. With this in mind, we have changed our breeding objectives from broad adaptation to specific adaptation towards these two differing environments.

Introduction

Bread was first introduced to Thai urban life by the bakery of the Oriental Hotel in Bangkok about a century ago. The consumption of wheat in various forms has gradually increased over the years until today it is 6.05 kg per capita. Currently, this wheat is imported and costs the country about US$80 million annually. Although wheat consumption has doubled in the last 25 years, it is still low in comparison to the consumption of rice (145 kg per capita).

Wheat experiments in Thailand were first conducted in northern Thailand in 1934. The results showed that wheat could grow well in the upper north and experiments were continued. The materials were introduced from various national programs, and in later years, from the International Maize and Wheat Improvement Center (CIMMYT). Initially, the introduced materials were advanced lines to test yield potential and adaptability. One bread wheat line from CIMMYT, Sonora 64, was found to be well adapted, early maturing, and demonstrated good yield performance in the upland growing conditions at Chiang Mai and Chiang Rai. Wheat experiments were extended to more experiment stations, not only in upland conditions, but also in the lowland paddy conditions, and the introduced materials were widened to include segregating materials as well as advanced lines. Meanwhile, a breeding program was being established at the Fang Horticulture Station by the Rice Research Institute. The main objectives of the breeding program were high yield potential, wide adaptation, and good baking quality.

In 1983, the Rice Research Institute released two bread wheat varieties, Samoeng 1 (INIA 66) and Samoeng 2 (Sonora 64). Samoeng 1 and Samoeng 2 have good baking quality, but after a number of years under farmers' conditions, Samoeng 1 proved to be best adapted to optimum management conditions (irrigation, high fertility), while Samoeng 2 showed wider

adaptation (good yield in irrigated or rainfed and more able to tolerate management errors) but was shown to be very susceptible to leaf rust.

In 1987, the Rice Research Institute released two additional varieties: Fang 60 (PK2858-7A-3A-3A-0A from Pakistan) and Phrae 60 (UP262 from India). Fang 60 was well accepted by farmers who recognized its tolerance of heat and drought and its ability to produce acceptable yields on poorly structured soils. In addition, it appeared to be more tolerant of crop management errors (seeding rates too high, insufficient fertilizer application, temporary waterlogging).

Breeding Strategies

In the past, the strategy has been to develop broadly adapted varieties. Fang 60 is a result of this strategy although the flour mills in Bangkok have expressed misgivings about its quality. Grain quality is not presently a serious issue as the locally produced wheat comprises such a small proportion of the mills' requirements. However, the breeding program must keep it in mind for the future.

The breeding program has now commenced selection aimed at more specific adaptation to different cropping patterns and stresses.

Wheat production in northern Thailand is broadly divided into upland (mainly rainfed) conditions and lowland paddy fields. Farmers' yields are generally 600-700 kg/ha, but tend to increase as the farmers become more experienced. Individual farmers have obtained yields as high as 4 t/ha.

Previously, the selection programs have been carried out under optimal conditions. Now, we have expanded the sites of selection to both favorable and less favorable conditions to simulate the farmers' circumstances.

In the upland rainfed situation, the farmers may sow wheat between mid-September and late October following maize, peanut, soybean, or upland rice. During this period, soil moisture is adequate (rainfall is still received during October), although temperatures can be elevated. However, in November and December, soil moisture becomes restrictive and as this coincides with the reproductive phase, kernel number and weight are reduced. We are therefore selecting genotypes for this area with drought tolerance or early maturity to escape drought. We also have to take into account acid soils that exist to varying extents in the rainfed upland area.

In the lowland paddies, wheat is sown after rice, rarely before mid-December. Temperatures are higher in the lowlands and at the vegetative stage result in reduced tillering, poor plant vigor and premature heading with fewer spikelets per spike. At the reproductive stage high temperature hastens spike development resulting in the abortion of late-forming florets and reduction in the potential grain number. Later high temperature stress reduces the grain filling period and hence, grain size (Wardlaw et al. 1980, Warrington et al. 1977).

Other problems in the paddy fields are crop establishment, waterlogging and surface crusting after irrigation. These are being approached by improvements in crop management.

Wheat varieties for these areas require heat tolerance and early maturity to escape the high temperature stress during grain-filling and to better fit the cropping system.

Varietal Demonstrations in Farmers' Fields

On-farm varietal demonstrations were initiated in 1987 to assess the performance of wheat lines under farmers' conditions and to create farmer interest in the crop. In these, Fang 60 outyielded the other released varieties and was well accepted by the farmers, although the quality was not always of the standard expected (for the future) by the Bangkok mills. In 1989, three promising lines were selected to be placed in the on-farm demonstrations. Although these lines are not significantly higher in yield potential than Fang 60 (Table 1), their quality is superior. These lines are all from crosses made in Thailand:

- FNBW 74013-52 (MD/McM-Ex/2/AFM//SA/McM/3/K117A//FN/4/FKN/5/S-10-273),
- FNBW 8101-7 (FNBW 7201-77-10-1/INIA), and
- FNBW 8301-5-5 (KP1/S-18-470).

This year, one additional line (SMGBWS 88001—a selection from China, YIE84-6151) has been entered in the demonstrations and, although of similar yield potential to Fang 60 under hot conditions, has earlier maturity (Table 2).

We hope these lines can replace Fang 60 if quality continues to be an issue.

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Table 1. On-farm varietal demonstration in northern Thailand, 1991-1992.

Varieties	Yield (t/ha)	TGW (g)	Days to maturity
FNBW 74013-52	2.0	34	90
FNBW 8101-7	1.98	31	88
FNBW 8301-5-5	1.85	33	87
SMG 2 (check)	1.76	32	89
FANG 60 (check)	1.93	34	96

Table 2. Performance of SMGBWS 88001 compared with Fang 60.

	Yield (t/ha)			
	Rainfed	Irrigated	TGW	Days to maturity
SMGBWS 88001	1.097	2.963	40	86
Fang 60	1.171	3.326	33	92

Wheat Breeding Strategies in the Rice Farming System of Bangladesh

M.A. Razzaque, A.B.S. Hossain, S.M. Ahmed,
A.K.D. Sarkar, M. Rahman, C.D. Barma, and R. Amin
Wheat Research Centre, Bangladesh Agricultural Research Institute, Dinajpur, Bangladesh

Abstract

The wheat breeding program in Bangladesh is designed to develop varieties suitable for farmers' situations in the rice-wheat system. Considerable emphasis has been given to high yield potential, disease resistance, and yield stability. Research in new areas such as tolerance to heat, drought, waterlogging, and sterility have been initiated. In addition, experiments for morpho-physiological trait identification for heat and drought tolerance and studies on root physiology and grain quality have begun. Sixteen varieties have been released so far for commercial cultivation. In 1992, two advanced lines were submitted to the National Seed Board for release as varieties. New varieties released by the Centre have 15 to 20% higher yield than the older ones. Nearly 100% of the country's wheat area is sown with recommended high yielding varieties.

Introduction

Bangladesh, being geographically situated between 21°34 and 26°38'N latitude and 88°45' and 92°40' E longitude, with elevations between 5 and 39 masl in the cropping areas, has a tropical climate with rainfall of 150 mm in the southeast to 50 mm in the northwest during the wheat season (November-March). The mean temperature during the coolest month (January) is about 18°C. December and February are about 1-2°C and March is about 6-7°C hotter. Relative humidity ranges from 62 to 87%. Soils of two major physiographic units, flood plain (80% of the country) and terrace (8%) are suitable for wheat cultivation.

Because of the limited cultivable area (about 8.85 million hectares), the cropping intensity is high (180%). Surveys in the greater districts of Dinajpur (Saunders 1990), Jessore, and Khustia (Saunders 1991) indicated that the rice-wheat pattern covered 90, 80, and 72%, respectively, while the transplanted rice and wheat pattern covered about 54% of cropped area. The rice-wheat rotation is expected to remain the dominant cropping pattern in Bangladesh. However, there are conflicts between the two crops, in soil management in particular. The major problems are development of suitable varieties for both rice and wheat, plant establishment of wheat, avoidance of waterlogging, maintaining fertility level of soils, and pest management.

Wheat Breeding Program

The wheat breeding program has been designed to develop varieties that fit well in the rice-wheat cropping system. Prior to the 1980s, the breeding program was based on a monocrop concept. Since then, the program has aimed to produce varieties to better fit within the constraints of the cropping systems. The recently initiated collaborative research programs between BARI, BRRI (Bangladesh Rice Research Institute), IRRI

(International Rice Research Institute), and CIMMYT will help to further identify opportunities for increasing the productivity of the rice-wheat systems through crop management and the adjustment of breeding objectives.

The goals of the Bangladesh wheat breeding program are to produce disease-resistant varieties with high and stable yields. Research in these areas is based on three wheat growing environments of Bangladesh: 1) optimum planting under irrigated conditions, 2) late planting under irrigated conditions, and 3) optimum planting under nonirrigated conditions.

Recently, the breeding program has also been modified and strengthened to address specific problem areas such as heat and drought tolerance, waterlogging tolerance, grain-set failure, sprouting resistance, assessment of root growth and development, and aspects of grain quality.

High yield potential

For the development of a variety suited to the rice-wheat system of Bangladesh, it is necessary to have genotypes that mature within 110 days, possessing high tillering ability, longer green leaf duration, stiff straw, good spike fertility, and large grains. For the rainfed situation, high tillering genotypes with medium-long maturity may be accepted, but the varieties would have to be planted within the optimum dates and managed with the recommended package of practices.

Disease resistance

The major diseases in the rice-wheat farming system are leaf blight (*Bipolaris sorokiniana*) followed by leaf rust (*Puccinia recondita*), and foot rot and seedling blight (*Sclerotium rolfsii*, *Helminthosporium sativum*, *Alternaria tenuis*, and *Fusarium* spp.).

Leaf blight—All commercial varieties are susceptible to this disease. It is considered to be both seed and soilborne. It attacks the leaves at the seedling stage and the infection increases from booting to physiological maturity. Yield loss due to this disease is 4-21% depending upon the variety. Yield loss is comparatively low in new varieties; the loss is reported to be 14, 8, and 14% in Akbar, Kanchan, and Aghrani, respectively. In Sonalika, the yield loss and grain weight reduction are 21 and 18%, respectively.

Black point caused by this disease is found in the seeds of all varieties. The incidence is aggravated when there is continual rain near crop maturity and when the plant lodges.

Breeding for resistance against leaf blight has been initiated and a number of tolerant/moderately tolerant lines have been identified, which are being used in the hybridization program. Searching for resistance for this disease under field conditions has been hampered by the fact that artificial infection by spraying inoculum or spreading infected straw at planting has not proved successful, and screening has had to rely on natural infections.

Leaf rust—The incidence of this disease is observed in mid-February only after anthesis and does not cause substantial damage to the crop. A highly susceptible variety showed a yield loss of 50% (Ahmed and Alam 1983). Many resistant lines are available and screening for leaf rust resistance by inoculum spraying of rust spores in the nursery has proven successful.

Foot rot and seedling blight—These diseases are generally noticed in poorly drained soils and also where moisture stress occurs. Only *H. tenuis*, *H. sativum*, and *Fusarium* spp. are pathogenic to the germinating seeds and are partially responsible for seed rot and

seedling infection. *Sclerotium rolfsii* and *Pythium* spp. may also be implicated. Genetic resistance has not yet been found. Seed treatment with Vitavax-200 has been found useful for controlling the disease (Meisner et al. 1994).

Stable grain yield

Development of stable varieties is particularly necessary for a food-deficit country like Bangladesh. Therefore, it is necessary to subject the segregating materials planted to all growing conditions to identify materials with superior performance even in stressed conditions. This approach is accepted and practiced in our wheat breeding program. As a result, the recommended varieties perform consistently under the farmers' conditions. Kanchan is a high yielding variety possessing average stability, which now covers about 80% of the total wheat area of Bangladesh.

New Areas of Research

To meet the need of wheat growers, specific production situations have also been taken into consideration for developing varieties suitable for all environments. These are noted below in the following sections.

Heat and drought tolerance

Heat and drought are two independent traits, but in developing varieties, these two together are required to be simulated. Generally, 10-15% of the wheat area is early planted (late October-early November) and is subjected to heat stress during seedling development. This area increases in years when the transplanted rice is affected by floods. On the other hand, 45-55% of the area is planted late (December 7-30) after delayed harvest of transplanted rice and is affected by late heat stress. It is estimated that some 55-60% of the total wheat area suffers moisture stress.

The early heat reduces the tillers per plant and causes premature heading with fewer spikelets/spike. Sometimes there is an increase in the incidence of foot and root rot diseases. In this situation, genotypes that have a longer vegetative phase, more tillers, maturity of about 115 days, and reduced leaf firing will be necessary to maximize yield. The present program for developing varieties for early heat tolerance is based on selection primarily from winter x spring crossed materials and recently spring x spring crossed materials planted in late October under nonirrigated conditions.

Late-planted wheat is subjected to high temperature at the reproductive stage forcing premature ripening, resulting in shortening of the life cycle (Midmore et al. 1982), abortion of the late forming florets, and reduction of potential kernel number (Warrington et al. 1977). The grain growth period is reduced resulting in low kernel weight (Sofield et al. 1977, Wardlaw et al. 1980, Weigand and Cuellar 1981, Bhullar and Jenner 1975). Acceleration of leaf senescence is also observed (Spiertz 1974, 1977; Al-Khatib and Paulsen 1984). With the current varieties, planting wheat after December 1 under Bangladesh conditions results in potential yield loss of 1.3%/day for each day delay (Saunders 1988). Therefore, it is necessary to develop varieties that have plasticity and can manifest their grain development properly under a short period of time. Like Kanchan, two more heat-tolerant lines, BAW 171 and BAW 452, have been developed and submitted to the National Seed Board for approval as varieties.

Considerable effort has been expended to develop varieties for drought prone areas. Here, the selection pressure has been given for a maturity period of 100-110 days associated with high biomass, high harvest index, comparatively narrow leaves, waxy stem, quick grain-filling period, good test weight, and a well developed root system.

Waterlogging

As a result of waterlogging, the seedling becomes stunted due to poor soil aeration causing yellowing of the lower leaves and a reduction of tiller primordia. Therefore, although speculative, a small selection program for waterlogging tolerance has been initiated in two locations, Dinajpur and Joydebpur in the 1992-93 season.

A study has been undertaken recently to identify morpho-physiological traits that may aid in selection for heat/drought tolerance.

Plants in hot/dry environments have the potential to cool their leaves several degrees below that of the ambient temperature (Idso et al. 1984). This cooling of the canopy temperature via evapotranspiration is well associated with yield. Measurement of canopy temperature using an infrared thermometer may offer a potential screening technique in hot environments. Similarly, leaf chlorophyll or "stay green" is another trait used to indicate heat tolerance (Acevedo et al. 1991, Kohli et al. 1991). These techniques are now being evaluated in our research program.

Sterility

Failure of grain setting in the northern part of the country has been observed in recent years. The prevalent situation in this area is foggy weather resulting in reduced sunshine hours accompanied by high humidity. To overcome these problems, the advanced lines are screened to identify those lines with consistently high grain-set under these conditions. This problem may also be overcome through management as well. Detailed physiological and agronomic studies to investigate the cause of sterility have been initiated by an in-service PhD student of the Wheat Research Centre.

Sprouting

Pre-harvest sprouting is also observed when there are rains for a number of days at the maturity stage. At present, all the breeding materials are white-grained and do not appear to exhibit resistance to sprouting. However, steps will be taken to collect some sprouting-resistant germplasm from abroad.

Root growth and development

This is the first year of physiological studies on growth and development of roots. It is postulated that a long and profuse root system in wheat might be helpful in moisture stress situations. Other related phenomena will be taken into consideration for both optimum and late-planted situations under irrigated conditions.

Grain quality

Hardness, color, and test weight are currently considered. Little work has been carried out to evaluate protein content. Equipment has been procured to start a study on baking and chapati-making qualities.

Breeding Methodology

Figure 1 presents a flow chart of germplasm movement. Introduced segregating populations (international program) are subjected to one cycle of selection and are then integrated into the national program for evaluation alongside the progeny of local crosses.

Selections from introduced nurseries are first evaluated for performance under late-planting conditions and the best lines are entered into the Bangladesh Screening Nursery for comparison with the most promising local lines. In this nursery, the materials are planted under irrigated optimum, irrigated late and nonirrigated optimum seeding dates at different locations for the identification of wide adaptability. The replicated yield trials (PYT, SYT, AYT) are grown under the same conditions.

In the breeding program, a modified bulk method is used. Individual plants are selected in the F2 generation and the heads of selected families are bulked from F3 to F6. Planting, selection, harvesting and threshing procedures are shown in Table 1.

Impact of the Wheat Breeding Program in Bangladesh

The wheat breeding program has had a great impact on national wheat production. Varieties are now available for cultivation under irrigated optimum, irrigated late, and nonirrigated conditions. The varieties so far developed are well adapted in these situations. Almost 100% of the wheat area is now sown to high yielding varieties (Table 2)

The performance of two lines currently under consideration for varietal release in comparison to the predominant varieties Sonalika and Kanchan is shown in Table 3, indicating a yield advantage of about 15-20% for the new lines. Under optimum

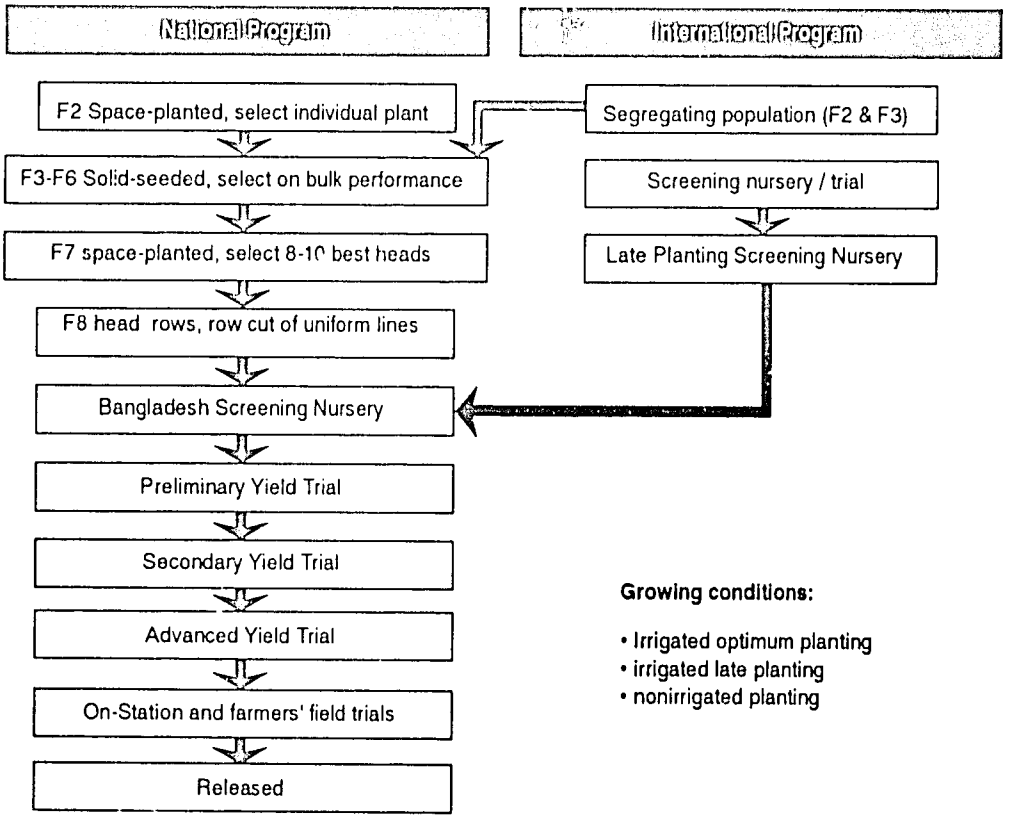

Figure 1. Methodology of germplasm evaluation at the Wheat Research Centre.

management conditions, the new lines have a potential yield of 5.0-6.6 t/ha.

As the growers are at marginal and subsistent levels and cannot afford proper fertilization of their crop, the breeding program is directed to develop varieties having average to high yield potential with average to high stability levels. Thus, the segregating materials are selected for these two traits. Attempts are being made to develop varieties for adverse environments such as drought, heat (late planting), sterility, etc.

Table 1. Procedures followed in successive segregating generations at the Wheat Research Centre.

Generation	Plot size and sowing method	Selection, harvesting, and threshing procedures
F2	10 m^3 double rows with a row spacing of 30 cm and 60 cm double between rows	Tag individual plants at heading stage for earliness. Families are then selected on the basis of good agronomic characters and disease resistance. Select plant again at physiological maturity, harvest and thresh separately. Final selection on the basis of grain type.
F3	2.5 m^3 rows, solid-seeded with a row spacing of 20 cm.	Select lines and pick best 20-25 heads from different plants and thresh in bulk.
F4 to F6	Same as F3.	Same as F3.
F7	2.5 m^3 rows, space-planted with a row spacing of 20 cm.	Select best 10-15 heads from different plants, Harvest and thresh separately. Final 10 selected based on grain type.
F8	Grow the seeds of individual heads in 2.5-m single row with a spacing of 20 cm between entries.	Row cut of uniform lines for pre-Bangladesh Screening Nursery.

Table 2. Area in Bangladesh covered by the dominant varieties in recent years.

	Percent of total wheat area		
Name of varieties	1989-90	1990-91	1991-92
Kanchan	40	55	78
Sonalika	55	40	16
Akbar	2	4	5
Other varieties	3	1	1

Table 3. Mean yields of two promising lines submitted for release (Means of 3 years' data at five experiment stations).

	Yield (kg/ha)		
Varieties/lines	IR OPT	IR LATE	NON-IR OPT
BAW 171	3,399	2,585	2,954
BAW 452	3,598	2,876	2,849
Sonalika	2,841	2,266	2,297
Kanchan	3,397	2,658	2,695

BAW 171 = Ias 58/3/Kal/BB/Ald'S' /4/Oln/Trm//7C//Ald'S';
BAW 452 = Kuhr 12.

Conclusions

In a rice-wheat system, new problems appearing are causing yield declines, particularly of wheat and to some extent of rice. Since wheat is grown on about 80% of the area as a succeeding crop after rice, these problems need to be addressed through research if we want to sustain the production of wheat in Bangladesh. A number of recent programs have already been undertaken by the Wheat Research Centre to deal with these problems. Upon successful completion of these programs, wheat production can be increased to attain food security.

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Questions/Discussion

Dr. A.B.S. Hossain, who had presented the Bangladesh paper in the absence of Dr. Razzaque, was asked if there are any advanced lines with yields superior to BAW 452. He explained that BAW 452 was a selection from Thailand introduced in 1986 as Kuhr 12, pedigree unknown, and has excellent grain characteristics and a certain amount of helminthosporium resistance/tolerance with a long green leaf duration. There are a few lines that have outyielded it on occasions, such as lines from the crosses Bue/Bjy'S' and Bue/Bjy'S'//Pvn'S'.

On the question of whether Kanchan was being grown in West Bengal, India, Dr. Hossain said that there have been reports of seed going across the border but the area of Kanchan under cultivation is not known.

Early Vigor in Wheat: A Useful Character for Heat Tolerance Selection

C.E. Mann
CIMMYT Southeast Asia Program, Bangkok, Thailand

Abstract

Many traits have been reported in the literature as contributing to heat tolerance. They are grouped into three categories: 1) easy to screen in breeding nurseries, 2) easy to screen but requiring special effort, and 3) unsuitable for mass screening because of high laboratory or greenhouse requirements. In the first group, visual assessment of early vigor is considered highly underused by breeders in hot environments as it integrates over a range of the less visible group 2 and group 3 factors (i.e., seminal root length, coleoptile length, leaf appearance rate, days to double ridge, terminal spikelet, low shoot/root ratio, and area of first leaf) that are of increased relevance under heat. In two experiments in Thailand. phenotypic correlations of early vigor are highly significant with grain yield (.51 and .68), biomass (.80 and .79), heads/m^2 (.80 and .56), days to anthesis (ns and -.34), days to maturity (ns and -.37), and plant height (.50 and .46).

Introduction

Many characters have been identified as contributing to heat tolerance in wheat and genetic variability has been shown for most of them (Table 1).

Some can be easily assessed by breeders. Wardlaw et al. (1989a) advocates yield components such as grains/spikelet, grains/spike, ear grain weight, and grain weight, although it is not sure whether the latter should be high or low (Briggs 1992). Opposing data for the sowing to anthesis periods and anthesis to maturity periods and their ratios have shown association with yield (Fischer 1985, Mann and Sirithunya 1990). Taller genotypes, mono- or oligoculm habit (Rawson 1988, Briggs 1992), canopy temperature and stay-green of leaves (Reynolds et al. 1992) have also been suggested.

Other characters are within the reach of small breeding programs in hot environments, but require a special effort,

Table 1. Characters reported in the literature as contributing to heat tolerance of wheat.

Mass screening possible	Mass screening difficult	Mass screening not feasible
• Yield components	• Grain set reduction	• Vernalization requirement
• Days to anthesis	• Grain weight reduction	• Long photoperiod requirement
• Days to maturity	• Leaf area index	• Rubisco content
• Long vegetative period	• Area of first leaf	• Julian days to double ridge and terminal spikelet
• Mono- or oligoculm	• Low shoot/root ratio	• Leaf appearance rate
• Canopy temperature	• Long phyllocron interval	• Coleoptile length
• Stay-green of leaves	• Large leaves	• Seminal root length
• Early vigor		

e.g., planting in two locations different for their temperature regime:

- Grain set and grain weight reduction (Wardlaw et al. 1989b, Tashiro and Wardlaw 1990);
- Leaf area index (Midmore et al. 1982); and
- Area of first leaf, low shoot/root ratio, long phyllocron interval, and large leaves (Rawson 1988).

Still other characters require artificial growth conditions or laboratory procedures that are not feasible for mass screening or not available to most breeders in the tropics:

- Vernalization and photoperiod requirements (reviewed in Vongburi 1992);
- Rubisco content (Lawlor 1994);
- Julian days and heat units to double ridge and terminal spikelet as well as leaf appearance rate (Briggs 1992);
- Coleoptile length and root growth (Woodruff 1988);
- Membrane stability (reviewed in Marshall 1982 and Gusta and Chen 1987).

In the first group, all characters are assessed routinely in most breeding programs except canopy temperature and early vigor. Visual assessment or measurement of a character is followed by a decision, which is made according to the weight given by the breeder for that character. The difference between canopy temperature and ambient temperature appears to be useful and easy to measure but depends on equipment availability and, more importantly, requires complete groundcover, which is quite often absent in hot environments. This paper advocates routine assessment of early vigor for reasons discussed below.

Material and Methods

Experience has shown that good early development of the plant up to about the four-leaf stage usually gives a cultivar a head start over genotypes that lack this early development. So, CIMMYT started to assess visually early vigor at this stage using a 0-to-9 scale, where 0 is very poor and 9 is very good.

Data presented are from two national trials at Chiang Mai, Thailand. The Wheat Thai Yield Nursery (WTYN) had 22 entries in four replications with a plot size of 4 m². The Wheat Thai Observation Nursery (WTON) had 67 entries unreplicated with a plot size of 1 m².

For the WTYN, the ANOVA for all characters gave highly significant differences (Table 2). Means over replications in the WTYN and single

Table 2. Correlation coefficients of early vigor with other characters at Chiang Mai, Thailand.

Early vigor with	WTYN n = 22[a]	WTON n = 67
Yield	0.51 **	0.68 **
Biomass	0.80 **	0.79 **
Harvest index	-0.41 *	0.08
Heads/m²	0.80 **	0.56 **
Grains/head	-0.03	0.14
Spikelets/head	0.04	
Grains/spikelet	0.04	
TGW	-0.34	-0.02
Days to anthesis	-0.14	-0.34 **
Days to maturity	-0.17	-0.37 **
Grain-filling days	-0.17	0.08
Plant height	0.50 **	0.46 **

[a] Means over four replications.
*,** significant at p = .05 and .01, respectively.
WTYN = Wheat Thai Yield Nursery; WTON = Wheat Thai Observation Nursery.

replication values of WTON were used for correlations of all other characters with early vigor.

Results and Discussion

Entries of WTYN had significant differences in early vigor. The 25% coefficient of variation was the same as that achieved for yield in the same experiment.

Yield and biomass showed highly significant correlation coefficients in both experiments, suggesting that early vigor is a factor that has a desirable effect throughout the life cycle of the plant. The negative correlation with harvest index in the WTYN is at the limits of significance and difficult to explain biologically. Heads per square meter is the only yield component significantly correlated with early vigor, suggesting that ability for the genotype to establish may be a factor in assessing early vigor (the influence of differing seed viabilities was eliminated by adjusting seed rates following a laboratory test before sowing). However, the measurement of early vigor is still recommended because plant establishment is considered a critical factor in hot environments.

True physiological factors affecting the ability to establish in hot soil belong to the third group (Table 1) and are therefore not measurable. We would have expected a closer association of early vigor with days to anthesis and days to maturity. Thus, it appears that early vigor is not just another measure for earliness but includes other factors as well. Probably it integrates the effects of several factors reported in detailed physiological studies such as fast water uptake and germination, good seminal root development, the effect of coleoptile length, and early vegetative growth, i.e., leaf area.

Such a mix of factors might be unacceptable to physiologists, however, we believe it is a useful trait for breeders. Naturally, there are still many other ways in which different genotypes respond to heat at later stages of the growth cycle. However, early vigor should be considered as a trait that can be combined with others for better heat tolerance. We believe it is underestimated in breeding programs although it has the advantage of easy visual assessment that requires no equipment at a time when breeders are usually not too busy.

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Questions/Discussion

Dr. Mann was asked for details of his early vigor measurement. He replied that it was a simple visual rating of the plots in an experiment, in his case using a scale of 0-9, with 0 for the worst plots to 9 for the best.

He was asked if seed size or embryo size was related to his early vigor ratings. He had not studied these aspects. Dr. Fischer suggested that test weight (grain plumpness) would be more important than thousand grain weight or size in early vigor. Dr. Mann agreed with a comment that grain size and plumpness should be added to his list of characters, which are easy to screen for terminal heat tolerance. He added, however, that there are suggestions that large, plump grains, because of a smaller surface to volume ratio, may take longer to imbibe and hence emerge.

In his presentation, Dr. Mann had made reference to Rubisco content. He explained that Rubisco is an enzyme controlling CO_2 absorption. He referred the questioner to the paper by Dr. D.W. Lawlor at the Sudan conference in these proceedings, pp. 127-142.

National Testing System, Breeding Strategies, and Recent Progress in Wheat Research for Warmer Area Rice Farming Systems in India

J.P. Tandon
Directorate of Wheat Research, Karnal, Haryana, India

Abstract

Wheat is grown in rotation with rice on more than 9 million hectares in India. A number of problems are associated with the system and its sustainability is feared to be under threat. The Indian wheat program divides the country into five main zones, differentiated mainly by latitude and altitude. Wheat varieties are developed for each of these zones. A national cooperative testing program is well developed. The breeding objectives are to obtain varieties with high, stable yield, with resistance to diseases, particularly leaf and stem rusts and leaf blights, and tolerance to abiotic stresses. More specific varietal and management recommendations, based on the particular requirements of the rice-wheat cropping system, have recently been developed.

Introduction

Wheat is cultivated on nearly 24 million hectares in India and production during 1991-92 was 55.17 million tons with an average yield of 2.3 t/ha. More than 90% is sown to bread wheat (*T. aestivum*) followed by 8% to durum wheat (*T. turgidum* var. *durum*). *T. dicoccum* is cultivated on a very small area in the south and coastal Gujarat. The wheat crop is grown during the cooler part of the year and its cultivation extends from about 10° N in Tamil Nadu to 37° N in the northwestern Himalayas. The duration of the cool season, when wheat is grown, ranges from more than five months in the northwestern plains to about three months in the southern plateau. In the northeastern regions, the crop duration is shorter, about four months, and winter temperatures are warmer than in the northwestern regions. In the southern states, the winters are shorter and warmer.

Wheat production in the country has always been regarded as a gamble with seasonal temperatures. The crop is exposed to excessively high temperatures at sowing and during grain-filling in all regions. Even during the remaining part of the winter, favorable temperatures prevail only for a short period in central, southern, and eastern regions. Normally, irrigated wheat is seeded in November in most parts of India, although sowings are continued until the end of December or even January, depending upon the cropping intensity. The rainfed crop is sown relatively earlier at the end of October. The harvesting season extends from the middle of February to May, depending upon latitude and altitude. In the lower latitudes in Karnataka and Maharashtra, the rainfed crop matures by the middle of February while the irrigated crop is harvested in the first half of March. However, in the more northern latitudes in Punjab and Haryana, harvesting takes place in the middle of April. In high altitude areas of the Himalayas, wheat is harvested in mid-May.

From experience, wheat sowings using high yielding varieties are not possible before the mean daily temperature falls to about 22°C. The crop starts maturing when the temperature reaches 25°C, irrespective of the date of sowing and the crop is ready for harvest shortly after. All the wheat crop is affected by high temperatures during grain filling and this becomes more acute with later sown crops.

The Rice-Wheat System

In India, irrigated wheat is grown in a system where cropping intensity is 200% or more. The crop preceding wheat varies with the region. In major parts of the Indogangetic plains, covering the entire northwestern and northeastern plains, the rice-wheat rotation is the dominant cropping sequence. It is estimated that more than 9 million hectares are under the rice-wheat sequence in these plains. An approximate coverage under the rice-wheat sequence in different Indian states is given in Table 1.

Almost all the wheat areas in India, excepting the northern hills and northwestern plains, as explained in more detail later, can be classified as warm regions. The rice-wheat sequence is prevalent in the entire northern region. However, in the warmer wheat growing regions, the north eastern plains which account for about 25% of the wheat area in India, the rice-wheat system dominates. In the central and southern regions, the rice-wheat sequence is rare and several other cropping systems are popular.

As the two crops are both cereals the sequence is very exhaustive. In addition, field conditions required by the two crops are drastically different. As such, a number of problems are reported to be associated with the system and the sustainability of the rice-wheat system is feared to be under threat. Various issues related to the system are under serious investigation at the national and international level. Some of these issues are: 1) varietal adjustments; 2)

Table 1. Proportion of wheat area in the rice-wheat system in the wheat producing states.

State	% area under rice-wheat	Area under wheat (ha, millions)	Actual area under rice-wheat (ha, millions)
Uttar Pradesh	50	8.72	4.36
Punjab	60	3.16	1.90
Haryana	35	1.83	0.64
Bihar	70	2.11	1.48
West Bengal	80	0.30	0.24
Assam	80	0.11	0.09
Gujarat	5	0.65	0.03
Himachal Pradesh	10	0.37	0.04
Jammu and Kashmir	10	0.27	0.03
Madhya Pradesh	5	3.67	0.18
Maharashtra	5	0.88	0.04
Rajsthan	5	1.77	0.08
Total	38	23.84	9.11

Source: All India Wheat Project Annual Report, 1989-90.

soil physical, nutritional, and biological health; 3) water management issues; 4) disease and insect problems; 5) crop residue management; 6) increasing cultivation costs; and 7) environmental aspects.

National Testing System

Keeping in view various aspects, the country is divided into five main agro-climatic zones to facilitate organization of wheat research. These are:

- Northern Hill Zone (NHZ): Higher latitude and altitudes with long winters and cool climate throughout the crop season.
- North Western Plains Zone (NWPZ): Similar or slightly lower latitudes to NHZ, low altitude plains, with moderately long winters and fairly cool temperatures.
- North Eastern Plains Zone (NEPZ): Similar or slightly lower latitude than NWPZ, low altitude plains with a shorter and milder winter and relatively humid atmospheric conditions.
- Central Zone (CZ): Medium low latitude, low altitude, a shorter winter season with milder temperatures and dry atmospheric conditions.
- Peninsular Zone (PZ): Characterized by very low latitudes, low altitude, and very short winter with moderately high temperature and dry atmospheric conditions.

A small sixth zone named the Southern Hills Zone has been constituted for strategic reasons primarily due to its crucial role in the survival and spread of rust diseases to several parts of India, particularly central and peninsular India. However, it has very little area under wheat.

Approximate distribution of wheat area in different wheat zones and average monthly temperatures during the wheat season are given in Table 2. It is seen from this table that average temperatures in the coolest month are well above 15°C in NEPZ, CZ, and PZ, which can be classified as warm wheat growing regions. Even in the NWPZ, several parts can be classified as warmer regions and average January temperatures remain well above 12°C in most years. The hottest wheat growing zone is PZ.

The main wheat research centers in the warmer rice-wheat regions of India are located at Kanpur, Faizabad, Varanasi, Sabour, Pusa, Ranchi, Kalyani, Malda, Coochbehar, Shillongoni, and Manipur. In addition to these research centers, a very large number of stations cooperate in the conduct of multi-locational testing.

Table 2. Approximate distribution of wheat area in different zones and average monthly temperature (°C) during potential crop season.

		Average temperatures during crop season						
Zone	% wheat area	Oct.	Nov.	Dec.	Jan.	Feb.	March	April
NHZ	4	18.4	15.2	10.7	9.7	10.8	14.0	18.5
NWPZ	40	24.6	19.7	14.4	13.3	15.4	19.6	26.3
NEPZ	25	26.1	21.9	17.4	15.6	19.1	22.9	27.7
CZ	25	26.2	22.8	19.2	18.5	20.6	24.6	29.8
PZ	6	25.2	22.1	20.6	20.8	23.0	25.8	29.7

NHZ = Northern Hill Zone; NWPZ = North Western Plains Zone; NEPZ = North Eastern Plains Zone; CZ = Central Zone; PZ = Peninsular Zone.

The coordinated varietal yield evaluation and germplasm screening/sharing system involves the following stages:

- Station Trials: Organized by the cooperating centers at their own level using newly bulked/introduced promising materials and may occasionally involve restricted multi-locational testing.

- Initial Varietal Trials (IVT): These trials are organized by the All India Coordinated Wheat Improvement Programme (AICWIP) at all research centers within each zone. These trials are constituted of entries identified as promising by the cooperating centers in the station trials. Each zone has a separate series of trials according to its cultural requirements.

- Advanced Varietal Trials (AVT): Strains found promising in IVTs are included in these trials and some of the superior entries from the previous year's AVT are also retained. These trials are sown at all wheat research centers and several additional testing locations in each zone.

- Other tests: Scientists from various other research disciplines cooperate to screen/evaluate test entries in various stages of the coordinated testing for characters related to their discipline. These tests invariably include reaction to important diseases, particularly rusts, and certain grain quality parameters at each stage of testing. Entomological, nematological, and agronomic evaluations of entries commence in the second year of AVT testing (3rd year of coordinated testing). The materials may also be evaluated for some physiological parameters such as salt, heat, and drought tolerance.

- Varietal Release: Lines that show good performance continuously over three years of coordinated testing and possess desired levels of disease resistance, grain quality and other required features are proposed for release, in a specified format, by the concerned breeders in the annual wheat workshop. If approved by the workshop, these lines are considered for release by the Central Varietal Release and Notification Committee before they can be recommended for general cultivation and enter commercial seed production channels.

- Germplasm Screening/Sharing: High priority is given to germplasm screening/sharing and all materials are easily available to the cooperators. All newly introduced germplasm received from CIMMYT, ICARDA, and other international sources is critically evaluated by the project and selected promising materials are constituted into elite germplasm nurseries and distributed to various research centers for utilization. Entries in the IVT testing in the various zones are consolidated in the form of a National Yield Observation Nursery and evaluated all across the country without restriction of zones. The promising materials are promoted for testing in coordinated trials in the specific zones.

Much germplasm is evaluated for important biotic and abiotic stresses in the form of screening nurseries. These nurseries are constituted on the basis of preliminary observations for their possible potential as recorded by individual co-operators and are evaluated systematically for their desirable features. These include rust, Karnal bunt, foliar blight, powdery mildew, hill bunt, flag smut, loose smut, and nematode and insect pest screening nurseries among the biotic stresses and salt, heat, and drought screening nurseries among abiotic stresses.

Other nurseries include yield components, short duration, and quality component screening nurseries. These nurseries help to identify sources of resistance/tolerance/desirable features that can then be utilized in varietal improvement programs.

Breeding Objectives

The main effects of high temperature on the physiology of the wheat plant include enhanced respiration rate, increased water demand, chlorophyll degeneration, necrosis of green tissues and rapid completion of various developmental phases.

The obvious effects of high temperature on wheat growth include reduced crop stand, shorter life cycle, reduced tillering, lesser biomass production, reduced number of grains/spike, lower grain weight, and reduced grain yield.

In view of the above adverse effects of high temperatures, the breeding objectives aim to produce genotypes with ability to produce good crop stands, vigorous growth, higher tillering capacity, higher grains/spike, larger grain, higher biomass production, and ability to maintain reasonable crop duration and to produce high and stable grain yields with acceptable grain quality under warm environments.

Among other objectives, breeding for resistance to leaf rust (*Puccinia recondita*) and stem rust (*P. graminis*) are considered as important as high yield and stability in performance. Leaf blight caused by *Helminthosporium* spp. is an extremely important disease in the rice-wheat region. However, strong and stable sources of resistance are not yet available so only highly susceptible types are discarded in the selection and evaluation process. In some pockets, Karnal bunt, and to some extent, loose smut are also reported to occur.

The breeding strategy involves the growing of various segregating materials in different filial generations in the warm and relatively humid environments prevalent in the region and selection of adapted types. Artificial epidemics are created during each segregating generation for important diseases, particularly rusts and foliar blights, which are important in the region. This helps in retention of resistant/tolerant types. The advanced generation bulk materials are then evaluated for yield potential and other desirable features as described earlier.

Recent Achievements

Until recently, most wheat production technologies were developed irrespective of the cropping sequence in which the wheat crop was grown. However, more specific and precise recommendations are now available and an increasing emphasis is given to a cropping system approach. For example, an application of 80 to 120 kg N/ha is recommended for irrigated wheat with the suggestion that 80 to 100 kg N/ha should be used if the preceding crop was a legume. Previously, the blanket recommendation of 120 kg N/ha was made. Similarly, it is advised that in the wheat-rice sequence, application of phosphorus can be omitted in rice if a full recommended dose is used in the preceding wheat crop. Some of the other recent findings are discussed in the following sections.

Varietal aspects

Experiments on varietal adjustment have shown that in the warm rice-wheat system area of the northeastern regions of eastern Uttar Pradesh, Bihar, West Bengal, Assam and Orissa, cultivation of normal duration varieties of rice followed by short-duration wheat varieties is the best combination for high grain production and productivity of the system. The recent short duration wheat

varieties recommended for the zone are HD 2307, HUW 234, BW 11, and Sonali. Sonali is a backcross derivative of Sonalika combining a high degree of resistance to leaf rust and some degree of tolerance to foliar blight. Recently, another variety K 8697 has been recommended for lands where wheat sowing is delayed due to waterlogged conditions. HD 2285 and HD 2402 have also shown adaptation to very late sown conditions. Earlier, Sonalika and HP 1209 were the only short duration recommended varieties for all these situations.

The wheat varieties suitable for cultivation, after the harvest of short duration rice varieties, are HUW 206 and K 8804 among the new ones and UP 262 and HP 1102 among the older types.

In future there will be a need for more specific varieties adapted to the rice-wheat system, which may be specifically suited for the newly evolving technology of minimal/zero tillage practices under which situation the crop establishment and rooting pattern needs may be markedly different.

Crop protection

The strategy for control of rust is primarily through varietal development and all cultivars that become susceptible are dropped from cultivation and new resistant types are recommended. As such, no fungicides are suggested for control of rusts.

In the case of foliar blights, adequate resistance is still lacking in the cultivars, although these are screened against severe susceptibility. In situations where severe infestation is expected, three sprays at two-week intervals of dicarbamates such as Dithane M-45 @ 0.25% is recommended. Tilt has been found very effective for the control of foliar blight.

Agronomy

All wheat varieties are tested for adaptability over a wide range of cultural environments and varied dates of sowing, fertilizer levels and irrigation levels. Response of the latest genotypes to these variables are summarized in Table 3.

For the control of weeds, the use of Isoproturon at 0.75 kg ai/ha 35 days after sowing, Pendimethalin at 1.0 kg ai/ha as a pre-emergence spray, and 2,4-D at 0.4 kg ai/ha are recommended depending upon the weed flora and population intensity.

Recent experiments have shown that there is a need to increase seed rate for higher yields. In place of 100 kg/seed/ha, the use of 125 kg/ha has been recommended for medium-grain sized varieties. For bold-seeded varieties, a further increase by 25% is recommended. Under late-sown conditions, the seed rate is recommended to be increased by 25%. Under broadcast sowing, also, seed rate is increased by 25% over the normal recommendation.

Attempts are now in progress to standardize management practices for minimal/zero tillage technology, which may have different crop management needs.

Table 3. Average response (over three years) of latest varieties for the North Eastern Plains Zone to important cultural variables.

Variable	Level	Yield (t/ha)
Date of sowing	End Oct.-Beginning Nov.	3.88
	Mid-November	4.04
	Mid-December	3.15
Fertilizer levels	0:0:0	2.44
	40 N:20 P:14 K	3.11
	80 N:40 P:27 K	3.73
	120 N:60 P:40 K	4.52
Irrigation levels	One	3.72
	Two	4.13
	Full	4.46

Using Phasic Development Differences in Wheat to Overcome Heat Stress in Northern Thailand

K. Vongburi
Phrae Rice Research Center, Phrae, Thailand

Abstract

In Thailand wheat is grown during the cool and dry season from late October to late February following rice in the preceding hot and wet (monsoon) season, under either rainfed or irrigated production systems. The former, in highland and upland areas, is dependent on stored soil moisture reserves. Planting has to occur on selected soil types and under supra-optimal temperatures if grain development is to occur before soil moisture is depleted. Under irrigated production, seeding has to be delayed until the harvest of the later flowering paddy rice. Temperatures are more favorable for wheat at that time although still above the optimum. Temperature increases after December, and together with a rapid increase in vapor pressure deficits, contribute to increasing environmental stress over the concluding stages of the life cycle.

Based on the finding that the duration of the stem/ear growth and grain development periods are relatively constant over genotypes, location and seeding dates, it is possible to predict when the vegetative phase would have to occur and when maturity should occur. The duration of the vegetative phase varies with genotype and seeding date. With the exception of Chiang Rai, considered the most suitable environment for both production systems, the appropriate genotypes would include those that do not respond to vernalization and are intermediate in their basic vegetative period (BVP). At Phrae, considered to be marginal for either production system, genotypes combining a zero response to vernalization with a short vegetative period represent the only prospect.

Introduction

In warmer tropical countries, heat is the major constraint to temperate cereal production. In northern Thailand, heat may affect wheat at the beginning (seeding) or later (grain-filling period) in the wheat's life cycle. Using a wheat variety having a suitable phenological development pattern which properly fits into the climatic conditions of northern Thailand, in association with appropriate management practices such as date of planting and mulching, may reduce the heat problem.

General Geography of Northern Thailand

Northern Thailand is located between 17°N and 21°N latitude and 97°E and 102°E longitude. It is represented by mountainous and forested highlands, with altitude ranging from 150 masl to about 2,000 masl of high mountain ranges in the north and northwest. There are alluvial plains in the river valleys, where intensive cultivation and cities are found, with altitude ranging from 150 to about 500 masl, and regarded as "lowland" areas.

The climate of northern Thailand is referred to as Tropical Savannah (Am). Seasonal climatic conditions are characterized by a rainy season from May to October, a cool dry season from November to February, and a hot dry season from March to May (Nuttonson 1963).

Climatic Variation of Northern Thailand

Because of major variations in altitude and a spread in latitude, there are variations in climatic conditions during the course of a year and between locations.

Temperatures

High mean maximum temperatures (>30°C) are a major feature of northern Thailand, with limited variation between sites (±4°C). There is some seasonal variation, being lower in November/December/January (26-32°C) and increasing to 32-37°C in March/April/May (Figure 1a). In contrast, mean minimum temperatures vary considerably with season (Figure 1b) so that seasonal variation in mean temperature reflects more the variation in the minimum rather than maximum temperatures.

Rainfall

Rainfall is distinctly seasonal and ranges widely from about 800 to more than 2000 mm. This may vary considerably from year to year under the influence of South China Sea typhoons or depressions that approach and pass over the region.

Approximately 90% of the annual rainfall occurs between May and October (Sukasem and Chotiwanwirat 1987). In the period from November to April, during the wheat growing season, when about 10% of the annual rainfall is received, the number of rainy days ranges from 4 (Chiang Mai) to 21 (Chiang Rai). December to February are the months with minimum rainy days in all river basins (lowlands), less than one day per month.

Fog and dew can be important sources of water for crops, particularly during a cool dry season. Fog and dew are highest during the winter.

Evaporation and relative humidity

Evaporation data are characterized by a relatively constant level of 100-150 mm/month from June to February (Figure 2a), rising rapidly in the period from March to

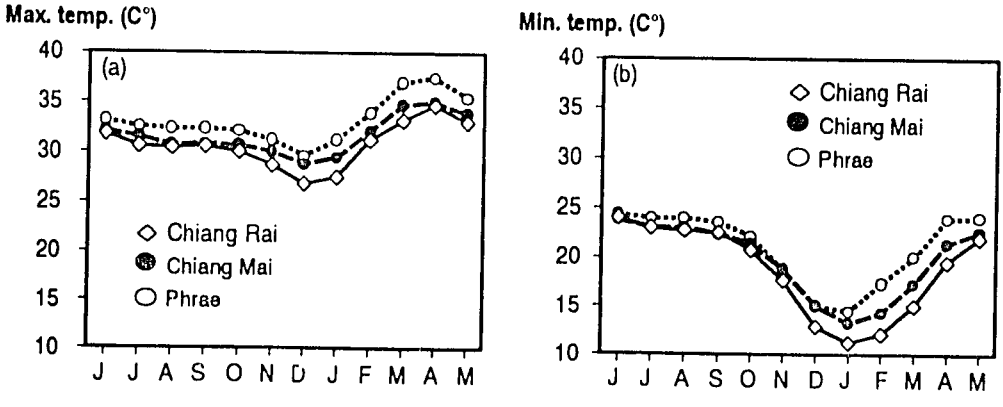

Figure 1. Mean maximum (a) and minimum (b) temperatures at Chiang Rai (19°54'N, 394 masl), Chiang Mai (18°47'N, 314 masl), and Phrae (18°13'N, 162 masl), northern Thailand (means of 1956-1985).

May and coincident with a corresponding decrease in relative humidity from February to April (Figure 2b). Although annual evaporation is lower than annual precipitation, monthly evaporation during the seasonally dry (cool) period from October to April is greater than precipitation. Under rainfed conditions this can lead to soil water deficits during the cool season.

Sunshine, cloud cover, and solar radiation
Solar radiation and actual sunshine (Figure 3) are strongly influenced by cloud cover. Astronomically possible sunshine (photoperiod) varies from 13.3 to 10.8 at Chiang Mai, a central location. A significant feature of these data include a rapid increase in sunshine hours and solar radiation during the cool period from October to February coincident with reduced cloudiness.

Farming Systems and the Place of Wheat in Northern Thailand's Agriculture

Field crop production is dominated by the cultivation of rice under irrigation during the rainy season from late May-December (with soil preparation and planting in June and July and harvest during November and December).

Data from the 1988-89 dry season show that field crops (soybean, tobacco, and garlic), vegetable crops, or a second rice crop are grown over 190,000, 30,000, and 10,000 hectares, respectively. They are planted after the harvest of paddy rice. Such plantings are generally confined to those areas where irrigation water is available for all or most of the cool/dry season.

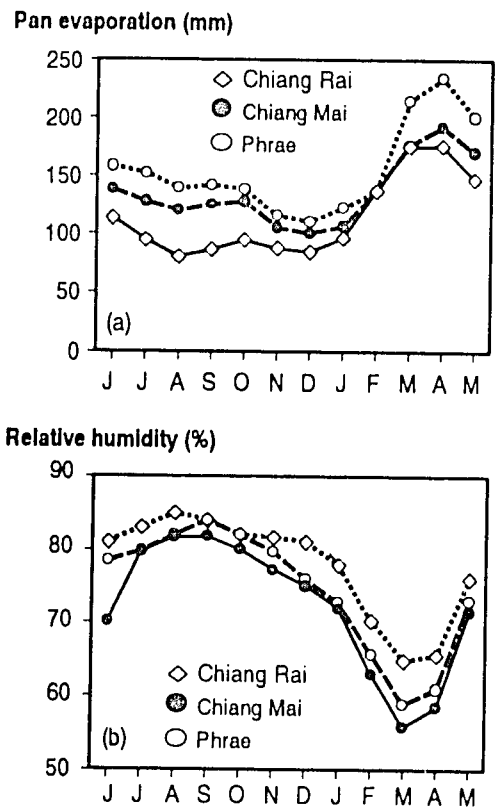

Figure 2. Mean evaporation (a) (A-pan, mm/month) and relative humidity (b) at Chiang Rai, Chiang Mai, and Phrae, northern Thailand (means of 1956-1985).

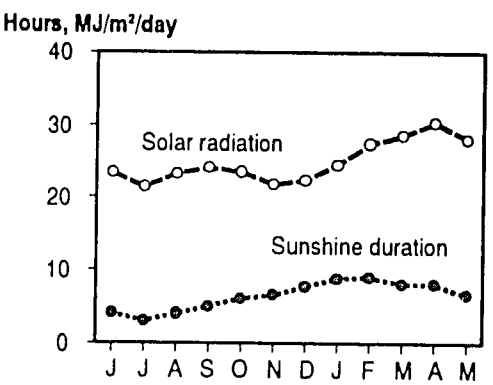

Figure 3. Mean sunshine duration (hours) and solar radiation (MJ/m²/day) at Chiang Mai, northern Thailand (means of 1985-1990).

Wheat would be an alternative "cool" season crop, in any one of three situations:

- In the highlands, where altitudes range from 700 to 1,600 m; temperatures during the cool dry season (October to February) most closely approximate the conditions to which wheat is adapted. Irrigation systems are not generally available. Wheat production is restricted to selected locations and soil types, and largely dependent on stored soil moisture, unpredictable rainfall over the winter period and fog or dew at night and early morning.

- In the uplands, where altitudes are lower, and the topography is flatter, wheat is grown following the monsoon season based on stored soil moisture. In this situation, monsoon-grown maize, cotton, peanuts, soybean, and upland rice are usually harvested by late September to early October when temperatures are still high and rainfall possible. However, wheat cannot be sown until late October when temperatures have decreased, but by then rainfall has diminished thus the same constraints apply as those indicated for highland areas. In both situations the potential for production is limited and seasonally variable.

- In the lowlands, there is potential for commercial wheat production due to the availability of irrigation. It is estimated that 350,000 ha of paddy fields could be available for irrigated wheat after the rice crop is harvested. However, rice is generally harvested late (late November to early December) due to the use of photo-sensitive and local late maturing rice varieties. In this situation the potential wheat yields are limited as the wheat growing season is short and the crop risks heat exposure during later growth stages.

How Wheat Is Affected by Heat

From the discussions of possible wheat cropping systems above, wheat could be affected by heat at seeding (for rainfed upland wheat) when sowing is early, or during the grain filling-period (for irrigated lowland wheat) when sowing is later. Most of the rainfed wheat in northern Thailand is produced in areas having good soil moisture storage at seeding, and although some rainfall usually occurs during the cool season, prolonging the sowing date to early November (when temperatures are lower), it is limited by water depletion at the conclusion of the wheat life cycle. For irrigated wheat following paddy rice, planting is usually late due to the preceding rice crop being harvested in late November/ early December. The risk of lowland irrigated wheats being exposed to excessive heat during grain-filling is therefore high. The effect is more severe if a late-maturing wheat variety is used.

The effect of heat at anthesis and during grain-filling due to late planting is widely recognized in northern Thailand as it reduces grain yield, number of grains/ear, grain size, and height (Julsrigiva[illegible]d Tiyawalee 1982, Na-Lampang et al. 1985, Sukprapan et al. 1985, Meechoui 1988) and results in short durations from emergence (E) to terminal spikelet (TS) (Meechoui 1985) from emergence to double ridge (DR), and from ear emergence (EE) to maturity (MTY). However, when seeding was delayed to mid-January the duration from E-DR was similar to that from late December sowing (Meechoui 1988). In northeast Thailand, late planting reduces durations (in days) of all developmental periods (from E-DR, DR-TS, TS-EE, and EE-MTY) (Singtonart 1989).

Laboratory experiments have shown that high temperatures (43°C) up to 24 hours at seeding severely reduced germination and seeding survival of "Gutha" wheat. This was due mainly to reductions in seed cell division, respiration rate, and soluble carbohydrate in the endosperm (Jongdee 1990). Temperatures of this magnitude have been recorded at the 1-cm soil depth at Chiang Mai (Vongburi 1992).

Phasic Development Differences in Wheat and Its Response to Sowing Date at Chiang Mai

A seeding date study (Vongburi 1992) was conducted at Chiang Mai on 16 wheat genotypes, which had previously been categorized for responsiveness to vernalization and photoperiod, and for their basic vegetative period (BVP = the duration from emergence to ear emergence after requirements of vernalization and photoperiod had been satisfied).

Results showed that the most sensitive developmental period was the vegetative phase, emergence to double ridge. It became progressively shorter as seeding date was delayed from 11 October to 25 December (Table 1).

The reduction in the length of this phase between the planting date extremes was 32-69% (based on days) or 46-73% (based on °Cd) depending on varieties (Table 2). This finding indicated that very high (soil) temperatures during the vegetative stage delayed phasic development.

Duration of the vegetative stage was highly correlated with duration to ear emergence (r^2 = 0.73**-0.96**) and to vernalization requirement (r^2 = 0.62**-0.87**) although correlations with BVP were poor. The durations to DR and to EE were not correlated with yield per plant from the November planting, but tended to be negatively correlated with yield in the late December planting (yield data were not collected from October sowing dates).

The reduction of the vegetative phase was comparatively larger for the genotypes responsive to vernalization and/or having a long BVP. The other development periods (DR-TS, TS-EE, EE-MTY) were little affected by sowing dates, irrespective of responses to vernalization or photoperiod, or the length of the basic vegetative periods, although ear growth (TS-EE) tended to be extended and grain-filling (EE-MTY) reduced at the last seeding date.

How to Overcome Heat Stress

Methods have been proposed by many researchers for wheat to avoid heat stress in hot environments. One such solution is to use a variety having a development pattern that best fits the climatic conditions. Generally, these have been early or medium-maturing genotypes that avoid the

Table 1. Mean durations in °Cd (days in parentheses) for successive development periods (means of 16 genotypes) for four sowing dates at Chiang Mai, Thailand.

Stage	Oct. 11	Oct. 25	Nov. 26	Dec. 25
S-E	105 (4)	106 (4)	113 (5)	118 (5)
E-DR	818 (33.3)	626 (26.8)	415 (20.2)	337 (16.1)
DR-EE	643 (29.5)	650 (30.2)	578 (27.8)	649 (30.0)
EE-M	644 (30.6)	631 (30.0)	637 (29.2)	684 (26.5)

See text for abbreviations.

high temperatures during grain-filling. Some researchers have proposed a genotype having a shorter grain-filling period and having a high seed/ear accumulation rate. For wheat grown in late November and December at Chiang Mai, genotypes having 3-4 days shorter grain-filling period than the mean of all genotypes were identified.

Although the current varieties released in Thailand appear to have appropriate development patterns, they are highly sensitive to seeding dates. Saunders (1990) collected data from many sources to compare the effect of sowing date on grain yields of Inia 66 in northern Thailand and found the yields ranged from less than 0.5 t/ha up to more than 5 t/ha. The optimum seeding dates were in November. However, for rainfed wheat, late October or early November have been suggested as optimal (Intawong 1981, Aggarwal and Penning de Vries 1989).

From the studies on the phasic development of wheat genotypes and their reactions to agro-climatic variables, it was concluded that wheats of the 01I development type (see Table 2) should be best adapted to northern Thailand environments. Analyses showed that the most broadly adapted varieties (Fang 60, Samoeng 2) are of this development type and are characterized by a variable duration of the vegetative phase,

Table 2. Duration in °Cd (days in parentheses) for the development period, emergence to double ridge, of 16 genotypes sown at four seeding dates at Chiang Mai, Thailand.

Variety names	Sowing dates				Response classes
	Oct. 11	Oct. 25	Nov. 26	Dec. 25	
Lerma Rojo	1376 (59)	1055 (47)	485 (23)	486 (24)	22L
Sonora Sharbati	434 (17)	372 (16)	255 (13)	192 (9)	01S
Inia 66	713 (29)	513 (21)	380 (19)	338 (16)	11S
Choti Lerma	847 (34)	605 (26)	463 (22)	367 (17)	01I
M1988	618 (24)	569 (23)	380 (19)	309 (15)	02I
Warrigal	982 (40)	736 (31)	471 (23)	338 (16)	12L
AUS20741	1344 (58)	1001 (45)	513 (25)	367 (18)	12S
Eradu	-	798 (34)	478 (23)	360 (17)	12I
77W/550	909 (37)	568 (24)	419 (20)	316 (15)	01I
Tincurrin	569 (22)	544 (22)	387 (19)	309 (15)	02I
Bodallin	556 (22)	360 (15)	419 (20)	295 (14)	01I
Canna	640 (25)	463 (20)	314 (16)	236 (11)	021
75Z/555	520 (20)	419 (18)	328 (16)	268 (13)	01I
CEP74138	921 (37)	702 (30)	485 (23)	500 (24)	01L
LD33761	1237 (52)	909 (40)	499 (24)	467 (23)	11L
Yecora Rojo	602 (23)	408 (17)	358 (18)	236 (11)	00I
Means	818 (33.3)	626 (26.8)	415 (20.2)	337 (16.1)	

Responses classes determined from experiments in Perth, Australia. First digit: response to vernalization, 0=0-5 days, 1=6-10 days, and 2=11-15 days; second digit: response to photoperiod, classification as above; third letter: basic vegetative period, S (short, 30-34 days), I (intermediate, 35-39 days), and L (long, 40-44 days).

depending on seeding date, followed by relatively constant durations of the DR-EE (630°Cd) and EE-MTY (650°Cd) stages. From climatic analyses, optimal dates for double ridge, ear emergence, maturity, and hence seeding date can be proposed. For most of northern Thailand, for rainfed wheat, these would be late-November (DR), mid-December (EE), and mid-January (MTY) with seeding in early December, and for irrigated wheat, mid-December (DR), mid-January (EE), and mid-February (MTY) from seeding in mid-November. In the more favorable environments such as Chiang Rai and Mae Hong Son, a later maturing variety, sown 7-10 days earlier, could take better advantage of the milder climatic conditions. For more marginal areas such as Phrae in the southern part of the region, a similar seeding date, but using an early-maturing genotype, would minimize the effects of environmental stress.

It is considered that, even in favorable environments, where late planting cannot be avoided, an early variety that flowers before temperatures increase, has rapid accumulation of leaf area and dry weight before flowering would be superior.

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Questions/Discussion

Dr. Vongburi was asked if his predicted optimum date for ear emergence as 7 January for irrigated wheat had been confirmed by seeding date experiments. He explained that the optimum date for ear emergence was based on average data for 011 genotypes (current Thai recommended varieties). It is 7 January for most of northern Thailand, although in the cooler climate of Chiang Rai, it is about 22 January. These were predicted dates; the revised optimal dates are about seven days later from a 15 November sowing.

AGRONOMY

Determining Yield Constraints for Wheat Production in Bangladesh

M. Badaruddin, D.A. Saunders, A.B. Siddique, M.A. Hossain, M.U. Ahmed, M.M. Rahman, and S. Parveen
Wheat Research Centre, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur, Bangladesh

Abstract

During 1984-85 through 1987-88, there was an apparent decline in wheat yields. Different groups (scientists, extension personnel, and Bureau of Statistics) have suggested this decline could be due to changes in climate, changes of the wheat area to more marginal areas, increase in cropping intensity accompanied by minimal input use, and increase in soil and plant pathogens. Results from agronomic experiments carried out by the Wheat Research Centre during 1983-91 indicated that planting wheat later than 1 December, less than optimal applications N, P, K, and S nutrients and virtually no use of micronutrients, low plant populations, use of old disease-susceptible varieties, and no measures for plant protection were the major constraints to high wheat yields. This paper considers those factors that are causing real losses in farmers' production or are constraints to achieve the potential yields promised by the newer wheat varieties.

Introduction

The development and introduction of semidwarf high yielding wheat varieties had a highly significant impact on both area and production of wheat in Bangladesh. Area and production of wheat increased significantly from 1974 through 1985. Wheat production growth rate during this period was almost 40% annually. However, both area and production declined by 11.6% from 1985-86 to 1987-88, although they have stabilized in recent years.

The production decline was partly associated with reduced wheat area, but it has been observed that productivity (yield) also decreased. Decrease in area occurred due to a rapid expansion of winter rice (Boro) cultivation with the increase in irrigation facilities from 1985. Expansion of Boro rice also caused a progressive movement of wheat from more favored traditional wheat land to more marginal land.

Temperatures during the wheat season were often higher than average during the period of yield decline. Elevated temperatures affect early wheat development and reduce potential yield by reducing tillering and spike size, while increased temperature in the grain-filling period reduces individual grain size. In addition, there can be indirect effects of increasing temperature in encouraging the development of *Helminthosporium* species. While both changes in area and high temperatures may be contributing to a yield decline, there is a stronger line of thought that suggests that the increase in cropping intensity accompanied by less than optimal input use and zero return of crop residues to the fields are leading to depletion of inherent soil nutrient reserves. Responses of crops to

nitrogen, phosphorus, potassium, sulfur, and zinc have become evident over recent years. More nutrients, especially boron, magnesium, molybdenum, etc. are reaching critical levels. In addition, under-fertilized crops become less tolerant of plant pathogens and consequently the relative yield loss due to pathogens becomes greater.

Long duration, high yielding rice varieties are being used as Aman rice (preceding the wheat crop). These rice varieties are normally harvested in December. This, in turn, results in late wheat planting. Late planting is further aggravated by the long turn-around time between crops due to difficulties of seedbed preparation with a country plow and bullocks or difficulties due to late monsoon rains.

Yield losses in late sown crops could not be reduced by increasing seeding rate, fertilizers or other management levels. But a great deal of improvement has been evident by using disease resistant varieties or controlling foliar diseases. The nitrogen response and efficiency of late-sown crops is very low compared to optimum-sown crops. Incidence of disease (leaf spot and rust) is higher at late seeding dates.

Achieving optimum plant populations in farmers' fields has been a complex problem for wheat agronomists. Plant establishment is commonly less than 50% of seed sown. This may be associated with loss of viability in storage, seeding method, seedbed preparation, soil moisture, and/or soil pathogens, insects or nematodes. Sometimes, birds attack seedlings after emergence.

Research results concerning the major constraints to wheat production are discussed in this paper.

Production Constraints

Major constraints limiting wheat production in Bangladesh are socioeconomic and technical. Socioeconomic constraints primarily deal with policy decisions, concerning such aspects as seed storage capacity, availability of inputs in time, easy access of farmers to the national credit system, adequate support price, and stable marketing systems (Ahmed and Elias 1986). Technical limitations, both biotic and abiotic, are imposed by environmental factors.

Socioeconomic constraints

Seed storage and supply—Over 80% of the total seed required by farmers is supplied from the farmers' own storage. Farmers' storage conditions are poor due to uncontrolled heat and moisture, and in addition, seed quality often deteriorates due to insect and rat attacks. On-farm survey data (Ahmed and Clements 1983) indicated that about 50% of farmers had below standard seed in their storage. Government controlled storages are good, but can only supply about 15 to 20% of total seed required by the farmers.

Financial support—Lack of capital and poor or no access of farmers to the national credit system means farmers normally cannot buy necessary inputs. It has been reported from farm surveys that about 70% of the farmers could not increase their wheat areas because of financial constraints.

Marketing and support price—The marketing price is very unstable in Bangladesh for almost every crop. Although the Government declares prices for procurement of wheat, the market price is very often lower than that declared by the Government. Farmers have to sell their produce immediately after harvest for cash

to finance the following crop and cannot hold the produce for the higher price available under the procurement scheme. As a result, the middle-man makes more money on the crop than the farmers, simply by keeping the grain for a few months.

Technical constraints

Abiotic—In Bangladesh, the major soil group is flood plain (80%) crossed by the three large rivers and their tributaries. The other two major groups are hill (11%) and terrace (8%) areas. About 3 million hectares of this land are suitable for wheat production. However, wheat production is mainly concentrated in north and northwestern parts of Bangladesh. The total land area under wheat is around 600,000 ha. Further expansion is limited by factors other than soil.

Climatic data averaged over 72 years indicate that temperature is generally constant from April to September. The coolest month is January (mean temperature 18.6°C). Relative humidity is the lowest in March and April, approximately 50%, and during the wheat season ranges from 70 to 80%. From November to March, the total rainfall ranges from 150 mm in the southeast zone to 50 mm in the northwest zone. Wheat production is limited by elevated temperatures in the latter part of growing season and by low rainfall where irrigation facilities are not available. Sometimes, early monsoon rains and hail damages the crops particularly in the southwestern districts.

Biotic—Environmental conditions discussed above determine biotic stresses, especially disease epidemics that severely reduce wheat production. Although genetic resistance has provided effective control of leaf rust in new commercial varieties, leaf blotch (*Helminthosporium* spp.) epidemics are still quite prevalent. In 1990-91, Sonalika, an old commercial cultivar (susceptible to leaf rust) and Kanchan, a newer variety (now very well accepted by farmers and resistant to leaf rust), were treated with Tilt-250 EC at 0.125 kg ai/ha (which controls both leaf rust and helminthosporium leaf blotch) at 35, 55, and 75 days after emergence. Table 1 clearly indicates that yield losses due to foliar diseases are dependent on environment and time of seeding. Late-planted crops (with higher temperatures after flowering) and crops planted in the southern, hotter, area (Hathazari, near Chittagong) were more affected.

A farmers' field survey in the northern districts showed only about 50% of viable seeds sown produced plants (Saunders 1990). This is a complex problem. It may be associated with low viability seed from

Table 1. The effect of Tilt application (yield increase over unsprayed check, %) under optimum and late planting conditions.

Sowing time	Variety	Sites					Mean
		Dinajpur	Jessore	Jamalpur	Joydebpur	Hathazari	
Optimum (30 Nov.)	Sonalika	3	24	28	0	35	18.0
	Kanchan	0	5	2	10	20	7.4
Late (30 Dec.)	Sonalika	31	68	16	42	229	71.0
	Kanchan	9	33	0	17	147	41.2

farmers' storage, low soil moisture at seeding, the seeding method (the broadcast and incorporation method results in a high proportion of seed either left too near the surface or buried very deep in the soil), soil fungi, insects or nematodes. Significant responses in plant population to seed treatment by Vitavax-200 (at the rate of 3 g/kg) and soil incorporated insecticide (Furadan at 0.4 kg ai/ha) was observed. Yield increases by Vitavax-200 and Furadan were similar and were from 10 to 15% on average. When both the chemicals where applied together, yield was increased by up to 26% in farmers' fields, and by an average of 30% at various seeding dates on research stations (Table 2).

Predominant soil pests appear to be *Sclerotium rolfsii*, *Rhizoctonia* spp., wire worms, and the root-knot nematode (*Meloidogyne* spp.). Nematode galls are observed on wheat roots in light soil areas.

Yield constraints due to management and inputs—Over 60% of the total wheat crop is being planted late (December and January) due to the late harvest of transplanted aman rice. A long turn-around time between the aman harvest and wheat seeding due to traditional methods of seedbed preparation, and occasional late monsoon rains, forces farmers to plant their wheat crop late (Badaruddin et al. 1991). Pooled data from three sites and two varieties over a number of years show that when wheat was sown later than 1 December, the yield reductions were 49 kg/ha/day and 33 kg/ha/day in high (120 N:60P_2O_5:40K_2O:20S) and low (40 N:40P_2O_5) fertility conditions. These reductions represent a loss of 1.3% per day from the potential yield of wheat sown at the optimum date. These declines could not be reduced by higher seed rates than recommended (Table 3) or by providing better fertility.

However, varietal differences were found. Kanchan, the new variety, and Sonalika, the older variety it has almost replaced, were similar in yield at optimum seeding dates, but were quite different when seeded late (Table 4).

Table 2. The effect on grain yield (t/ha) of Vitavax-200 seed treatment, and soil-incorporated Furadan.

Date source	Control	Treated with Vitavax	Treated with Furadan	Both Vitavax and Furadan
Research station[a]	1.94	2.34	2.20	2.51
Farmers' field[b]	2.80	3.27	3.20	3.54

[a] Research station data are means of optimum (30 Nov.) and late (30 Dec.) sowings.
[b] Farmers' fields sown near the optimum seeding date.

Table 3. The effect of seeding rate on the yield reduction (%, mean of eight varieties) from seeding on 15 December, compared to one month earlier.

	Seed rate (kg/ha)				
Location	80	100	120	140	160
Joydebpur, irrigated	27	24	23	22	23
Jessore, irrigated	45	45	46	46	46
Jessore, rainfed	34	34	31	28	30
Mean	35	34	33	32	33

Late-sown crops do not respond up to the same nitrogen levels as optimum-sown crops (Table 5), and at any nitrogen level, the nitrogen-use efficiency is lower.

Thus, yield reductions due to late planting do not appear affected by seed rate or (nitrogen) fertility levels. If late planting persists in the country, yield increases seem most likely through varietal improvement.

Yield maximization trials have been carried out in both experiment stations and farmers' fields. On experiment stations recommended nitrogen, phosphorus, potassium, sulfur, magnesium, boron, and organic manure (cowdung) were applied and compared with the low fertilizer rates used by farmers. From 14 experiments during two years over seven sites, it was found that soil fertility could explain at least 25-40% of the yield variability. However, although organic matter of the research sites was low (about 1%), responses to organic manure were not significant at any site (in the year of application).

Large-plot demonstrations have been conducted with recommended N, P, K, S, Zn, B, Mg, and 10 t cowdung/ha in farmers' fields to maximize yield. Grain yield of wheat from these trials was from 5.0 to 6.6 t/ha (Table 6).

Table 4. The yield advantage of Kanchan (% increase over Sonalika) in relation to seeding dates.

	Seeding date					
Location	1 Nov.	15 Nov.	1 Dec.	15 Dec.	1 Jan.	15 Jan.
Jessore[a]	29.2	1.5	9.8	7.2	19.8	22.4
Ishurdi[a]	15.5	12.7	-1.6	10.2	41.1	53.8
Dinajpur[b]	20.9	10.3	4.0	25.9	40.4	66.2

[a] Means of four years.
[b] One year's data.

Table 5. The efficiency of nitrogen application (kilograms of additional yield per kilogram of nitrogen applied) within the maximum response range.

Location	Seeding date	Response range (kg N/ha)	Response efficiency (kg yield/ kg N)
Dinajpur	Optimum	0-120	17.3
	Late	0-30	16.5
Ishurdi	Optimum	0-60	22.5
	Late	0-60	19.8
Jessore	Optimum	0-60	23.6
	Late	0-30	16.7

Table 6. Yields obtained in yield maximization demonstrations in farmers' fields, 1990-91.

Site (district)	Yield (t/ha)
Nilphamari	6.60
Rangpur	6.24
Dinajpur	6.25
Rajshahi	5.55
Dhaka	5.06

Over the past few years, head sterility has been observed in the northern zone. Soil analyses in these areas showed low organic matter content (< 1%). All major, and some of the minor elements, such as boron, zinc, and molybdenum, were below established critical levels. Head sterility of wheat in this region has been presumed to be associated with soil fertility, especially with deficiency of boron, although some environmental factors are likely to have affected the overall sterility problems. Farmers' field demonstrations with boron and molybdenum showed that wheat yield was increased by up to 24% with both boron and molybdenum (Table 7).

Experiments on micronutrients are still on-going. Among these, experiments are examining boron application method and the residual activity of a boron application on the incidence of head sterility.

Soils in the northern wheat growing areas have pH in the range of 5.0 to 6.5. These soils contain relatively high amounts of soluble iron. As a result, applied phosphorus efficiency is relatively low. Banded phosphorus has an advantage in these soils. Experiments on banded phosphorus have indicated the phosphorus efficiency from banding with the seed may be at least double compared to the traditional broadcast and incorporated method.

Table 7. Yield increases (% of check) from the application of boron and molybdenum in which head sterility has been observed (number of on-farm tests in each area is in parentheses).

Site	Boron (B)	Molybdenum (Mo)	B + Mo
Jessore	25.3(4)	0.8(2)	6.8(2)
Dinajpur	11.2(5)	4.0(1)	23.8(3)
Nilphamari	6.0(5)	1.6(3)	13.9(2)
Kurigram	10.0(2)	22.2(1)	18.0(2)
Gaibandha	3.9(3)	3.7(2)	-
Rangpur	6.0(10)	22.3(5)	5.7(6)
Mean	10.4	9.1	13.6

Conclusions

Crop management research at the Wheat Research Centre has been addressing the major wheat production constraints and developing technologies to eliminate practical field problems. More recently, crop management research has been considering problems in wheat-based cropping systems in order to sustain or increase national yields on system bases. In this context, soil fertility, tillage practices, and plant establishment related problems are being addressed to define the major production constraints restricting the high yields promised by the newly developed wheat varieties.

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Questions/Discussion

Dr. Badaruddin, in answer to a question regarding the benefits of increasing fertilizer, particularly nitrogen, application rates under heat or water stress conditions, considered that yield increases were unlikely. Under late planting conditions in which terminal heat is a problem, two years' data indicate that response efficiency is lower than that at optimum planting and that the peak response is at a lower nitrogen rate. Further, under rainfed (water-stressed) conditions, peak responses are lower than under fully irrigated conditions.

When asked to prioritize the constraints to wheat yield in Bangladesh, he said the most important constraints were late planting and the use of less than optimum fertilizer applications. These are followed by the problem of low plant population, which has been addressed in research, resulting in the current extension thrust on the use of fungicide seed dressing. The viability of farmers' seed is also a factor in low establishment rates and in answer to a question whether farmers were advised to conduct seed germination tests on their stored seed, Dr. Badaruddin felt that, while this could help, a more appropriate approach would be to influence farmers to use better storage methodology developed from research, and this is also a subject of current extension thrusts.

Tillage Methods for Wheat after Rice in Paddy Soils in Thailand

B. Jongdee
Phrae Rice Research Center, Phrae, Thailand

Abstract
Wheat was introduced into Thailand's lowland rice-cropping system some 10 years ago. A major factor contributing to the success of wheat under these conditions is soil management. The studies discussed in this paper indicate that wheat sown in a seedbed prepared by conventional tillage produced higher yields than with zero tillage. However, when a rice straw mulch was spread after seeding, yields from conventional and zero tillage were similar.

Introduction

Wheat has been cultivated for more than 30 years in upper northern Thailand on small areas to supply a local specialty market. This has been under rainfed conditions after upland crops such as maize and yields have been limited and unstable due to the lack of soil moisture, particularly during the grain-filling period.

In recent years, national consumption of wheat has been increasing substantially and with a view to at least partially substituting some of the imports with local production, the Government has placed increased emphasis on research and the development of production in northern Thailand, particularly on the irrigated lowland areas following rice. Although still a small area, this cropping pattern of lowland rice-wheat is increasing. A major constraint to successful wheat production in these conditions is soil management.

This paper discusses tillage systems, soil problems, and some agronomic management issues for wheat after rice in northern Thailand.

Tillage Systems

Traditional tillage

In the farmers' fields, the soil is left to dry following the harvest of rice. A two-disc plow attached to a two-wheel tractor is the implement normally used to prepare the seedbed. Often, the standing rice straw is excessive and is cut at ground level and burned or removed from the field and used as soil mulching on another crop. Traditional tillage can consume much time and labor, particularly on very compact soils or where weed infestations are heavy. However, farmers are accustomed to plowing the soil, particularly to control weeds.

Minimum or zero tillage

In these systems, the rice straw is cut at the soil level and burned or removed from the field. Where the straw is removed, some weeding of the field by hoe or knife may be necessary. The land is then cut into beds by using the two-disc plow to make irrigation/drainage channels 2-5 m apart, depending on soil type and slope of the land. Soil from the channels is spread across the bed between the channels. Small fields, or very level well-drained ones, may only require a drainage channel around the perimeter.

Traditional tillage versus minimum and zero tillage

Initially, a complete tillage package was recommended to farmers in order to prepare a seedbed suitable for wheat. However, due to the poor soil structure and compactness of these lowland paddy soils, seedbed preparation was extremely expensive and time consuming. Soil tillage research was initiated with the objectives of minimizing seedbed preparation costs and optimizing the yield levels.

A study was conducted at Chiang Mai (Jongdee and Limpiti 1987) on a sandy loam soil (bulk density 1.52 g/cc; organic matter 1.3%), which had grown two rice crops per year over a number of years, to compare conventional tillage systems (utilizing disc plow and rotary hoe) with a zero-tillage system. The full seedbed preparation, when sown at the same time as the zero tillage treatment, resulted in yields nearly 11% higher (Table 1). The higher grain yield may have been associated with lower bulk density (Table 2) and superior root growth (Table 3) following full (plow plus rotary hoe) preparation. Meechoui and Polwong (1988) also reported that yields following zero tillage were nearly 9% lower than with conventional tillage.

Table 1. A comparison of different tillage methods on wheat yield and yield components at Chiang Mai, Thailand.

Tillage methods	Grain yield (t/ha)	Total biomass (t/ha)	Spikes per m²	Grains per spike	1000-grain weight (g)
Plow+Rotary	1.86	24.27	260	28	32.8
Rotary	1.80	21.61	238	27	33.3
Zero-tillage	1.68	23.18	264	23	33.9

Source: Jongdee and Limpiti (1987).

Table 2. The effect of tillage method on soil bulk density (g/cc) at 30 and 60 days after emergence (DAE).

DAE	Tillage methods	Depth (cm)				
		0-10	10-20	20-30	30-40	40-50
0	-	1.52	1.69	1.75	1.79	1.71
30	Plow+rotary	1.47	1.77	1.88	1.90	1.88
	Rotary	1.50	1.70	1.84	1.86	1.86
	Zero-tillage	1.55	1.73	1.89	1.91	1.91
60	Plow+rotary	1.50	1.80	1.88	1.87	1.89
	Rotary	1.52	1.68	1.88	1.87	1.87
	Zero-tillage	1.56	1.78	1.84	1.82	1.85

Source: Jongdee and Limpiti (1987).

Tillage Methods Associated with Planting Methods

It has been recommended that wheat should be row-seeded at a 2-4 cm depth. No seeders are currently available for wheat in Thailand and the normal farmer practice has been to open a small furrow with a hand hoe after which the seed is sown by hand. This is impractical in soil that has not been cultivated.

Broadcast sowing was therefore investigated. When wheat seed and fertilizer were broadcast on uncultivated soil and covered with a rice straw mulch, the yields were not different from sowing in furrows.

This technology was then extended to farmers' fields and results have been consistently good (Table 4). Farmers have found, however, that when the fields are irrigated immediately after sowing, there is some movement of seed and fertilizer. They have suggested that this problem is largely overcome by waiting two or three days after broadcasting the seed/fertilizer and spreading the rice straw, before irrigating.

Pre-irrigation before seeding has been suggested as a means to avoid waterlogging during the establishment phase (Saunders 1985). Recent research (P. Hanviriyapun, pers. comm.) has shown that pre-irrigation before broadcast seeding and mulching on zero-tilled soil improved plant establishment by 42% (and improved plant population uniformity) and increased yield by 10% compared to irrigating after the seeding/mulching operation.

Table 3. The effect of tillage methods on root length density (cm/cc soil).

Tillage methods	Root length density (cm/cc soil) 15 DAE Depth (cm) 0-20	15 DAE 20-100	45 DAE Depth (cm) 0-20	45 DAE 20-100	75 DAE Depth (cm) 0-20	75 DAE 20-100
Plow+rotary	0.82	0.02	1.18	0.05	0.73	0.04
Rotary	0.60	0.02	0.77	0.05	0.84	0.06
Zero-tillage	0.61	0.02	0.88	0.12	0.62	0.03

Source: Jongdee and Limpiti (1987).

Table 4. Wheat yields (t/ha) following different tillage and planting methods in farmers' fields at five locations in northern Thailand.

Tillage and planting methods	Location 1	2	3	4	5	Ave.
Tillage+drill	2.0	1.6	2.1	2.4	2.8	2.2
Tillage+broadcast+mulch	2.5	1.9	2.5	3.3	2.8	2.6
Zero-tillage+drill+mulch	2.8	1.6	2.2	3.4	3.2	2.6
Zero-tillage+broadcast+mulch	2.5	1.7	2.5	2.8	3.0	2.5

Conclusion

Wheat production in the lowland areas of northern Thailand is slowly increasing. Farmers are enthusiastic for zero or minimum tillage technology. It is concluded that to obtain reasonable yields with zero tillage, straw mulching is required to cover the seed and/or reduce evaporation and soil surface temperatures. It is recognized, however, that zero tillage may not be appropriate on very compact soils.

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Soil Physical Factors Limiting the Productivity of the Rice-Wheat Rotation and Ways to Reduce their Impact through Management

P.R. Hobbs
International Maize and Wheat Improvement Center, Kathmandu, Nepal
T. Woodhead
International Rice Research Institute, Los Baños, Philippines
C. Melsner
International Maize and Wheat Improvement Center, Dhaka, Bangladesh

Abstract

The more than 20 million hectares of the rice-wheat cropping system grown in South Asia and China have concerns of low productivity (compared to potential), lack of sustainability of system productivity, and production that may not keep pace with population expansion despite farmer use of modern varieties and inputs. Physical degradation of soils is one major hypothesis for these problems. Puddling of rice reduces soil aggregate size by breaking down soil into smaller particles and also results in the development of a plow pan. These two and other soil physical parameters are discussed in the context of a rice-upland crop system. The discussion is followed by a description of various management options that farmers could adopt to minimize the detrimental effects of these soil physical degradation processes. These include tillage and land management for rice and wheat, drainage and water management, management of crop and animal residues, and crop rotations. It is important that a concerted, integrated research effort is made to better understand this major system in the region so that farm level productivity can be increased and sustained.

Introduction

The rice-wheat rotation is estimated to cover 12.6 million hectares in South Asia—India (10.0), Pakistan (1.5), Bangladesh (0.6) and Nepal (0.5)—and 10.3 million hectares in China (Huke and Huke 1992). This rotation was first recorded in China in the 8th century and in South Asia in the late 19th and early 20th centuries. In South Asia and China, this cropping pattern expanded rapidly with the introduction of shorter duration rice and wheat cultivars associated with the Green Revolution in the 1960s and 1970s. Today, it is one of the major patterns responsible for the supply of the cereal calories needed by the more than 2 billion people who live in South Asia and China. Rice-wheat is and will continue to be the predominant source of income for millions of poor farm families in this area of the world.

The rice-wheat pattern is found in the northern semi-arid, tropical to subtropical areas of the Indian Sub-Continent where a distinct wet summer monsoon is followed by a cooler, dry winter season. The rotation is found extensively on the flood plain soils of South Asia but also in the mid-hill and valley bottoms of the Himalayas. Most of the rice-wheat areas have irrigation to supplement rainfall although in some places this is limited. In extensive areas of Pakistan and India, large irrigation schemes provide water for this pattern. Most of the rice and wheat varieties used are the recently

developed, short-statured, high-yielding modern varieties. Fertilizer use, especially nitrogen and to a lesser extent phosphorus is common. In many locations, the use is equal to or above recommendations. Despite the use of this modern technology, there are three concerns related to this rotation (Anon 1992):

- Low productivity of the system (compared to potential);
- Lack of sustainability of system productivity; and
- Production may not keep pace with population expansion.

There are several hypotheses for the above concerns with the ability of the soil resources to support the exhaustive nature of this double or triple cereal pattern and the issues of soil chemical, physical, and biological interactions figure extensively in these discussions. This paper highlights and discusses the soil physical features associated with the problems in this pattern. This is followed by a set of possible management practices, recommendations, and research to help solve these problems. The paper draws extensively from papers presented at an IRRI (International Rice Research Institute) conference on "Soil Physics and Rice" held in the Philippines in 1985 and some work conducted in northwestern India and China. As pointed out in the opening IRRI conference paper (Greenland 1985), there are few soil physical scientists working on the problems of wetland rice culture and more collaboration on this topic is needed. The collaboration of soil physicists studying the interactions within the rice-wheat and rice-upland crop systems is even less.

Puddling of Rice Paddies

One of the unique management options in the rice-wheat rotation affecting the soil physical properties is the puddling of the rice fields prior to transplanting seedlings of rice. Puddling lowers the water percolation rate leading to soil submergence, a beneficial soil-redox regime and a change in soil physical, chemical, and biological properties that make these soils different from well drained soils. Puddling can be defined as the process of cultivating the surface layers of water-saturated fields. Cultivating under these conditions causes clay colloids that normally are aligned in layers and chemically bonded together to slip. This slippage results in an impermeable layer in finer clay soils. However, in certain soils, a very distinct layer is formed. This process usually results in a pan and is done to reduce the hydraulic conductivity of the soil and maintain an aquatic condition preferred by rice. Puddling breaks surface soil aggregates into smaller fragments, disperses the clay fraction, alters pore size distribution, and compacts the underlying soil aggregates. Figure 1 shows the effect of puddling on the pore size distribution. There is a decrease in larger pore sizes and an increase in the smaller pores and aeration porosity. This has an effect on soil strength, bulk density, soil-root contact, soil heat, and

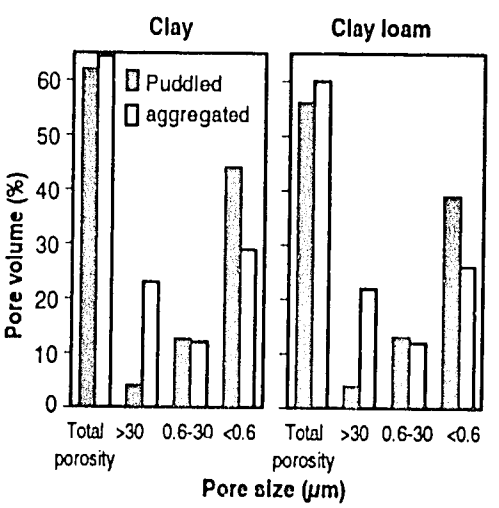

Figure 1. Effect of puddling on pore-size distribution of soil.
Source: Sharma and De Datta (1986).

soil air, which favorably affect rice root growth. It also slows down water infiltration by reducing hydraulic conductivity in the plow layer and provides support of animals or tractors—all important considerations for rice cultivation.

Compaction and the formation of a hard pan over time at the 10- to 25-cm depth is a common feature of puddling (Figure 2). This pan has a big effect on rooting as will be discussed later. The ability and speed to form this pan are related to soil texture. Fine loamy soils have pans created faster and stronger than fine clays (Figure 2). Pans were formed in three years in fine loamy soils in mechanized lowland rice cultivation in Kenya (Curfs 1976). In Japan, no pans were formed after 10-12 years of rice culture on fine, clay sediments (Motomura et al. 1970). Cracking and self-mulching clays result in the break up of pans. Pans form more slowly in soils that are more stable such as soils with high organic matter .

The main objective of puddling is to restrict percolation and maintain standing water in rice fields. Sanchez (1973) showed a large decrease in water drainage in puddled rice soils (Table 1). Yun-Sheng (1981) also showed a reduction in hydraulic conductivity in the cultivated rice pans (Table 2) although total porosity and bulk density were not significantly different from those in the cultivated layer. The reduction in hydraulic conductivity was due to the increased ratio of smaller pores to larger pores. Pans not only restrict water movement, but also air movement both of which have effects on germination, emergence, root extension, water and gas fluxes, microbes, and solubilities of

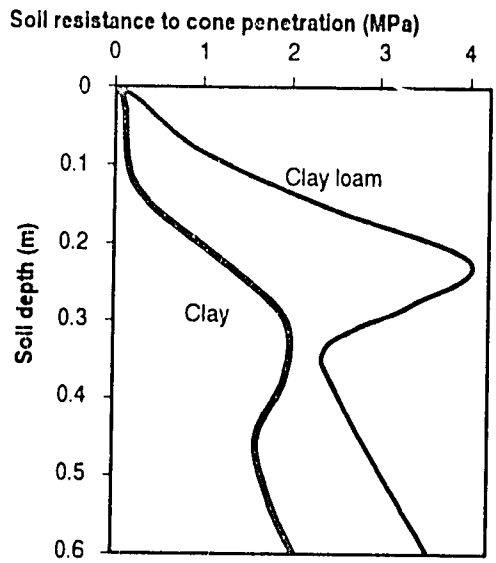

Figure 2. Penetrometer resistance as a function of depth for two lowland soils.
Source: Sharma and De Datta (1986).

Table 1. Effect of puddling on drainage rates of six Philippine rice soils.

Soil		Clay (%)	Drainage (cm/day) Aggregated soil	Drainage (cm/day) Puddled soil
Psamment	Siliceous	9	267	0.45
Fluvent	Mixed	24	215	0.17
Aquept	Montmorilonite	30	183	0.05
Aqualf	Montmorilonite	40	268	0.05
Ustox	Kaolinitic	64	155	0.05
Andept	Allophanic	46	214	0.31
Mean			217	0.18

Source: Sanchez (1973).

nutrients. For high rice yields, though, some percolation of water is required. Lal (1985) indicated that some water percolation is essential to regulate soil temperature, improve N-use efficiency and leach away anaerobic decomposition toxins. He suggests 5-20 mm/day of percolation are required for high yield. Values higher than 20 mm/day, though, would result in excessive leaching of nutrients.

Puddling is also done to control weeds, ease transplanting, conserve water soluble nutrients and provide a pan for support of animals or tractors during cultivation. Disadvantages of puddling may be encountered in the nonrice crop planted after rice harvest. Puddling makes it more difficult to prepare a good seedbed tilth for the following nonrice crop. Tillage conducted after drying puddled soils usually results in more clods due to the hard nature of the resulting soil and more energy is needed to prepare a tilth suitable for the next crop. Puddled soils also retain more water at low tensions than nonpuddled soils and require more time to dry to a suitable tilth for cultivation (Figure 3). This often results in delays in planting succeeding nonrice crops and consequently lower yields especially on fine textured soils. Puddled soils may also have poorer aeration for a longer time after a rain or irrigation with detrimental affects on the nonrice crop growth.

Table 2. Comparison of soil physical properties of the cultivated layer and of the plow pan of a rice soil in the Taihu Lake region of China.

Soil property	Cultivated	Plow pan
Bulk density (t/m³)	1.20 ± 0.07	1.35 ± 0.09
Total porosity (%)	53.5 ± 2.6	50.0 ± 3.4
Pores>0.2 mm diam. (%)	11.5 ± 3.1	5.4 ± 2.3
Pores 0.2-0.01 mm diam. (%)	4.6	2.6
Pores<0.005 mm diam. (%)	35.0 ± 3.0	41.0 ± 3.0
Hydraulic conductivity (cm/d)	1040	1.7

Source: Yun-Sheng (1981).

Rooting

Deep rooting is important for high yields of nonrice crops. Woodhead and Maghari (1984) showed the dependence of depth of rooting on yield of mung beans (Figure 4).

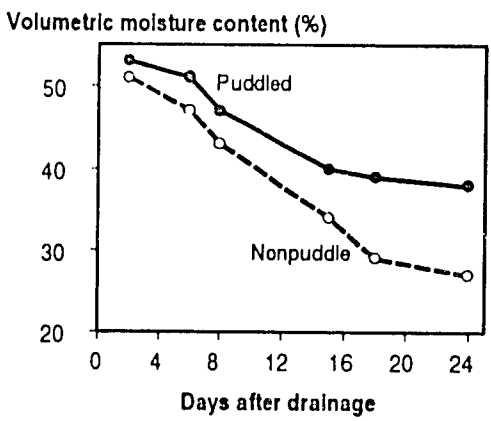

Figure 3. Drying characteristics of the top 5 cm of puddled and nonpuddled soil at harvest.
Source: Gupta and Jaggi (1979).

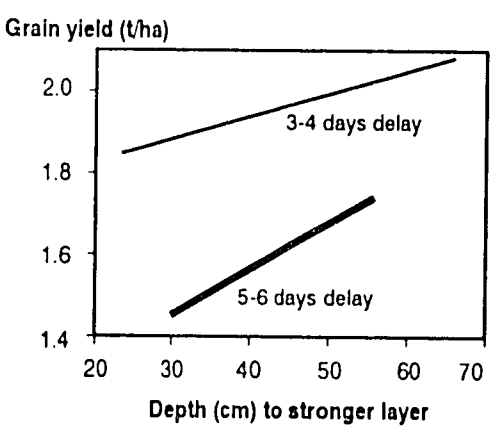

Figure 4. Grain yield of mungbean as affected by depth to the stronger soil layer and by delay between field-draining and seed-planting.

Rice roots on the other hand are usually shallow compared to nonrice crops. IRRI (1978) showed that 90% of the root length of rice was within the top 20 cm of soil. Hasegawa et al. (1985) reported that the root system in IR36 was fully developed 30 days after transplanting with an effective depth of 30 cm. Percolation favored deeper rice rooting. Ishihara (1967) found that percolation promoted primary rice root elongation and development of secondary roots and root hairs, which in turn promoted uptake of soil nutrients. Nonrice crops on the other hand have been shown to root to 180 cm on well drained, light textured soils without any hard pan or other restricting layers (Jalota et al. 1980).

Wheat rooting density and distribution was also shown to differ in maize-wheat compared to rice-wheat patterns when grown on the same soil (Sur et al. 1980). The root density of wheat was greater in the maize-wheat than the rice-wheat pattern in all soil layers and total root mass was 48% more in maize-wheat. Most of the wheat roots were in the 0-5 cm depth in the rice-wheat pattern with far fewer roots at greater depths (Figure 5). These data were obtained from light-textured soils in the Punjab. In fine textured soils, this difference is likely to be even greater. The data in Figure 6 show that nitrogen applied after an irrigation gave better wheat yields than when applied before an irrigation (M. Ruckstuhl, pers. comm.). This could be related to wheat rooting depth on these heavier Nepal terai soils where hard pans exist. The soil structure below the plow pan is compact thus the root depth is shallow. The nitrogen is probably leached below the wheat roots when it is applied before an irrigation and is therefore unavailable to the wheat plant. This has very important implications on nitrogen management. More research is needed at this site to measure rooting depth but initial observations indicate that very few roots grow below the pan that exists in this area at 10 cm.

Rooting is inversely related to soil strength. Hasegawa et al. (1985) suggested that in the field, soil strength values as low as 0.05 MPa are sufficient to slow rice root growth (Figure 7) and that figures greater than 0.3-

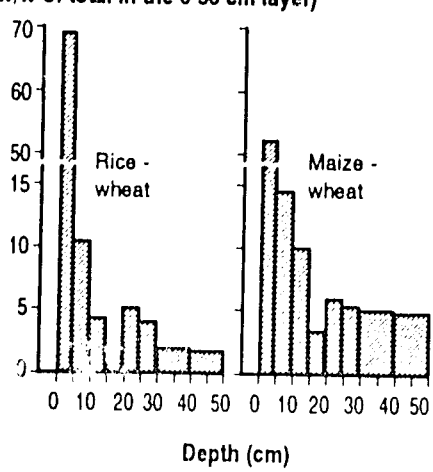

Figure 5. Wheat root distribution in plots under rice-wheat and maize-wheat rotations after wheat harvest.

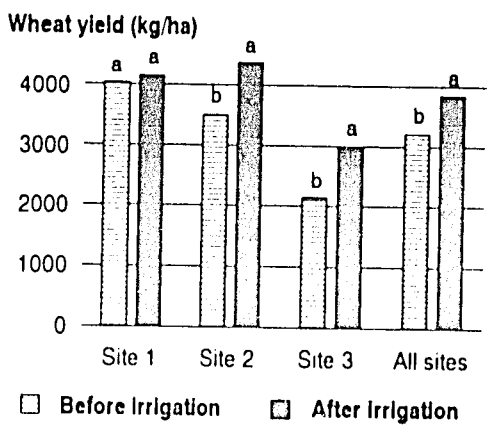

Figure 6. Effect of nitrogen timing on wheat yield in the Nepal terai.

0.5 MPa decrease root growth and extension by 75%. Taylor and Gardner (1963) showed that tap roots of cotton could not penetrate compacted soils with a soil strength exceeding 3 MPa. They also showed that elongation rate was not much affected until penetrometer resistance exceeded 0.4 MPa. Barley et al. (1965) showed that pea and wheat rooting densities were reduced by resistance's between 1 and 2.5 MPa. The penetrometer resistance encountered in the Nepal terai soils in the example above in the wheat season exceeded 3 MPa, suggesting that wheat roots cannot penetrate this pan. Soil strength increases as a soil dries and in a dry soil, rooting is largely affected by its ability to penetrate the soil. In wet soils where aeration is poor, root extension is also affected by the lack of oxygen. Water-free soil pore space is essential for providing the oxygen necessary for root growth in nonrice crops. Oxygen diffuses 10^4 times less in water than air. Water-free soil pore space is reduced in puddled soils.

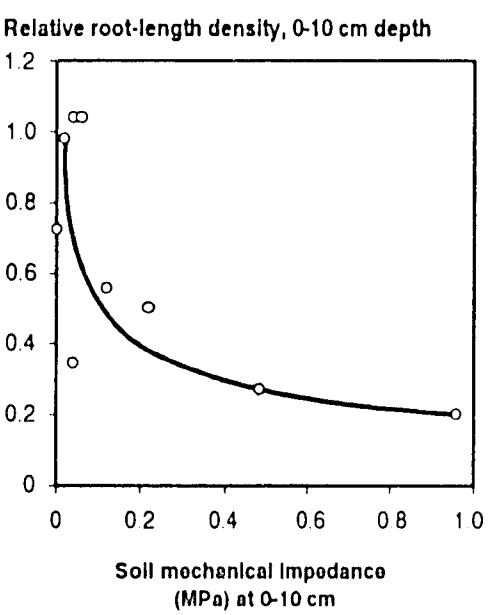

Figure 7. Relation between root-length density and soil mechanical impedance in a drying puddled lowland soil.

Soil Moisture Effects

Soil moisture effects have mostly been covered in earlier sections of this paper. These include waterlogging caused by the reduced drainage imposed by the hard pan and problems of tillage delays because puddled soils take longer to dry. Waterlogging can be a major problem in the rice-wheat system through its affect on restricting oxygen supply to the roots. It has been observed in many rice-wheat growing areas of South Asia that wheat and other nonrice crops turn yellow and have reduced growth following a rain or irrigation that result in waterlogging for more than 24 hours. This is probably a major limiting factor for wheat yield in the lower lying, heavier soils of South Asia. In the Nepal terai (at Bhairahawa), it is often observed that rainfed wheat yields more than irrigated wheat. This situation exists because it is difficult to apply small quantities of irrigation water using the flood system available, and drainage is very slow. This is strongly related to soil texture. Waterlogging is less of a problem on the sandy loam soils of the Indian Punjab than the soils at Bhairahawa. However, water use for rice in the Punjab is much higher than at Bhairahawa. In Bangladesh, waterlogging symptoms can be seen on the lighter soils where flood irrigation is used. Though not confirmed, evidence points to a hard pan that restricts both root development and water flow (Badaruddin, pers. comm.)

Seedling Emergence

Another factor in the rice-wheat system affected by soil physical properties is seedling emergence. This is a crucial factor for the following nonrice crop because poor plant stands will limit yield potential and the response of the crop to added inputs. Seedling emergence is related to many factors including seed quality, temperature,

soil aeration, soil moisture, physical impedance above the seed (crusting), and the interaction of these factors with soil biological activity. A review of these factors can be found in Zhang (1990) and will not be discussed here in detail.

Water is essential for seed imbibition and triggering the physiological processes of the seed. However, it also plays an important role through its affect on soil strength and the resulting effects on root and coleoptile growth. The speed of germination and emergence each increase with increasing matric potential as long as oxygen does not become limiting. Also important in emergence is good seed-soil contact to ensure good uptake of moisture. In puddled soils, tillage often results in more clods, faster soil drying and poor contact between the seed and soil. This could be one of the many reasons for poor plant stands for nonrice crops following rice.

Management to Overcome Soil Physical Constraints

Reduced puddling

Puddling the soil for rice may be a concern in rice-wheat systems. Rice growth is favored by a puddled reduced soil whereas nonrice crops prefer aerobic, freely drained soils. This creates the problem of soil structure management. If puddling could be eliminated or reduced, the establishment and yield of the nonrice crop might be improved. Obviously, the ability to reduce puddling without affecting the productivity of the system is very site-specific and related to the soil and hydrological properties. It is also likely that reduced puddling might result in less rice yield, but increase the economics of the annual production through higher nonrice yields and reduced costs of production. It is important, therefore, to evaluate the results for the whole year and not for a single crop. The following are some situations where reduced puddling may be feasible.

Low-lying terai soils where water tables rise above the ground surface during the monsoon season—In this situation, there is no need to puddle the soil to reduce percolation. Similar situations occur in areas of India and Bangladesh where flooding from rivers inundate the land but flooding is not too deep to damage rice. In fact, the deep water rice crop grown in these areas does not use a puddled soil management system but is planted into dry, tilled soil.

Soils with predominantly high-activity clays—Soils that are easily dispersed when submerged and on soils with low water permeability rice can be grown without puddling, assuming weeds are adequately controlled.

Coarse-textured soils with predominantly low activity clays—Yields of rice are reduced because of high percolation and nutrient

Table 3. Effect of tillage method on cumulative water infiltration of a sandy loam soil.

Tillage method	Cumulative water infiltration (mm)			
	10 min.	50 min.	90 min.	120 min.
Compacted	25	42	47	55
Puddled	29	48	57	57
No-till	34	61	73	87

Source: Ogunremi et al. (1981).

leaching. Effective puddling is difficult and soil compaction may be a more effective method of reducing percolation. Table 3 shows that cumulative water infiltration was less when a sandy loam soil was compacted than when puddled or given no tillage (Ogunremi et al. 1981). In some of these areas, it may be necessary to look at substitutes for rice and increase the returns per unit of water. The rice growing tracts of the Indian Punjab and Haryana are examples where low costing of water encourages farmers to grow rice when, in terms of water efficiency, selection of nonrice crops would be better.

Compacted soils with poorly drained subsoils and surface horizons—These may respond better to dry than wet tillage. Obviously, there are soils where puddling is essential if rice is to be grown because of limitations of water supply. Other management not described here may be needed in these situations.

Dry seeding of rice

Puddling and transplanted rice are almost synonymous. Most of the transplanted rice in South Asia is on puddled soil. However, if the soil could be kept moist and soil-submergence maintained, there is no reason why rice cannot be transplanted into flooded, nonpuddled soils. In fact, in some rice growing areas of Asia, a succeeding rice crop is transplanted into the soil without land preparation following the harvest of the first rice crop. The main requirement for nonpuddling for rice is to lessen percolation of water to maintain soil submergence and hence create soil redox regimes favorable for rice production, and also to control weeds.

Dry seeding of lowland rice is quite common in rainfed areas of the region where short duration, local varieties or deep water rice varieties are grown. This leaves a much better soil condition for the following upland crop. This has the advantage of allowing rice to be planted well before sufficient rains have fallen to allow the soil to be puddled, although this system is usually followed where pre-monsoon rains are reliable and the risk of drought is not too great. In the deep water rice areas, it is very important to establish rice early so it can withstand the flooding that comes when the monsoon rains start. Dry seeding allows farmers to increase the number of crops grown per year although total economic returns may be lower than growing a single puddled rice crop. Dry seeding of rice has decreased in the region as irrigation and modern rice varieties have been introduced. If a farmer has irrigation, he prefers to grow improved rice varieties with puddling as shown by the large increase in transplanted Boro rice in Bangladesh compared to the local, direct-seeded Aus crop.

One of the problems with direct seeding of rice is the poor performance of improved transplanted varieties when direct seeded and their poor competition with weeds. Breeders may have to develop a new phenotype of rice for this type of management that better competes with weeds while increasing yields over the old local direct seeded types. Better management systems for weeds would also help promote dry seeding of rice on nonpuddled soils. All of the rice grown in the USA is direct seeded on nonpuddled soils because of labor costs, assured irrigation, and the ability to control weeds with chemicals.

Increased rooting depth

Although there is little research or data on wheat rooting following rice in South Asia except from the lighter textured soils of the Indian Punjab (Sur et al. 1980), it can be hypothesized that one of the factors limiting wheat yields following rice is restricted rooting, which could be quite severe on soils

of finer texture and with a strong hard pan. In China, yields of wheat following rice are high in the Yangtze River Valley. In these areas, farmers are encouraged to plow deeper during the land preparation for rice. This is usually done with a small tractor and moldboard plow after the fields have been flooded. This results in puddling and a pan at about 30 cm compared to 10-15 cm in most of the rice soils of South Asia. Deep plowing is done for rice, with zero or reduced tillage for the wheat crop. The advantages of this deeper rooting are better moisture and nutrient availability for both rice and wheat. It would also reduce the incidence of drought and waterlogging in the system because more soil moisture would be tapped. Deeper tillage has been tried in South Asia, but usually for the nonrice crop.

Table 4 shows the benefits of deep tillage on wheat yield after rice in the light textured soils of the Indian Punjab (Gupta et al. 1984). In heavier soils, however, the subsoil is very wet just after rice harvest and the effect of chiseling or subsoiling may be minimal compared to deep tillage before rice when the subsoil would be drier. Gupta and Jaggi (1979) demonstrated that puddling to 15-20 cm depth significantly increased the rice yield when compared to shallow puddling and unpuddled soil treatments (Figure 8), which supports the practice of deeper tillage for rice in China. More research is needed in this area.

Table 4. Effect of tillage on yield of wheat after rice in farmers' fields in the Indian Punjab.

Soil	Grain yield (t/ha)	
	Conventional	Deep tillage
Silt loam	3.8	4.4
Sandy loam	3.7	4.2
Sandy loam	3.5	4.0
Silt loam	3.4	3.7

Source: Gupta et al. (1984).

Tillage

This is the most common method for alleviating the constraints of puddled soils. It achieves this by mixing the soil, reducing soil strength, increasing gaseous exchange and hydraulic conductivity, controlling weeds, incorporating residues and chemicals, and reducing the effect of surface compaction on root growth. It is usually done by animal or tractor power using shallow implements in the rice-wheat areas. Only in a few places in the region are disc harrows used. Although this shallow tillage improves seedling emergence, it does little to alleviate and probably worsens the pan problem. More studies are needed on this issue and, in particular, on testing other implements that could do the job more efficiently.

Tillage in the rice-wheat system is one of the major costs of production; it is therefore relevant to ask whether direct drilling with zero or reduced tillage can be used in the system. Research in Pakistan (Aslam et al.

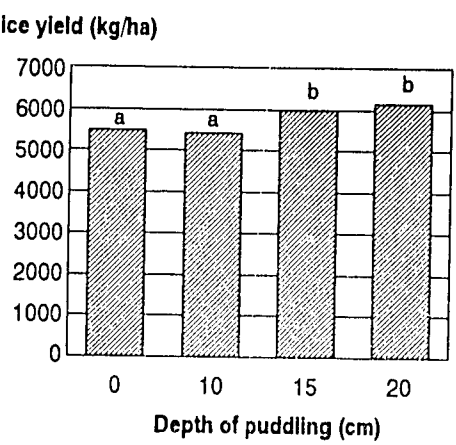

Figure 8. Effect of puddling depth on rice yield at Jabalpur, India.
Source: Gupta and Jaggi (1979).

1989) has shown that wheat yields using an inverted-T coulter seed drill imported from New Zealand were equivalent to wheat yields with tillage when the plots were planted on the same day (Table 5). They further showed that zero-tilled plots had a yield advantage over tilled plots when the zero-tilled plots were planted soon after rice harvest and before the tilled plots (Table 6). In these studies, weeds were less of a problem than in the tilled plots because of the very distinct differences in weed species that grow in the rice and wheat seasons.

Table 5. A comparison of zero and traditional tillage on yield of wheat over 23 locations in farmers' fields of Punjab, Pakistan.

Method	Grain yield	Total biomass	Spikes /m	Grains /spike	Grain wt (mg)
Direct drilling	3.52	10.6	255	38	39
Farmer method	3.41	10.3	242	43	38
Significance	ns	ns	ns	0.05	ns

Source: Aslam et al. (1989).

Table 6. A comparison of direct drilling versus conventional planting when planting at different dates in Punjab, Pakistan.

Location	Direct Drill	Conventional	Difference in planting days
Mundair Sharif	4,250	2,660	33
Mauglamania	2,691	2,200	22
Daska	3,145	3,245	16
Ahmednagai	4,312	3,529	20
Glotian	3,845	2,737	12
Average	**3,649**	**2,874**	**19**

Average percent increase in yield = 27% or 41 kg/ha/day.
Source: Aslam et al. (1989).

The use of direct drilling and zero and reduced tillage is gaining popularity in the rice-wheat areas of China. Zunpu et al. (1986) investigated the applicability of no-tillage to the rice-wheat system over the long-term and conclude that no-tillage favors the maintenance of better soil physical properties including increased air filled porosity and decreased soil shrinkage. Water penetration was also promoted. The no-tillage system added more to wheat than rice yield, especially when soil moisture was high. Some unfavorable yield effects did occur in the 5th year of rice, which was associated with weeds. The authors propose a rational reduced tillage system coupling suitable successive no-tillage with plowing when needed.

Besides yield and optimum planting for wheat, direct drilling with zero tillage also allows quick turnaround after rice harvest, better use of available moisture, and reduced costs of production. However, some farmers have reported difficulties plowing their land for the next rice crop following zero-tillage in wheat. This was associated with a hardening of the soil without tillage. This factor needs more study within the tillage system in future research.

Most of the wheat in the rice-wheat areas is planted by broadcasting the seed and then incorporating with a plow. This is done because seed drills available to farmers perform poorly where rice residues and trash occur. More research is needed to develop effective drill coulters that give better emergence, especially since mechanization appears to be on the increase in the rice-wheat region. Chaudhury and Baker (1981) confirmed that differences in emergence do exist between different coulter designs, with their success determined by their ability to retain and utilize the liquid and vapor moisture present in the seed micro-environment. Tessier et al. (1991) also

demonstrated that seeding tool design can influence emergence and that this can be used to develop precise guidelines for future designs of furrow openers and press wheels. One of the most important concepts is to ensure sufficient soil moisture near the seed for imbibition and germination. This can usually be achieved by sowing when soils are wetter compared to soil moisture needed for optimum tillage or by using press wheels to get good seed-soil contact.

Drainage systems

Waterlogging can in part be avoided, and high percolation of water in rice can be achieved, through drainage. Si-Tu Soong and Zhang (1985) described subsurface drainage systems in China. They conclude these systems increase yields of rice and nonrice crops and can pay for their investment in a few years. One benefit of drainage, even in rice, is to keep the oxygen level high and thus promote rooting. The Chinese believe that sun drying the rice field at the end of maximum tillering is important for high yields. This can only be done if drainage is available. Drains also allow earlier planting of the nonrice crop following rice. Various designs of equipment that can be used on two-wheel tractors for preparing drains are available from China. More research is needed in South Asia on this issue.

Organic matter, residues, and green manures

These three products are important in contributing to the high yield and sustainability of the rice-wheat systems of China. Besides their chemical effect, they are also important for improving the soil physical properties and helping to restructure the soil after puddling. However, Rixon et al. (1991) showed that heavy applications of manure to a rice-rice-barley system in China did not lead to an improvement of soil physical properties. The absence of improvement was suggested to be the result of breakdown due to the action of puddling, which was consistently practiced prior to transplanting and establishing each rice crop. This also needs further study within the rice-wheat system for puddled and nonpuddled fields.

Mulching with crop residues reduces surface evaporation compared to a bare soil (Lal 1985) and increases crop water-use efficiency (Zandstra 1982). Mulching can also moderate the temperature in the seed zone, an important consideration where wheat is planted early after rice and in the warmer environments. Mulching can also modify the surface soil moisture and strength and help minimize crusting. Weeds can also be partially controlled by mulches. With the increasing use of mechanical harvesters in South Asia and increased pollution from burning stubbles, more research is needed on using mulches and residue management to benefit rice and wheat yields.

Rotations

The last management factor that can influence the soil physical properties is rotation. Many of the rice-wheat areas of South Asia, especially in northwestern India, grow sugarcane in complex rice-wheat-sugarcane rotations. Rice and wheat yields are higher after sugarcane. Part of this effect can be attributed to biological factors such as weeds, but soil physical factors such as soil aggregation and effects on rooting also play a role. The use of deep rooted crops as biological plows in the rice-wheat system need further study in long-term rotation trials. Additionally, in Bangladesh, jute is part of the complex jute-wheat-rice rotation, and growers report the same higher yields in crops after jute.

Conclusions

Management practices for rice and wheat are sometimes incompatible. On the one hand rice prefers a puddled reduced soil and on the other wheat prefers an aerobic, freely drained soil. However, there is very little possibility that South Asian farmers will give up this cropping pattern. It provides much needed food that cannot be easily replaced by other crops. Only by increasing the productivity of this pattern can farmers consider other options. Their first priority is to provide for their family food needs. It is therefore very important that research focuses on this pattern to improve its productivity and efficiency. This must be done in an integrated way by studying the interactions and interdependencies that occur in the system and not by isolating each crop in a separate research program. Different disciplines and commodity programs must work together, plan and each actor take responsibility for areas that involve his expertise. This paper highlights some of the soil physical problems associated with this rotation; some of the solutions involve not only soil physicists, but members of the entire agricultural research system. Future research in South Asia must be given incentives to reward scientists who can work together to solve complex farmer management problems.

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Questions/Discussion

Dr. Hobbs was questioned on the sustainability of a rice-rice-wheat rotation. He felt that a triple cropping system was possible as shown in various parts of Asia, but that it is probably not to be recommended in the future. It could only be sustained by high (and increasing) levels of inputs and careful attention to pests and diseases. He felt that the effect of disease and pest carry-over on the previous crop stubble warrants more investigation. He said further research was also needed into appropriate mechanization in the rotation, particularly with reference to plowing depth.

Grain Set Failure in Warm, Nontraditional Wheat Growing Areas of Asia: The Boron Response

B. Rerkasem
Agronomy Department, Faculty of Agriculture,
Chiang Mai University, Chiang Mai, Thailand

Abstract

Grain set failure is common and widespread in the warm, nontraditional, wheat growing areas of Asia. The problem is distinguishable from the depression of grain number and yield by two other causes: frost damage and limited grain-filling capacity. Responses to boron (B) determined by the Boron Probe Nurseries throughout the region in 1990-91 confirmed earlier findings by researchers from National Agricultural Research Systems in China, India, Nepal, and Thailand, and helped to establish B deficiency as a major cause. Management of the problem is complicated by extreme variability of the B responses in wheat. In one study, the grain set index of SW41, a Thai selection, on a low B soil at Chiang Mai without B application, ranged from 27 to 69% and always >90% with B. Large differences in sensitivity to B deficiency found among wheat genotypes suggest that selection for tolerance may be one way to overcome the problem. A simple screening method for tolerance to B deficiency in a sand culture is presented.

Introduction

Grain set failure is a common and widespread problem in the warm, nontraditional wheat growing areas of Asia. It has been observed by researchers from the National Agricultural Research Systems as well as CIMMYT outreach staff in China, Nepal, Bangladesh, India, and Thailand. Yield loss estimates are not currently available, but there are many anecdotal observations, for example, from Yunnan Province, China (Table 1, Rerkasem 1992).

Table 1. Examples of extreme losses resulting from grain set failure, Yunnan Province, China.

Count	Year	Cultivar	Area (ha)	% yield loss
Ruili	1984	Spring 980	230	50
Ying Jiang	1987	0103	40	100
		Spring 980	3	100
Luxi	1992	Spring 980	2-3	90

These observations were made due to the obviously extreme levels of yield loss. Less severe losses, of 15-30%, are more common, but have remained undocumented.

The Grain Set Index

The problem of grain set failure or sterility in wheat as discussed here is caused by the absence or failure of fertilization, which can be associated with poorly developed pollen (Rerkasem et al. 1989) or unsuccessful fertilization by apparently normal looking and viable pollen grain (Cheng 1992). The number of grains on the wheat spikelet can indicate the extent of grain set failure, but it is also influenced by the process of grain-filling. To remove the effect of grain-filling, "basal floret fertility" (average number of grains in the two basal florets of 10 central spikelets) has been suggested as an index for assessing grain set failure (Rerkasem et al. 1991). As this first index, with full fertility at 2, has been found somewhat

difficult to appreciate, a slight modification is suggested, i.e., express the index as the percentage of grain bearing in these 20 basal florets and call it the "grain set index".

Boron Response and Boron Probe Nurseries

Widespread occurrence of low boron (B) soils has been reported in the warm, nontraditional wheat growing areas of Asia (China, Liu et al. 1981; Nepal, Khatri-Chhetri and Ghimire 1992; Thailand, Bell et al. 1990; Bangladesh, Reuter 1987 and Sillanpaa 1982). In the last few years, there have been many reports in the region of this grain set problem in wheat responding to B application (Sthapit 1988, Rerkasem et al. 1989, Yang 1992).

The Boron Probe Nurseries (BPN) were designed to test responses to B of wheat genotypes with known reactions to B deficiency in different environments. Each set of BPN contained six wheat genotypes, two were identified as sensitive to B deficiency (SW41, BL1022, or CMU285), two moderately sensitive (SW23, Sonalika, or Kanchan) and two tolerant (Sonora 64, NL460, CMU26, or Insee 1) with two levels of B application (0, 1 kg B/ha), in duplicates. A total of 11 BPNs were distributed in Asia. Results were obtained from seven of the 11 sites and responses to B were observed at five sites (Lumle and Tarahara in Nepal; Samoeng, Chiang Mai, and Chiang Rai in Thailand). Two sites were not responsive (Mae Hia, Thailand and Dehong, China). At responsive sites, SW41 responded strongly to B application (Figure 1), no response was observed with tolerant Sonora 64 and Insee 1 (Figure 2). The lack of response at Mae Hia in Thailand, a normally responsive site, illustrates a problem with extreme variability over short distances. The Dehong site, on the other hand, has had a long history of B application.

Boron deficiency in "sensitive" crops in these areas was identified several years ago. Many areas of the Yunnan Province in China, for example, have long been classified as a B-deficient area and B

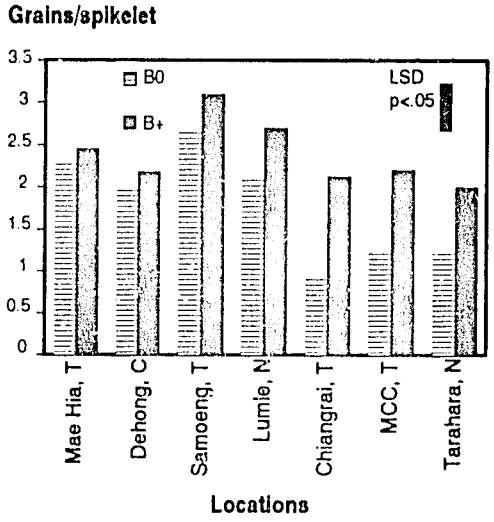

Figure 1. Responses of SW41 to boron application at seven sites in Asia (T = Thailand, C = China, and N = Nepal).

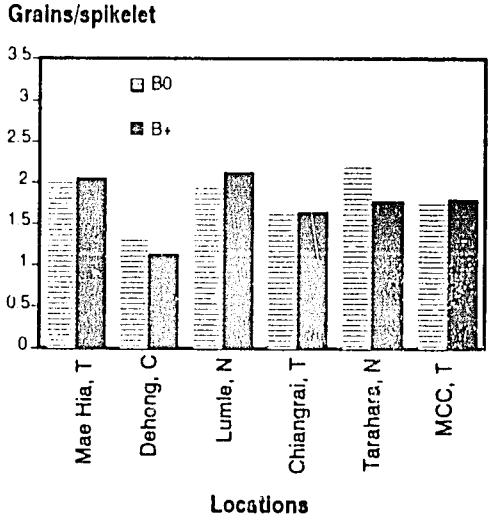

Figure 2. Responses of Insee 1 to boron application at six sites in Asia (T = Thailand, C = China, and N = Nepal).

fertilizer is routinely recommended for tobacco, broadbean, and canola (rapeseed). Similarly, peanuts in northern (Rerkasem et al. 1988) and northeastern (Keerti-Kasikorn et al. 1991) Thailand are commonly found with "hollow heart", a typical symptom of B deficiency. Fertilizer recommendations for tobacco in Thailand have long included B. Unlike in these crops, in which responses are predictable and the practice of B fertilizer application is well established, the management of B deficiency problems in wheat is hampered by the still widely held view that wheat is insensitive to B deficiency (e.g., Martens and Westermann 1991). Furthermore, even when B deficiency is recognized, management is complicated by extreme variability of the problem over time and space.

Variability of Responses

Large differences in B responses in wheat sown four to five weeks apart have been reported (Rerkasem et al. 1991). In Tuanjie Village, Ruili County, China, in 1992 a field of Mianyang 11 growing on 2.5-m beds had grain set indices of 68 to 78% on the edges and 91% inside the beds.

In the three years since 1989-90 growing season, a field experiment has been carried out on a low B soil (hot water soluble B, HWSB, 0.14 mg B/kg) at Chiang Mai. In each year, SW41, a Thai selection, was grown with four levels of B application (0, 0.5, 1.0, and 2.0 kg B/ha) in four replicates. Effects of B application on the number of grains/spikelet, grain set index, and grain yield over three years are shown in Table 2.

Screening for Tolerance to Boron Deficiency

Large genotypic variations in the response of wheat to low soil B (Sthapit 1988, Rerkasem and Jamjod 1989), and difficulties in fertilizer management, indicate the potential for genetic solutions to this

Table 2. Effects of boron application on the number of grains/spikelet, grain set index, and grain yield of SW41 wheat over 3 years at Chiang Mai.

Boron rate (kg B/ha)	1989-90	1990-91	1991-92
Grains/ spikelet			
0.0	0.9b	0.5a	1.5c
0.5	2.0d	2.1d	2.5e
1.0	2.2d	2.1d	2.6e
2.0	2.3de	2.3de	2.6e
Grain set index (%)			
0.0	48.0b	26.8a	68.7c
0.5	92.0d	84.8cd	92.5d
1.0	91.0d	82.0cd	93.8d
2.0	89.5d	89.5d	91.2d
Grain yield (kg/ha)			
0.0	1285b	857a	1157b
0.5	1758c	2268d	1782c
1.0	2008c	2388d	1660c
2.0	1600c	2125cd	1639c

Numbers in each set of data followed by different letters are significantly different at $p < 0.05$.

problem. However, there is as yet no quick method to screen for tolerance to B deficiency. Responses to B of early vegetative growth (leaf expansion and root growth) of a number of wheat genotypes showed no correlation with their reproductive responses, which are related to grain set failure (R. Netsangtip and B. Rerkasem, unpublished). Unlike the screening for tolerance to B toxicity, which can be performed on seedlings (Moody et al. 1988), responses to B deficiency in wheat can be evaluated at anthesis at the earliest. No clear relationship has been found between B toxicity and deficiency responses.

Field variability, in time as well as space, is the major limitation for field screening. Selection sites may have had a long history of B application or are on soils not deficient in B. Even when sites for yield trials are relatively low in B (e.g., Thailand, Rerkasem et al. 1989), B deficiency in moderately sensitive genotypes is clearly expressed only in severe years. Unless grain set is specifically estimated, mild effects of B deficiency in terms of grain yield may not be readily detected as 15 to 25% grain set failure (grain set index measuring 75-85%) can be effectively compensated for by an increase in the size of individual grains (Rerkasem et al. 1989). Thus, one Thai selection ARTC 87001 (Junco'S'/Buc'S', CM64478 from the 4th Hot Climate Wheat Screening Nursery), which has been top yielding for three years in national yield trials (Wheat Thailand Yield Nurseries 1989-90, 1990-91, and 1991-92) was showing severe sterility (open glumes, poorly developed anthers) during anthesis in an on-farm rainfed trial in Pai, Mae Hong Son in the 1992-93 growing season. The grain set index of ARTC 87001 averaged 79.5% (range 64.5 to 96.5%), compared with 97.7% (range 95.3 to 100%) in Fang 60, a genotype with strong tolerance to B deficiency. Preliminary data from 1992/93 sand culture screening (see below) showed a grain set index of 30% for ARTC 87001 without B added to the nutrient solution compared with 100% in Fang 60 and 100% in both genotypes when supplied with 0.002 mg B/L in the solution culture.

The procedure adopted for screening for tolerance to B deficiency consists of growing wheat in drainable pots containing washed river sand (with traces of available B), which are watered twice daily with a complete nutrient solution with different B levels. Results from 1990-91 screening (Table 3) show a wide range of sensitivity to B deficiency among wheat genotypes, from extremely tolerant such as Fang 60 to those extremely sensitive, which failed totally to set grain when B was omitted from the nutrient solution. Other lines from the region (Bangladesh, China, Nepal, India, Thailand) are currently being screened, and preliminary results indicate responses to B that reflected observation of sterility in the field. For example, BL1022 (Nepal), Spring 980 and De Mai 3 (China), and Glennson, which are commonly seen with sterility problems in the field, set virtually no grain when B was omitted from the nutrient solution.

Acknowledgment

This research was supported by the Australian International Development Assistance Bureau.

Table 3. Grain set index[a] of 23 wheat genotypes grown in sand culture without (B1 = 0 mg B/L) and with boron (B2 = 0.002 mg B/L) added to the nutrient solution.

Genotype	Grain set index (%)		Days to anthesis
	B1	B2	
B Deficiency tolerance standards			
CMU26	32.5d	76.5j	69
Sonora64	16.5bc	81.0ij	53
Dt5 (Fang 60)	71.0fg	94.5k	57
Dt6 (HAHN*2PRL)	72.0fg	98.5k	58
Dt12 (#144)	80.5g	96.5k	58
Dt14 (CNO79*2/PRL)	61.5ef	80.0jk	55
Dt15 (KUHR#6)	28.0cd	94.0k	59
Dt16 (#1510)	52.5e	61.5fgh	61
Dt1 (TSI/VEE#5)	29.0d	66.5ghi	62
Dt10 (GEN/3/GOV/AZ/MUS)	10.5ab	69.5hij	54
Dt19 (BOW/URES//KEA)	16.5bc	81.0j	60
Dt2 (SERI 82)	0.0a	46.5de	74
Dt4 (ALD/IAS58.103A //NOB /3/CEP76148/4/GEN)	0.0a	10.0ab	63
Dt7 (JUNCO)	0.0a	41.0d	61
Dt9 (1D13.1/MLT)	1.5a	26.0c	69
Dt8 (MRL/BUC)	3.5a	54.5efg	57
Dt11 (MRL/BUC'S')	0.0a	15.5bc	62
Dt13 (KAUS)	0.0a	13.0b	75
Dt17 (BUC/BJY)	3.5a	49.5def	59
Dt18 (VEE/3/GOV/AZ//MUS)	0.0a	0.0a	59
Dt20 (THB/KEA)	2.5a	17.0bc	65
B Deficiency susceptible standards			
SW41	0.0a	8.0ab	66
SW23	1.0a	49.0de	62

[a] Grain set index = percentage of grain bearing in the 20 basal florets (F1 and F2) of 10 central spikelets.

Numbers in same column not followed by same letter are significantly different ($p<0.05$), with DMRT.

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Questions/Discussion

When questioned about soil boron determination and critical levels, Dr. Rerkasem explained that she extracted boron from soil using hot water, although some workers use calcium chloride plus mannitol solution. After extraction, color is developed (a number of reagents can be used for color development) and the solution is then read using a colorimeter, spectrophotometer, or I.C.P. She said that her correlations between soil boron measurements and plant responses had been very poor, due to the fact that uptake of boron is a function of many things—of the amount of boron present but, more importantly, is a function of water uptake that is influenced, not only by soil water but also by environmental conditions (temperature, relative humidity etc.). Nevertheless, soil boron can be used as a guide—in her experience, she would suspect a soil with less than 0.15 mg B/kg soil to be one in which a response to boron could be expected. However, she cautioned, other workers use different levels and in China, less than 0.5 mg/kg is considered deficient.

Dr. Rerkasem was questioned about the variability in boron deficiency—adjacent plants in a field can be totally sterile and fertile, sterility can occur in a crop sown at a certain time, but not in one sown one week earlier or later, sterility occurs in some years, not in others. She said her group has evidence that boron deficiency is accentuated by low soil moisture—again, the uptake of boron is related to uptake of water; no water uptake, no boron uptake. Because boron is relatively immobile once in the plant, if the supply is cut even for a very short time during the critical period (ear development), a deficiency is developed. There is also evidence that waterlogging (which cuts water uptake) can cause deficiency—for instance in China, deficiency (50% grain set index) was found on the edge of raised beds while the plants in the middle of the bed had a grain set index of nearly 100%. In addition, low temperature has been found to depress boron uptake. In summary then, any environmental condition that reduces water uptake. reduces boron uptake and if this occurs at a critical period, a deficiency may result.

Questions of boron application rates and methods were raised. Dr. Rerkasem explained that usually, the preferred application was Borax, incorporated into the soil at 10 kg/ha (1 kg B/ha). While foliar applications had been successful in mungbean, they had virtually no effect in wheat because the critical part (the developing ear) will not be hit by the spray application. Again, she emphasized that boron in the plant is immobile. Loading boron into the seed (as discussed by Dr. Graham for other micronutrients) has not been researched, but any effect on wheat sterility is unlikely as the critical period for boron uptake is much later than seedling growth.

Agronomic Value of Seed with High Nutrient Content

J.S. Ascher and R.D. Graham
Department of Plant Science, Waite Agricultural Research Institute, Glen Osmond, South Australia
D.E. Elliott
South Australian Research and Development Institute, Adelaide, South Australia
J.M. Scott and R.S. Jessop
Department of Agronomy and Soil Science, University of New England, Armidale, New South Wales

Abstract

Seed with high mineral content has been shown to increase early seedling vigor and nutrition; similar to a starter fertilizer effect. The nutrient content of seed is dependent on soil type, nutrient availability, species, and to a lesser extent season and variety. Fertilizer applications at sowing and during grain-filling were investigated as a means of increasing nutrient content of grain kept as seed for subsequent crops. This paper describes current research designed to develop fertilizer strategies to increase the translocation of nutrients (P and Mn) to wheat and barley grain kept for seed and to evaluate the effect of this seed with high nutrient content on growth, nutrient status, disease resistance, and grain yield of the subsequent crop.

The Case For High Nutrient Reserves in Seed

Reserves of nutrients in the seed must be sufficient to sustain growth until the root system has developed sufficiently to supply nutrients from the growing media. During plant establishment, nutrients are supplied partly from the seed reserves and partly from the soil. Obviously, high levels of seed nutrients are particularly important in soils of low nutrient availability as a larger root system is required before the soil can supply the needs of the crop. Low nutritional status of seeds has been reported to reduce plant growth when grown under conditions of low nutrient availability (Asher 1987).

The nutrient status of seed has been shown to affect both seed viability and seedling vigor. There are reports in the literature of minimum seed concentrations below which seedlings will not grow normally (Table 1). While the critical level for seedling growth was not determined, Harris and Brolmann (1966) demonstrated that peanut seed with low B content had hollow-heart defect and

Table 1. Critical levels of nutrients in seeds for normal seedling growth.

Element	Species	Critical level (mg/kg)	Reference
Molybdenum	Maize	0.08	Wier and Hudson (1966)
Nickel	Wheat	0.1	R.M. Welch (pers. comm.)
Boron	Green gram	15	Rerkasem et al. (1990)
Boron	Black gram	14	Rerkasem et al. (1990)
Manganese	Lupins	10	Hannam et al. (1984)

development of cotyledons was not normal. Low Ca content of peanut seed resulted in darkened plumules, reduced germination, and death of 60% of seedlings within two months; those that survived had deformed roots and shoots (Harris and Brolmann 1966).

In addition to being important for subsequent plant growth, seed nutrient levels may also be an important consideration in quality for end product use, especially in areas where a hig' dependency on grain food may result in nutrient deficiencies (notably zinc) in susceptible populations. Seedling nutrition has been shown to be an important factor in plant susceptibility to pathogens (as reviewed by Graham 1983, Graham and Webb 1991); seed nutrient levels that fail to maintain adequate nutritional status of seedlings in infertile soils may result in a decrease in plant resistance to some seedling diseases.

Phosphorus

Austin (1966) reported an increase in vigor of watercress grown from seed varying upward in P concentration from 0.47 to 0.95 g P/kg of seed; these differences were apparent seven to nine weeks after sowing, but had disappeared at maturity. Lupins grown from seed with higher concentrations of P had increased grain yield in a field study in Western Australia (Bolland et al. 1989). When grown under a P-deficient regime, narrow-leafed lupin seed with low P seed levels resulted in greatly reduced root length, fewer lateral roots and depressed nodule numbers (Thomson et al. 1992). These workers concluded that seed P may be particularly important for nodulation of narrow-leafed lupins. Increasing levels of P in *Medicago polymorpha* and *Trifolium balansae* seed increased herbage yields under field conditions for each harvest (up to maturity) and increased seed yields (only measured for *M. polymorpha*). There was no effect of seed concentration on establishment or nodulation (Bolland and Baker 1989).

For wheat grown in pots in the glasshouse, Bolland and Baker (1988) reported that seed with higher P concentrations of 2.5 g P/kg of seed resulted in a yield increase for three times of sampling when compared to plants grown from seed with a lower P concentration of 1.4 g P/kg seed (Figure 1). The influence of seed P decreased when the soil was fertilized with P.

De Marco (1990) investigated the effect of seed size and P and N concentration of wheat seeds on seedlings in a pot experiment. He found no effect of seed N concentration or content on seedling growth; however, within the seed P treatments heavier seeds produced larger leaves, more dry matter, and longer root systems. High seed P content resulted in greater rate of emergence, larger area of youngest leaves and greater root length of seedlings (10 days after emergence). This larger root system will have added advantages in acquisition of

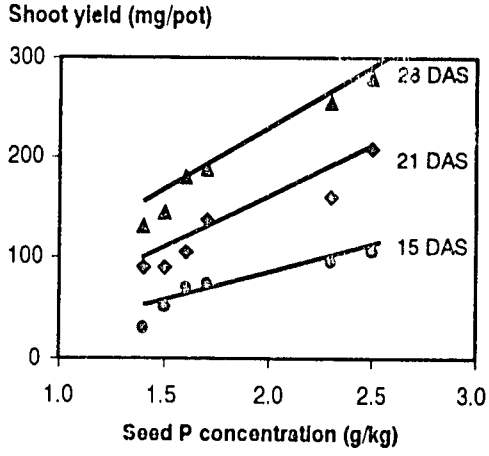

Figure 1. Effect of seed P concentration on dry matter yield of Jacup wheat sown in pots (modified from Bolland and Baker 1988).

nutrients from both soil and fertilizer sources. The effects of seed weight and seed P concentration were additive. He concluded that P contained in the seed could partially compensate for low P availability during early seedling growth.

Attempts in South Australia to assess the importance of seed P concentration on soils varying in fertility have produced equivocal results. In adjoining experiments in 1991 at a site with bicarbonate extractable P of 10 mg P/kg soil, there was a response in grain yield to increasing levels of P in the seed across all rates of soil applied P fertilizer for barley; however, there was no effect in wheat. Both experiments were sampled on three occasions between 28 and 56 days after sowing (DAS); dry matter yield and P concentration of the youngest emerged leaf blade increased with increasing seed P concentration in barley, but no effect was observed for wheat. Four field experiments were conducted in 1992; in three of these increases in plant dry weight due to seed P were measured when sampled between 28 and 56 DAS. In two of the experiments, the response to increasing seed P levels declined with increasing soil-applied P fertilizer (Table 2).

Manganese

As with P, the Mn content of wheat (Marcar and Graham 1986) and barley (Longnecker et al. 1991) seed has been demonstrated to affect both dry matter production, and subsequently grain yield, when grown in a highly calcareous soil of low Mn availability, regardless of whether the soil had been fertilized with Mn or not (Table 3). Longnecker et al. (1991) reported that high amounts of seed Mn increased dry weight of roots and shoots, Mn content of roots and shoots, number of early tillers, plant survival, and number of grains per plant. The most successful treatment in overcoming Mn deficiency was a combination of high Mn seed and fertilizer Mn.

The manganese nutrition of wheat has been shown to affect the incidence of take-all (*Gaeumannomyces graminis* var. *tritici*) (Graham and Rovira 1984). Since the effects of Mn on the incidence of take-all have been demonstrated, as early as 26 days after sowing, it seems probable that early acquisition of Mn from the seed may also reduce disease incidence. Wilhelm et al. (1988) demonstrated that artificially increasing the Mn content of wheat seed by soaking in 1.5% w/v $MnSO_4$ solution (using

Table 2. Effect of P concentration in seed on plant dry weight at tillering at varying levels of soil-applied P.

Sampling time	Seed p concentration (g/kg)	P applied (kg/ha) 0.0	4.0	16.0	LSD P<0.05)
28 DAS	1.5	2.9	3.9	4.4	
	2.2	3.4	4.3	5.4	0.26
42 DAS	1.5	6.8	12.4	14.7	
	2.2	8.2	11.8	14.9	1.00
56 DAS	1.5	14.9	23.6	34.1	
	2.2	17.1	25.8	33.0	3.17

Table 3. Effect of seed Mn content on grain yield of Galleon barley grown under field conditions at Wangary, South Australia in 1987. The +Mn treatment was attained by both soil and foliar application of Mn.

Mn content of seed (mg Mn/seed)	Grain yield (t/ha) -Mn	+Mn
0.08-0.26	0.09	1.87
0.34-0.62	0.21	2.35
0.74-1.20	0.37	2.53

Modified from Longnecker et al. (1991).

the method described by Marcar and Graham 1986) decreased by half the length of take-all lesions per plant when compared with the nil Mn treatment, for wheat grown in a severely Mn-deficient soil, but it was not as effective as incubating the soil with $MnSO_4$ (0.36 g Mn/kg of soil) for two weeks prior to sowing. Huber and Dorich (1988) showed that enhancement of seed Mn by coating seed with $MnSO_4$ (0.6 to 1.0 kg/ha) prior to sowing was effective both in supplying Mn and in reducing take-all. Seed with high Mn content may have a similar effect in reducing the severity of disease.

Other nutrients

There have been few reports of the importance of Zn concentration of seed on the early growth and final yield of plants. Gawade and Somawanshi (1979) reported increased growth of wheat when seed was coated with Zn prior to sowing. The Zn content of wheat seed can influence the interpretation of Zn efficiency, Excalibur was more Zn-efficient than Gatcher at low seed Zn (250 ng/seed), but no different when compared at high levels of seed Zn (700 ng/seed) (Z. Rengel, pers. comm.).

The importance of seed nutrient content on early vegetative growth has also been reported for cobalt in *Lupinus angustifolius* (Robson and Snowball 1987), molybdenum in maize (Weir and Hudson 1966), boron in black gram (Bell et al. 1989), and calcium in peanut (Harris and Brolmann 1966).

Fertilization Techniques to Manipulate Seed Nutrient Reserves

Nutrient seed content can be increased by fertilization of the parent crop or by soaking seeds in, or coating seeds with, nutrients. Some work has been reported on the natural variation of seed content (Singh and Bharti 1985, Marcar 1986, Marcar and Graham 1986, Longnecker and Uren 1990); on soaking seed in nutrient solution prior to sowing (Roberts 1948, Drennan et al. 1961, Khalid and Malik 1982, Marcar 1986, Marcar and Graham 1986, Longnecker et al. 1991) and on coating seed with nutrients (Scott 1989, Scott et al. 1991, McEvoy et al. 1988). However, there have been few reports in the literature of directing fertilizer strategies to enhance the nutrient content of seeds (Asher 1987, Kannan 1987) as an agronomic practice.

Phosphorus

Increases in P concentration of seed may be obtained as a result of fertilizer applications to the soil or foliar applications to the parent plant. Results from experiments where a range of P rates were applied to a single crop suggest that it may be difficult to achieve a large range of grain P concentration by soil applications at sowing using conventional rates of fertilizer. Bolland and Baker (1989) reported that increasing rates of P at sowing from 50 kg/ha to 300 kg/ha only increased seed P concentration by a factor of two, i.e., from 3.4 to 6.3 g/kg for *Trifolium balansae* and similarly for *Medicago polymorpha*. Levels of P in the seed of Jacup wheat ranged from 1.4 g/kg when no P was applied to 2.5 g/kg when 544 kg of P/ha was applied at sowing (Bolland and Baker 1988). Similar responses in P concentration in grain to fertilizer applied P have been obtained in South Australia (unpublished data of Elliott et al. for wheat and Tasker et al. for barley) but from a more restricted range of P rates: zero to 103 kg P/ha (Table 4). However, the relationship between P concentration in the grain and rate of P fertilizer applied was dependent on initial P fertility status of the soil and seasonal conditions.

On soils of low-moderate fertility (e.g., bicarbonate soluble P of 10-12 mg P/kg soil), the relationship is curvilinear, reaching an asymptote beyond the highest P rates applied. On virgin or very deficient soils,

there is no increase in grain P concentration at rates of applied P up to 8-17 kg P/ha and then a curvilinear response to higher rates similar to that on low-moderately fertile soils.

On more fertile soils in the Clare District of South Australia, the application of 40 kg/P ha increased on average the P concentration in the grain by 0.3 g/kg (Table 5). In fact, with these data, site factors other than bicarbonate soluble P in the soil appear to determine the P concentration in the seed.

An alternative to using a single application of P fertilizer is to build up the soil P fertility of seed paddocks over several years by applying above maintenance levels of P fertilizer. For a mallee loam at Mallala, South Australia, application of 150 kg P/ha over a seven-year period increased the bicarbonate soluble P from 11 to 48 mg P/kg soil, and increased the seed P concentration of the subsequent wheat crop from 3.7 to 4.3 g P/kg seed.

Foliar applications of P during grain-filling were investigated as a means of increasing seed P concentrations. When foliar applications of P (two equal sprays of 1.3 kg P/ha) were applied at flowering and soft dough to wheat and barley in the field, they have been unsuccessful in significantly increasing seed P concentrations. In three experiments the grain from the untreated controls had high concentrations of P (0.35 g/kg in barley and 0.4 g/kg in wheat). Although these experiments were unsuccessful, Schultz (1975) demonstrated that foliar applications of 16 kg P/ha (in three equal applications mid-tillering, first node and first ears visible) did increase grain P concentration (Table 6).

Table 4. The effect of rate of application of P fertilzer on the concentration in grain of wheat in 1982 and 1983 and barley in 1986.

P rate (kg/ha)	1982 wheat[a]	1983 wheat[a]	1986 barley[b]	1986 barley[b]
	(P concentration in grain, g/kg)			
0.0	1.9	1.5	1.5	1.9
4.3	2.1	1.4	1.7	2.1
8.6	2.1	1.4	1.6	2.3

[a] Site: Zameroo.
[b] Site: Parilla.
Selected treatments from unpublished data of Elliott et al. and Tasker et al.

Table 5. The effect of P concentration of wheat grown on five locations in South Australia in 1991.

Site	Bicarbonate soluble P (mg/kg)	P applied (kg/ha) 0	40
		Seed P concentration (g/kg)	
Auburn	41	2.6	2.7
Mintaro	29	2.5	2.8
Waterloo	54	1.6	1.6
Hill River	48	2.5	2.6
Clare	43	2.8	3.1

Table 6. The effect of foliar application of P on seed P concentration of wheat (g/kg).

Treatment	Seed P concentration (g/kg) Reeves Plains	Freeling
Nil (no fertilizer)	2.1	2.5
Soil (8 kg P/ha)	2.1	2.5
Spray (8 kg P/ha)	2.3	2.4
Soil 8 + Spray 16	2.5	2.7
LSD (P<0.05)	0.2	0.2

Modified from Shultz (1975).

Manganese

In contrast to P, Mn concentrations in grain can be manipulated considerably. While soil applications of Mn at sowing have been shown to increase levels of Mn in the grain

(Graham et al. 1985, Cooper et al. 1988) in conditions of severe Mn deficiency (highly calcareous soils of high pH), the increases are not large. This is because Mn applied at sowing is quickly rendered unavailable (Reuter and Alston 1975) and thus inadequate to supply the full Mn requirement of cereals. Applications must be followed by at least one and sometimes two foliar applications of Mn during tillering for optimal grain yield. Even then, in spite of large increases in yield, this will still result in low levels of Mn in the seed (as low as 5 mg Mn/kg of seed or on average 0.17 5 g Mn/seed for barley). This is at the lower end of the range of seed Mn levels reported by White et al. (1981) in a survey of seed Mn concentration involving 15 sites in Western Australia, wheat ranged from 17 to 84 mg Mn/kg and barley from 6 to 118 mg/kg. Growers who retain their own seed therefore need other strategies to ensure that grain being kept for seed has adequate Mn content.

In a study of factors determining the Mn content of seeds, Longnecker and Uren (1990) concluded that the largest factor was location, probably due to differences in availability of soil Mn. They observed seasonal effects only when Mn availability was low, and did not see any effect of variety. Species vary in Mn concentration of seeds (Table 7), Marcar (1986) and Longnecker and Uren (1990) observed higher concentrations in wheat seed than barley seed when grown at the same site. Faba beans (small-seeded type) had a much lower concentration of Mn in the seed than either wheat or barley when grown at the same site (Longnecker and Uren 1990); however, total seed Mn content was similar among these species.

A strategy for increasing seed Mn content was achieved by post-anthesis foliar sprays of Mn. A field experiment was conducted to ascertain whether fertilizer practices could be developed to enhance the Mn content of barley grain. Higher contents of seed Mn were achieved by application of foliar sprays (1.3 kg/ha Mn as $MnSO_4$) during grain-filling; the timing of these applications is not critical, but application must be after grain development commences. One foliar spray at soft dough increased seed Mn content from 0.24 to 0.48 5 g Mn/seed and a second spray two weeks later further increased seed content to 0.86 5g Mn/seed (Table 8). By varying seed Mn content in this way, other factors that affect seedling vigor, e.g., the status of other nutrients and environmental effects during grain-filling, are minimized.

Table 7. Mn concentration and content of seed from three species grown at Urrbrae, South Australia in 1986.

Species	Seed weight (mg)	Mn concentration (mg/kg dry weight)	Mn content (mg/seed)
Wheat (cv. Tatiara)	38 (1)	48.0 (2.0)	1.8 (0.1)
Barley (cv. Schooner)	53 (9)	21.0 (0.6)	1.1 (0.2)
Faba bean (acc. 195)	271 (42)	5.4 (0.6)	1.5 (0.3)
F ratio	29**	286.7**	3.1

** Signficant at P<0.001.
Values in parentheses are standard errors of the mean three replicates.
Source: Longnecker and Uran (1990).

Other nutrients

Soil applications of Zn at sowing have been shown to increase Zn concentration of wheat seed by two to three times depending on variety (Graham et al. 1992). Recent work in South Australia has demonstrated that Zn deficiency can be induced by the use of sulfonyl urea herbicides in situations where the cereal plants have a marginal tissue concentration of Zn (O'Keeffe and Wilhelm 1993). Growers using these herbicides may thus be unaware of low concentrations of Zn in the parent plant and subsequently low concentrations of Zn in the grain being kept for seed. Late foliar applications of Zn to the seed crop may ensure against this and result in greater seedling vigor. We are currently testing foliar sprays during grain-filling for wheat and barley; preliminary data indicate that they will be effective in increasing seed Zn levels.

Conclusions

The nutrient concentration of seed is important for the successful establishment of crop and pasture species. The advantages that improved early seedling nutrition may confer in resistance/tolerance to diseases

Table 8. Effect of foliar Mn applications during grain-filling on the Mn concentration and content of barley.

Time of spraying/ growth stage	Mn concentration (mg/kg)	Mn content (mg/seed)
1988 Schooner barley		
Nil	5.8	0.24
Week 1/milk stage	16.0	0.66
Week 3	16.2	0.77
1989 Schooner barley		
Nil	6.9	—
Early dough	12.5	—
Late dough	13.2	—
1990 Skiff barley (9 reps for Nil; 6 reps for Wk 1; and 3 reps for the others)		
Nil	4.7	0.17
Week 1/early dough	13.0	0.47
Week 2	12.5	0.45
Week 3/hard dough	11.1	0.42
Week 1+3/81+87	20.7	0.77
1991 Skiff barley		
Nil	7.0	0.25
Week 1/caryopsis water ripe	12.3	0.43
Week 2	16.7	0.58
Week 3/early dough	15.7	0.56
Week 5/caryopsis hard	22.1	0.79
Week 1+3	19.1	0.70
Week 1+5	27.2	0.95

are also a consideration. For farmers in the southern Australian context on soil types where resulting seed contents of P and trace elements are low, the concept of buying seed from certified growers is costly and unacceptable; exchanging seed with growers from more fertile areas is fraught with problems (for example importing herbicide resistant weeds, rye grass toxicity or new weed species). For these farmers other strategies such as fertilizing seed paddocks or foliar fertilizer applications during grain-filling may confer the same benefits without the additional risk. Late foliar applications of Mn may be the most efficient method of loading Mn into seed for cereals grown on calcareous soils with low Mn availability.

The advantages of seed nutrition are not always apparent, the dependence on seed resources probably being related in part to soil temperature and moisture conditions, so that in slow growing environments there is a greater dependence on seed nutrients. However, if boosting of seed reserves can be achieved relatively reliably and economically, it may prove to be a good preventive technique that may in fact confer other benefits such as disease resistance or tolerance on the emerging seedling. In all our work, the best yields have been achieved where a combination of soil and seed nutrition has been used.

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Questions/Discussion

Dr. Graham, who presented this paper, was asked how long the seedling would depend solely on seed reserves. He replied in three ways. First, from a purely technical standpoint, the seedling would no longer be 100% dependent on seed reserves as soon as the first root emerges and makes contact with the soil. Generally though, the consensus is that the seedling depends on seed reserves for 10-14 days. Another way to answer this question would be to say how long it takes for symptoms of deficiency to appear when the seedling is grown in a nutrient-free medium. In the case of manganese, this takes two weeks, zinc about three weeks and for copper, somewhat longer. With molybdenum, cobalt, and nickel, for which the plant requirement is very low, enough nutrient can be stored in the seed to last the whole crop cycle, and this is a technique used in some hybrid seed systems to ensure that the crops do not develop molybdenum deficiency.

He explained that, generally, seed coating of nutrients is also effective but the nutrients stored in the seed are complexed in a transportable form that moves more easily through the phloem.

When questioned about seed source in breeding yield trials, he emphasized that all seed in a comparative yield trial must be produced at the one location. When seed from different sources is used, the differences in the seed nutrient contents can lead to differences which dominate genotypic differences.

He was asked how he would rate nutrient application in deficient soils against the use of a nutrient efficient genotype. Dr. Graham said a superior solution is to combine both—the efficient genotype makes better use of the limited nutrients available in the seedling stage before the seedling roots contact the fertilizer and commence uptake.

Dr. Graham was also questioned on other aspects of micronutrients, outside the topic of his paper. He was asked about any relationship between manganese and sterility. He cited evidence of manganese deficiency resulting in sterility by preventing dehiscence of the anthers by affecting the synthesis of lignin. Another part of the question related to zinc. From his work, zinc doesn't seem to have a specific effect on the reproductive phase—the depression in grain yields seem to be in proportion to the depression in vegetative yield.

In response to a question, Dr. Graham outlined some circumstantial evidence for a boron-manganese interaction. In his work, he has found a very strong negative correlation between tolerance to boron toxicity and manganese efficiency, i.e., tolerance of manganese deficiency.

During his presentation, Dr. Graham had made reference to micronutrient-disease interactions. He was asked how the critical nutrient values for disease resistance compare to those for plant growth. He admitted there were limited data on this aspect. His group has worked from a first assumption that they are the same and this is so for some micronutrients studied. However, they have shown that in the presence of Take-All inoculum in the soil, plants will respond to a higher level of manganese than that to which they would respond in the absence of the fungus, suggesting that any resistance mechanism

that is controlled by manganese operates at a higher manganese requirement than growth itself.

Dr. Graham had pointed out that often, nutrient deficiencies predisposed plants to disease. However, nitrogen is the exception. Generally, increased nitrogen increases the susceptibility or predisposition to disease and it does so not only in the deficiency range but in the sufficiency range as well. Over a very wide range of nitrogen application rates, susceptibility increases, but so does tolerance. Therefore, when a high nitrogen situation is compared to low nitrogen, there is more disease on the high nitrogen plants but the yield is also higher—that is, the plants with the adequate nitrogen level can carry that higher disease burden and still produce a higher yield.

How do the elements discussed increase resistance? Dr. Graham admitted this was not clear but there is a theory that the effect is through lignification in the case of manganese. Manganese can have a huge effect on lignification. It also has a large effect on powdery mildew but little effect on rust. These two obligate parasites have very different modes of entry to the plant. Powdery mildew forms appresoria that punch through the epidermis, so the strength of the cell wall is probably important. On the other hand, the rusts grow down through a stoma and tend to find thinner cell walls below. That tends to support a lignification theory.

In the case of zinc, there is good physiological evidence to show that it is involved in membranes. In both plants and animals, evidence suggests that zinc-deficient membranes are leaky, and sugars and amino acids leak out. It is speculated that provides a chemotoxic stimulus to encourage the pathogen to the root surface.

Results of a Long-Term Rice-Wheat Soil Fertility Experiment in the Terai of Nepal

G.S. Giri, G.P. Acharya, and A.P. Regmi
National Wheat Program (NWRP), Bhairahawa, Nepal
P.R. Hobbs
CIMMYT, Kathmandu, Nepal

Abstract

A long-term rice-rice-wheat cropping pattern trial was initiated at the National Wheat Research Centre at Bhairahawa in the Terai of Nepal in 1978. The experiment started with the normal or second rice crop and has received the same treatments for the two rice crops and the one wheat crop annually since that date. Nine fertilizer treatments allowed the experiment to look at the effect of P and K in factorial combination, the effect of applying P and K to just wheat and measuring the residual carryover to the two rice crops, the residual effect of incorporating crop stubbles, and the effect of applying farmyard manure only. Results showed a distinct decline in yield for both rice crops for all treatments with minus P plots being affected more drastically than two plus-P treatments. One hypothesis for the decline in rice yields even where N-P-K is applied is the reduction in available zinc to below critical levels. This could have alarming implications for food production in the region if the results of this experiment can be verified in farmers' fields and other areas of South Asia.

Introduction

Rice has been cultivated in Nepal for a long time. Wheat, on the other hand, has only become an important food grain since the 1960s and is presently grown on more than 600,000 ha. Most wheat is grown in a cropping pattern following rice. This became feasible with the introduction of the shorter duration, nonphotosensitive rice and wheat varieties derived from the International Rice Research Institute (IRRI) and CIMMYT in the late 1960s. Before the introduction of these modern varieties, farmers in Nepal's Terai Zone, grew traditional, tall rice varieties with low yield potential in the monsoon season and kept their lands fallow in the drier winter season. Farmers maintained their soil fertility by leaving the rice stubble in the field and allowing their animals to graze there, leaving cowdung droppings where they fell. There were no other crops on the land and therefore no need to protect the fields from free roaming animals. Firewood was in plentiful supply and there was no need to collect the cowdung for fuel purposes.

With the introduction of the new rice varieties, land use was intensified. At the same time, farmers from the hills were encouraged by the government to settle and farm the land in the Terai Zone. This led to deforestation, a reduction in animal numbers because of a reduction in grazing fields, a shortage of feed and fodder, and a reduction in the amount of cowdung for crop production. There was an increase in stall feeding of animals, less free roaming of animals, and more of the manure was used for fuel. The farm yard manure (FYM) that was returned to the fields was given mostly to the rice nurseries, kitchen gardens, and nearby fields. Over time, less and less manure was applied to rice or wheat fields. Instead, farmers began to use more

chemical fertilizers, especially urea, and later, phosphorus containing chemicals on these two cereal crops. Less stubble was left in the field. Chemical fertilizer doses were mostly below recommended levels and often unbalanced in terms of the nutrients removed by these two exhaustive crops.

The rice-wheat management practices followed by farmers in the terai consists of growing a puddled crop of rice followed by an upland crop of wheat. This results in a degradation of soil physical properties. The continual growing of rice and wheat has also led to an increase in weeds, insects, and diseases, both foliar and soilborne. At present, about one third of the rice crop is followed with a wheat crop. This proportion will increase in the future as more land is cropped to wheat and more irrigation infrastructure is developed. Since farmers are unlikely to abandon this cropping pattern, but rather increase its area, the above problems need to be addressed in a systematic way. This paper presents some data collected by the Wheat Research Centre in Bhairahawa, Nepal, that provides evidence on the above issues and relates to the important issue of sustaining crop production in the future.

Materials and Methods

A long-term rice-rice-wheat cropping pattern trial with nine treatments (Table 1) was initiated at the National Wheat Research Centre at Bhairahawa in the Terai of Nepal in 1978. The experiment started with the normal or second rice crop it has received the same treatments for the two rice crops and the one wheat crop annually since that date. These treatments allowed the experiment to look at the effect P and K in factorial combination, the effect of applying P and K to just wheat and measuring the residual carryover to the two rice crops, the residual effect of incorporating crop stubble and the effect of applying FYM only. The best available variety for each crop was selected at the start of the experiment. However, because of changes in varietal disease incidence with time, the varieties had to be changed during the 14 years of the experiment. Soil samples were taken at the start and at intervals since then. However, constraints with soil analysis have prevented these data from being available for interpretation. Attempts to keep planting date and other crop management practices constant over the years to reduce variability were attempted but not always successful or possible.

The analysis used in the data presented here was done by fitting a general linear model to the data using the MGLH procedure in the SYSTAT software package. The model used was:

$$\text{Yield} = \text{Constant} + \beta_1{}^*\text{Variety}(i) + \beta_2{}^*\text{Rep}(j) + \beta_3{}^*(\text{Treatment}(k) + \beta_4{}^*(\text{Treatment}(k)^*\text{Year} + \beta_5{}^*\text{Like Year}$$

Table 1. The fertilizer treatments (kg/ha) used in the long-term rice-rice-wheat soil fertility trial in the National Wheat Research Centre at Bhairahawa, Nepal.

Treatment	Rice crop (N-P-K)	Wheat crop (N-P-K)
1	0-0-0	0-0-0
2	100-0-0	100-0-0
3	100-30-0	100-40-0
4	100-0-30	100-0-40
5	100-30-30	100-40-40
6	100-0-0	100-30-30
7	50-0-0 + 30 cm straw*	50-0-0 + 30 cm straw
8	50-20-0 + 30 cm straw	50-20-0 + 30 cm straw
9	10 t FYM /ha	10 t FYM/ha

* 30 cm of straw was left from the previous crop and incorporated in the plot.

Variety, replicate, and treatment were used as categorical variables and year as a continuous variable. This allowed statistical removal of the effects of these discontinuous variables and plotting of yield against year for each of the combinations required. The data presented are for the first variety and replicate of the four P and K factorial combinations found in treatments 2, 3, 4, and 5. The model allows for change of the variety and replication numbers but the effect is to move the plot up or down an equal amount for each treatment and not affect the slope.

In year 12, the plots were split in half during the early rice crop to look for possible deficiencies of zinc. Twenty-five kilograms of zinc sulfate per hectare was applied at random to one of the half plots in all treatments. For comparison, the other half was left as a check without zinc. These two sub-plots in each treatment were harvested separately and treated as distinct plots for the following rice and wheat crops so that residual carryover effects could be measured.

Results

A plot of the yield of each crop over years for treatments two through five are shown in Figures 1-3. Both rice crops showed a distinct decline in yield for all treatments with the minus-P plots being affected more drastically than the two plus-P treatments. In the normal rice crop, an additional effect can be seen with respect to potash use in the presence of phosphorus (Figure 2). The parallel nature of the two lines suggest that potash does boost the yield of rice and that this effect was apparent from the very beginning of the experiment. A similar effect was not seen in the minus-P or early rice crop. Wheat shows a completely different response (Figure 3) with no decline in wheat yield when the full N-P-K dose was used. However, declines were evident when P was not used and a smaller decline when only potash was omitted. The potash response started to appear as an increase in leaf firing and spotting in the 12th year and

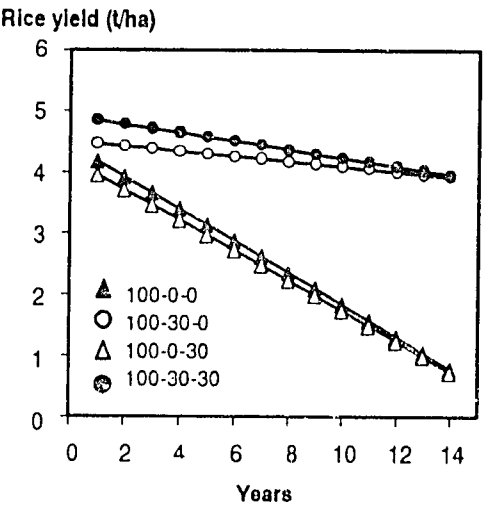

Figure 1. Yield of early rice by year in a rice-rice-wheat cropping pattern trial with different levels of P and K.

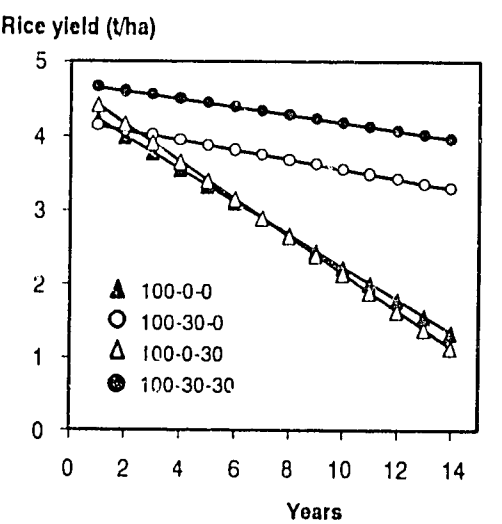

Figure 2. Yield of second rice crop by year in a rice-rice-wheat cropping pattern trial with different levels of P and K.

a subsequent reduction in yield. A linear representation of the data may not be the best model. Instead, one that shows a linear nonresponse for the first 10 years followed by a decline after that may be a better representation. This needs to be looked at as more data become available.

Similarly, the effect of no-P is not linear, especially for the early rice crop. Figure 4 shows a truer representation of the decline. There is a very rapid decline in yield for the first six years at which time the yields are zero. For the second rice and the wheat crops, the yields have not reached zero although the wheat yields are very low. More data and analysis for these are needed before fitting the best curve for these two crops. The yields may drop to zero in time or stabilize at a low constant yield. However, it is obvious that phosphorus is essential for maintaining the productivity of this pattern. For potash, more time is required before soil potash levels reach critical levels and yields start to decline. Recently, the plots were split again and applications of phosphorus and potash were applied to test whether there are responses to these elements in treatments where they are missing. These data have just been collected and are still to be analyzed.

One hypothesis for the decline in the rice yields even where N-P-K is applied is the reduction in available zinc to below critical levels. Zinc is recommended for high rice yields throughout the Gangetic flood plain of the Subcontinent. The results in Figure 5, however, do not support this hypothesis. In fact, zinc depressed yields in the early rice crop. Figure 5 only shows the response from treatments where phosphorus is used since yields are zero where no phosphorus is applied. Figure 6, however, shows that some zinc carried over to the second rice crop and presents a more complete picture since minus-P plots do yield some rice. The analysis of the data provided a nonsignificant affect of added zinc. However, the interaction P by zinc term was significant. In plots where P was not used, zinc gave a positive response and where P

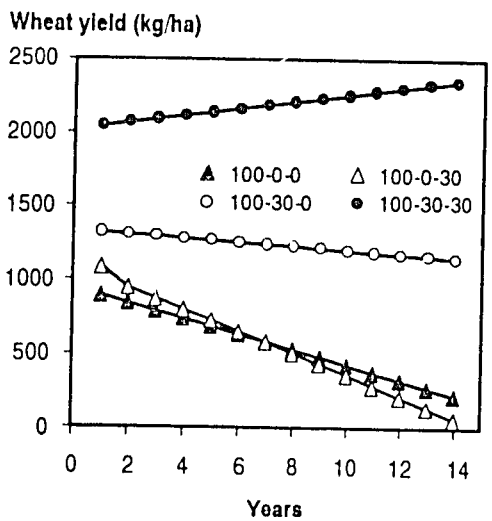

Figure 3. Yield of wheat by year in a rice-rice-wheat cropping pattern trial with different levels of P and K.

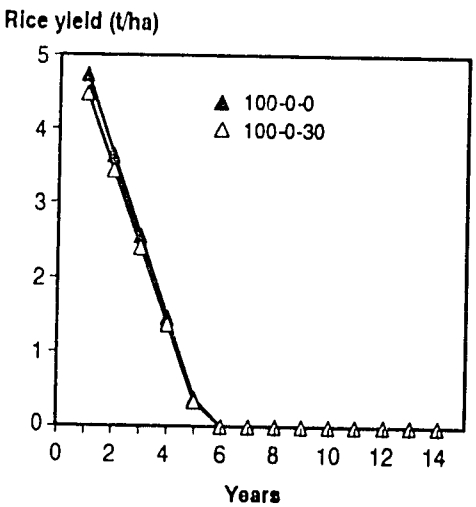

Figure 4. Effect of no addition of phosphorus to the early rice crop.

was used the response was negative. There was no residual response of zinc application in the next wheat crop. These results need further study to help unravel the interaction between zinc and phosphorus. It is still unclear whether zinc is a deficiency or not. Soil tests suggest very low levels of available zinc (Neue 1989). Unfortunately, the small plot size used in the experiment prevent them being used for further study of this topic.

Discussion

The results of the above experiment could have alarming implications for food production in the region if the results can be verified in farmer fields and other areas of South Asia. Data from a similar soil fertility experiment at Pantnagar University in Uttar Pradesh, India, for a rice-wheat system did show the same rice declines for all treatments including those with recommended N-P-K, N-P-K plus zinc, and N-P-K plus FYM (Hobbs et al. 1991). Data from IRRI in the Philippines (Flinn and De Datta 1984 and Cassman, pers. comm.) also show a yield decline for rice with full recommended fertilizer. Nambiar and Abrol (1989) analyzed many manurial trials from India and showed a declining trend in productivity even with recommended N-P-K fertilizer in many of their trials. These data could be an anomaly of experiment stations where tractor use is normal and excessive tillage commonly done. However, at present, there is very little data available from farmers' fields to allow an analysis and comparison. Several farmers indicated that they needed to use more fertilizer today for the same yield than they did 10 years ago. In other words, the productivity of the system had declined. Hopefully, this question can be better addressed when data from monitoring research become more available. In monitoring research, data on yields and inputs are collected from a set of farmers' fields over time. This type of research is being initiated in various rice-wheat areas of South Asia.

Obviously, rice and wheat yields decline if farmers do not use phosphorus. For the early rice crop following the exhaustive

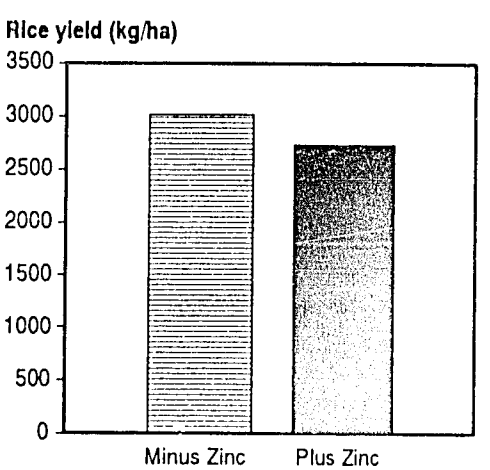

Figure 5. Yield of early rice in the 12th year following the application of zinc in the plus P treatments.

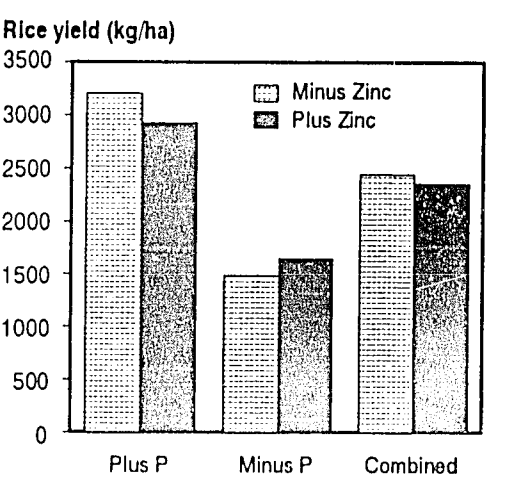

Figure 6. Yield of the second rice crop in the 13th year with and without zinc and with and without phosphorus.

wheat crop, this does lead to no yield in the Bhairahawa soil. However, because the soil remains wet and reduced during the second rice crop, the pH tends to become neutral and more soil phosphorus becomes available for rice growth. Based on the results of the diagnostic survey in Bhairahawa (Harrington et al. 1993) and results from the benchmark for the monitoring research in the same district, most (90%) of the farmers in the District use some phosphate fertilizer. A few don't use any, but use FYM instead. It is important for the farmers to continue using phosphorus. The results from some of the other treatments in the experiment described suggest that 20 kg of phosphate applied to each crop was sufficient to provide the phosphorus needed for the system. However, 20 or even 40 kg/crop is less than the amount removed by the crop per season and long-term deficiencies could arise.

Potash responses were observed in the experiment by the 12th year with symptoms of increased leaf spotting and firing and reduction in yield. Since very few farmers use potash fertilizers in South Asia, this deficiency needs more attention. The symptoms appear much later in the growth of the crop and may be confused with an increase in disease and may not be identified as a nutrient problem by farmers, researchers, or extension personnel. Poor grain-filling and shriveled seed is another symptom of potash deficiency, which can also be confused with other problems. Other deficiencies that have been postulated include zinc, sulfur, and boron. The data presented indicate that the zinc deficiency may be complex and involve an interaction with phosphorus. Boron and sulfur responses have not been reported in Bhairahawa, but have been reported in other areas of South Asia. Boron deficiency is particularly evident in eastern Nepal, India, and parts of Bangladesh (Misra et al. 1992) where sterility for boron and yellowing for sulfur is seen.

Soil physical degradation and soil health are two other possible causes of yield declines. Most of the rice crop is grown using puddled technology. This results in disaggregation of soil particles and development of a root restricting plow pan (Hobbs et al. 1994). Continued use of the rice-wheat pattern could lead to a slow reduction in yield of both crops because of this reduction in root growth and increase in soil pores of smaller size. Obviously, if roots are restricted, the available soil nutrients will be less and the rooting zone nutrients will be mined quicker than if rooting was deeper. The long-term experiments in South Asia need to be used by soil physicists to measure these soil physical and rooting parameters and complement the work on soil fertility.

The build up of soil pathogens, insects, and nematodes can also have an effect on yields of crops in the rice-wheat system. Data from the diagnostic surveys in Bhairahawa indicated high levels of the rice root nematode (*Herschmaniella*) in the root zone of the rice crop during the survey (Harrington et al. 1993). More research is needed to see whether this and other pathogens buildup and affect the rice and wheat yields over time. The pathologists should also be associated with the data collection from the long-term trials so that soil health issues can be addressed.

The role of organic fertilizers in maintaining rice and wheat yields needs to be clarified. Many scientists suggest that use of FYM and green manures is essential for crop production. However, FYM supplies and the use of FYM on rice and wheat fields is

declining as more of this by-product is used for fuel and cooking purposes and becomes more expensive to transport to the field because of increasing labor costs. It is also becoming more difficult to feed and care for animals and with the introduction of tractors, the amount of FYM available is declining. FYM can provide an array of nutrients and benefits to the soil physical properties. As its supply becomes more limiting, it becomes important to understand its role in maintaining soil health so that alternatives can be found and used. There is also a role for research on fast growing legume trees to help relieve the pressure on FYM for fuel and thus make more of this by-product available for crop production. A combination of organic and inorganic fertilizer may help increase the efficiency of both types of nutrients (Hobbs et al. 1987).

Very few farmers in the region grow green manure crops. Research has shown that they provide a boost to rice yields following the incorporation of the green manure. Khan (pers. comm.) reported that the rice grain yields obtained from 45- to 60-day old Dhaincha (*Sesbania cannabina*) green manure was equivalent to 80 kg N/ha. However, there seems to be little benefit or carryover to the next wheat crop. Farmers cite the problems of irrigation, hot weather, and costs of incorporating the green manure as reasons for not growing it. Seed supply is also a problem. More research is needed on evaluating the use of this technology in the system. The use of legumes as substitutes for rice and wheat in longer term rotations also needs to be evaluated.

The rice-wheat systems of South Asia will continue to be important in the future. Farmers have few alternatives as substitutes for either crop. Many farmers in South Asia are also subsistence farmers, who must grow sufficient rice and wheat for their family needs before thinking of alternative and more risky cash crops. It is therefore imperative that research focuses on the issues of sustainability in an integrated way so that solutions to these problems can be quickly found. Data show that there will be a requirement of a 2.5% annual (compounded) increase in rice and wheat production through the year 2010 to meet the food needs of South Asia. This region cannot afford to have yields and productivity declining during this period.

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Technologies Generated in Wheat Research and Methods of their Transfer in Bangladesh

M.A. Razzaque, M.A. Samad, A.B.S. Hossain, M.A. Suflan, M. Haque, N.K. Saha, Rahimullah, A.B.M. Rahman, A. Hossain and M.S. Zaman
Wheat Research Centre, Dinajpur, Bangladesh

Abstract
Technologies generated in wheat research have been transferred using different methods since 1973. Initially, the modern methods of transferring technologies were not adequately applied due to lack of proper facilities and manpower in Bangladesh. Since 1980, the methods that have been utilized are: demonstration, training, farmers' rallies, field days, workshops, seminars, travelling seminars, publications, mass-media publicity, diagnostic surveys, and monitoring at the farm level. Special emphasis has been given to demonstrations at the farm level, and training of farmers, agricultural extension personnel, and personnel engaged in related nongovernment organizations. As a result, 100% of the wheat area is now sown with high yielding varieties and 85% of seed wheat is preserved by the farmers themselves.

Introduction

Systematic research on wheat was initiated in Bangladesh in 1970. Following some encouraging results in varietal development, the wheat production program was launched in 1975. However, until 1980, technology transfer was limited due to the shortage of manpower. Attempts were made for block farming demonstrations of newly introduced varieties, organized by the then Jute Growers Association of the Extension Department. Seed preservation methods and other technologies developed in research were taught to the extension personnel for transmission to the farmers through the field level workers. Moreover, booklets on seed production and preservation were also distributed for adoption of these technologies by the farmers. These approaches contributed to increasing wheat area and productivity in the early program. More recently, when new or improved technologies were generated in different areas of wheat production, intensified activities have been undertaken to transfer these to extensionists and farmers, through on-farm demonstrations, training programs, field days and seminars, publications, and mass media campaigns.

Demonstrations

On-farm demonstrations of modern wheat varieties were initiated by the Wheat Research Centre (WRC) from the Regional Agricultural Research Station, Ishurdi, in 1973. The Soil Fertility and Testing Institute of the Bangladesh Agricultural Research Institute (BARI) also conducted fertilizer demonstrations for wheat. Due to the lack of proper supervision resulting from a shortage of manpower, there was very little impact from these demonstrations. An intensified program was made possible from 1984-85 with the involvement of CIMMYT and the Canadian International Development Agency (CIDA), in close association with the Agricultural Extension Department.

The objectives of the demonstration program have been to assess the performance of new varieties or management technologies over the various agro-climatic zones of the country, to aid in the dissemination of new varieties (the farmers keep the harvest from the demonstrations), and to provide a rational base for advising the seed production agency on the varietal requirements in seed production and seed distribution patterns.

The various types of on-farm demonstrations distributed since 1984 are shown in Table 1.

Varieties

The demonstrations conducted from 1985 to 1992 (Table 2) demonstrated the yield advantage of the new varieties over Sonalika with Kanchan proving its superiority over the other new varieties consistently over the years. Due to the success of Kanchan in being accepted by an overwhelming proportion of farmers, the varietal demonstrations have been reduced during the last two years. However, when the new lines developed by the Wheat Research Centre are registered as varieties, these demonstrations will be re-emphasized.

Table 1. On-farm demonstrations conducted in Bangladesh since 1984.

Crop Season	Varieties	Boron	Seed treat.	Yield max.	Ferti-lizer	Minimum tillage	Nitrogen management	Total
1984-86	300							300
1985-86	500							500
1986-87	750							750
1987-88	900	50						950
1988-89	910	50	110	20				1090
1989-90	820	50	200	35	200			1305
1990-91	820		200	30	200	50	30	1330
1991-92	240		100	18	100	47	27	532
1992-93	200		260	54	200	100		814
Total	**5440**	**150**	**870**	**157**	**700**	**197**	**57**	**7571**

Table 2. Summary of results from variety demonstrations, 1985-92.

	1985-86		1986-87		1987-88		1988-89		1989-90		1990-91		1991-92	
Varieties	Mean yield (t/ha)	Yield over Ska(%)	Mean yield (t/ha)	Yield over Ska(%)	Mean yield (t/ha)	Yield over Ska(%)	Mean yield (t/ha)	Yield over Ska(%)	Mean yield (t/ha)	Yield over Ska(%)	Mean yield (t/ha)	Yield over Ska(%)	Mean yield (t/ha)	Yield over Ska(%)
Kanchan	2.76	17.4	2.58	19.0	2.60	16.9	3.21	17.4	2.79	16.5	3.38	19.0	3.53	25.6
Akbar	2.69	14.5	2.38	9.5	2.45	10.0	3.06	12.0	2.61	7.0	3.21	13.0	2.97	5.7
Aghrani	-	-	2.42	11.5	2.42	8.6	2.99	9.6	2.51	4.8	3.16	11.3	3.19	13.5
Sonalika	2.35	-	2.17	-	2.22	-	2.73	-	2.40	-	2.84	-	2.81	-
Mean yield	2.59		2.39		2.42		3.00		2.58		3.15		3.13	
No. demons. analyzed	363		711		543		760		509		648		150	

Ska = Sonalika.

Boron application

In the light soils of the northern region, boron was applied with the objective of combatting sterility, which became obvious in farmers' fields from 1986-87. The results are shown in Table 3. During the subsequent years (1987 and 1988) as sterility was still observed in Kanchan and Sonalika even after the application of boron, it was assumed that sterility was not due to boron deficiency alone, and this study in farmers' fields was terminated until the other factors can be determined from more detailed studies on the research stations. However, the response of applied boron for the three year-demonstration indicated that there were significant yield increases.

Table 3. The response of Kanchan and Sonalika to applications of boron.

Crop season	No. of demonstrations	% yield increase with boron application	
		Kanchan	Sonalika
1987-88	29	5.1	9.0
1988-89	43	12.1	12.4
1989-90	30	9.0	13.0

Table 4. Average yield response of Kanchan to P, K, and S in Bangladesh.

Year	+ NPKS Yield (t/ha)	Yield loss (% of NPKS)		
		-P	-K	-S
1989-90		12.50	11.50	13.00
1990-91	3.31	17.22	11.48	13.29
1991-92	3.57	19.32	13.73	11.48
Mean		16.35	12.24	12.59

Fertilizer

These demonstrations aimed to sensitize farmers to the need for phosphorus, potassium, and sulfur. Farmers are aware of the benefits of nitrogen application and so it was not a variable in these demonstrations. When the elements P, K, or S were omitted from the fertilizer package, the yield reductions were 16.4, 12.6, and 12.2 %, respectively (Table 4).

Yield maximization

Using the best variety, sown at the optimum time, with the recommended rate of fertilizer along with the addition of cowdung, followed by proper irrigation and weed management are key factors to obtain the maximum yield in wheat. The variety Kanchan was used in these demonstrations, optimizing all of the above factors, in large plots (1300 m^2). In most of the locations, the yield exceeded 5 t/ha. So far, the highest yield recorded in these demonstrations was 6.6 t/ha at Nilphamari, near Dinajpur. The highest yields in each district are shown in Table 5.

Seed treatment

This demonstration was initiated in 1988-89 under irrigated and nonirrigated conditions. From 1990, the demonstrations were sown only under irrigated conditions, as the experience of the first two years indicated, the response to seed treatment was more

Table 5. The best district yields from Yield Maximization demonstrations in farmers' fields, 1990-91.

Site (District)	Yield (t/ha)
Nilphamari	6.60
Rangpur	6.24
Dinajpur	6.25
Rajshahi	5.55
Dhaka	5.06

consistent where the crop was irrigated. The percent yield increase was greater for Sonalika than Kanchan (Table 6). Superior establishment of the crop stand by the use of Vitavax-200 was the major reason for obtaining the higher yields.

Minimum tillage

Minimum tillage and tillage using the farmers' practices were compared in the rice farming system with the objective of decreasing the turn around time after the rice harvest and to establish the crop at a more optimal date. Some difficulties have been experienced in implementation of this demonstration but the results obtained in two years were consistent indicating a 6.86% yield decrease following minimum tillage compared to conventional tillage when sown at the same date. The mean yield of minimum tillage over two years was 3.53 t/ha (Table 7). We believe this yield can be increased by making better use of the shorter turn-around time and the consequent earlier seeding date made possible by the use of minimum tillage.

Training

The training sessions are organized at the WRC as well as other locations. Curricula have been developed for one- to five-day courses depending on the program. Training notes and manuals are prepared and pre- and post-evaluation of the students' knowledge are conducted. The training courses held at different locations are mainly conducted by the WRC scientists

Table 7. A comparison of wheat yields from sowings following conventional and minimum tillage.

		Grain yield (t/ha)	
Year	No. of demonstrations	Minimum Tillage	Normal Tillage
1990-91	43	3.56	3.80
1991-92	27	3.49	3.77
Mean		3.53	3.79

Table 6. The effect of seed treatment (Vitavax-200) on wheat yield (t/ha).

		Yield of Kanchan			Yield of Sonalika		
Year and growing conditions	No. of demon-strations	No treat-ment	Treat-ment	Yield increase (%)	No treat-ment	Treat-ment	Yield increase (%)
Irrigated							
1988-89	54	3.30	3.67	11.21	2.88	3.25	12.84
1989-90	54	2.68	2.91	8.58	2.26	2.47	9.29
1990-91	140	—	—	16.54	—	—	—
1991-92	75	3.02	3.29	8.94	—	—	—
Nonirrigated							
1988-89	33	2.57	2.82	9.72	2.33	2.61	12.01
1989-90	45	2.38	2.61	9.66	2.12	2.40	13.2
Mean		2.46	2.70	9.76	2.21	2.49	12.67

and by scientists of different regional research stations. A program is sent from the WRC to the respective Deputy Directors of the Agricultural Extension Department and other concerned officials of different organizations with a copy to the program leader and team leader of the wheat program in the particular region. The program is finally approved by BARI authorities. Generally, three types of training are organized:

- Farmers' training on management of demonstrations as well as improved production practices (one day);
- Training of Extension Department, Bangladesh Agricultural Development Corporation (the seed production authority), and Water Development Board personnel on production practices and modern technology (up to 5 days);
- Training of personnel engaged in related Non-Government Organizations (NGOs) on new technology and production practices (up to 5 days).

The number of participants at the various training courses are shown in Table 8.

Table 8. Wheat training participants, 1984-1992.

SL No.	Participants	Number
1	Farmers	7,569
2	Extension officers	24
3	Block supervisors	4,400
4	BADC personnel	63
5	NGO personnel	80
6	Grameen bank personnel	250

Field Days, Workshops, Seminars, and Meetings

The following activities are performed during the crop season:

- Field days—About 100 farmers and extension personnel normally attend these events, which are centered on outstanding demonstration sites. In addition to observing the demonstrations, information is given about general crop conditions, improved harvest technology, and methods of seed storage. Farmers are encouraged to express their problems with wheat production.
- Mobile workshops—About 50 farmers plus a number of extension personnel and scientists attend this program for one day. The group visits research stations, surrounding farmers' fields, contract seed growers' fields and on-farm demonstrations to observe the different production practices.
- Workshops and seminars—Regional, national, and sometimes international workshops are organized. Monthly meetings at district and regional levels are also organized with extension and local government officials to discuss the field problems and to formulate local extension thrusts.
- Travelling seminars—All wheat scientists and scientists of related divisions of BARI and other organizations jointly visit farmers' fields across a particular zone, and interact with the farmers. This program helps junior scientists to become acquainted with farmers' problems. It also provides a chance for them to develop their own programs on the basis of the farmers' needs.

Surveys and Monitoring

Diagnostic surveys

These are organized in a particular region involving a group of scientists and extension personnel. A questionnaire is prepared in advance to collect desired information and a report is prepared (Monograph) regarding:

- Identification of farmers' problems;
- The consequent implications for research;
- Consideration of the possible technical factors, which may be restricting yields in the farmers' fields;
- Implications of the survey data on extension methods and thrusts.

Monitoring of selected farmers

Six sites have been selected where the three-cropping system of upland rice (Aus), transplanted rice, and wheat is sown every year. This will continue for the next five years. A questionnaire was prepared in collaboration with the Interational Rice Research Institute (IRRI), CIMMYT, and the national programs of BARI and the Bangladesh Rice Research Institute (BRRI). Farmers will be interviewed regularly to gather information about their existing cultivation practices, production, costs involved, and other related issues. The main objective is to determine the status of productivity and sustainability of the rice-wheat systems in Bangladesh.

Publications

Booklets, leaflets, and posters are regularly prepared and distributed to the farmers. Quarterly newsletters are published and distributed among the scientists, administrators, planners and concerned officials of different organizations including personnel of NGOs. Monographs are for the planners, researchers and concerned extensionists. Annual reports and scientific papers are also published and distributed to the scientists.

Mass Media Publicity

Radio, television, newspapers, and strip films are media used for effective publicity of information on production practices.

Conclusions

By the use of different methods of technology transfer, farmers have become acquainted with the modern varieties and production technologies. Almost 100% of wheat growers are now cultivating high yielding varieties. More than 85% of the seeds required are preserved by the farmers themselves by using low cost technologies generated by the WRC. Many farmers, extension personnel, and others have been trained in wheat production.

The Wheat Development Action Project: Philippine Experiences

C.R. Escano
Crops Research Division, Philippine Council for Agriculture, Forestry and Natural Resources, Research and Development (PCARRD), Los Baños, Laguna, Philippines

Abstract

Research on wheat began in the Philippines in the early 1960s, resulting in the release of three varieties to date. The possibility of wheat production was raised in the early 1980s and a Wheat Pilot Project was established to demonstrate its viability. Over a five-year period, it was shown that wheat production could be an economically viable option for farmers in northern Luzon in areas in which lack of irrigation precludes the growing of a second rice crop. More recently, wheat production projects have been implemented. The major technical problem encountered has been helminthosporium leaf blotch, which under certain circumstances, has resulted in near total crop failures.

Introduction

Wheat is the highest food grain import of the country and amounted to 1.56 million tons valued at about US$ 227.3 million in 1990. Although efforts had been made in the past to find possible substitutes for wheat flour, there has been no significant impact on reducing wheat importation. Historical records show that wheat was grown in the Philippines as early as 1664 and was a flourishing industry during the Spanish regime. The places where wheat had been reportedly grown successfully were the Luzon provinces of Ilocos, Cagayan, Batangas, and Cavite. However, as wheat importations increased during the American regime, the crop was eventually abandoned.

Past results of research studies conducted by several research and development institutions in the country, started in the early 1960s, indicated the potential of growing the crop in some selected areas. In fact, three improved wheat varieties (Trigo 1, 2, and 3) were approved by the Philippine Seed Board for commercial planting.

The Wheat Pilot Production Project

The Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD) supported and coordinated for five years (1982-1987) the Wheat Pilot Production Project, which was aimed primarily at demonstrating the viability of growing the crop in selected northern Luzon provinces; Cagayan, Ilocos Norte, and Ilocos Sur.

Specifically, the project's objectives were to:

- Demonstrate and verify the package of technology (POT) for wheat growing in selected pilot areas;
- Determine the economics of wheat production;
- Identify specific component technologies in wheat growing that would require further refinements; and
- Increase the supply of certified seed of recommended wheat varieties.

Scope of the Project

The wheat crop was targeted at areas in which the planting of a second rice crop is not possible due to limited irrigation water. The project initially covered selected pilot areas in three regions of Luzon, involving a total area of about 20 ha and 60 farmer-cooperators. However, as the project progressed, the pilot testing was concentrated in provinces where initial successes were obtained such as in Cagayan and in the Ilocos provinces, but was changed from widely-separated individual sites to compact farm production modules.

For the whole duration of pilot testing, the project was involved in two major activities—demonstration of wheat production technology, and conduct of applied research to refine the package of technology. In addition, several support activities were conducted such as training of farmers/extensionists, technical and market assistance, characterization of selected pilot sites, seed certification, granting of credit assistance, and development of prototype communication materials.

Implementation Arrangements

The pilot project was jointly implemented by the National Food Authority, the Department of Agriculture, and the Mariano Marcos State University. CIMMYT assisted the project by providing technical advice, appropriate training, and some research equipment. The trial sowings in the farmers' fields were conducted by farmer cooperators who fully understood the commitments and risks associated with the collaborative project.

An interagency management committee chaired by PCARRD was created to monitor the progress and to ensure the smooth coordination and implementation of the project. By and large, PCARRD only coordinated and monitored the overall project implementation and assisted in assuring that the vital support services were provided and commitments of the various participating institutions were fulfilled, while the different implementing agencies in the regions performed the major activities in the field. The appointed project and study leaders supervised the implementation of the project and gathered data for the assessment and evaluation of the project's performance. To have a general overview and to ensure appropriate interpretation of gathered data, the following additional data were obtained regularly by the project/study leaders—climatic and soils data, farm management practices employed by the farmer-cooperators, and socioeconomic data.

Credit and Marketing Assistance

During the first three cropping years, the National Food Authority (NFA) provided financial assistance as loans to cooperating farmers in some selected pilot areas in the form of seed, fertilizer, and chemical pesticide, while the farmer-cooperators provided the land and the labor inputs needed for growing the crop. NFA then served as the marketing conduit for the farmers' produce at predetermined buying prices.

Training, Workshops, Seminars, and Meetings

To accelerate the transfer and adoption of the POT, prospective farmer cooperators and extensionists were trained through orientation seminars held in the pilot areas. In addition, training was given to housewives, school teachers, and nutritionists for the processing and utilization aspects of the crop. A total of 446

participants attended the seminars held during the duration of the pilot production project. Field days were held to demonstrate to neighboring farmers and policymakers the excellent prospects of the crop in the farmers' fields.

Wheat review and planning workshops co-sponsored by CIMMYT and PCARRD were convened annually to review and evaluate the results of the pilot production project and research conducted during the previous cropping season. Fifteen scientists from the National Research System were sent to CIMMYT Headquarters in Mexico for six-eight months' intensive training aimed at increasing their expertise in such areas as wheat production agronomy, breeding, pathology, and experiment station management. In addition, specialized equipment for plant breeding and improvement were donated by CIMMYT to the National Wheat Program.

Extent of Farmers' Participation

The project covered a total area of about 136 ha and involved 316 farmer-cooperators during the duration of the five-year pilot production project. The major areas of concentration were the Ilocos provinces (83 ha) and the Cagayan Valley (36 ha). A total of 223 farmers from Ilocos and 60 farmers from Cagayan Valley were trained on the proper cultural practices needed to grow the crop.

Improvement of the POT

Considering that wheat was a new crop, there was continuous improvement of the component technologies for growing the crop, based on the yearly results of pilot production and applied research trials. Necessary revisions were done through multi-agency consultation to improve the package of technology. Specific recommendations for proper land preparation, dates of planting, fertilization practices, crop protection measures, and appropriate harvesting/threshing practices were formulated and packaged.

Yield Data Obtained

From the experiences learned in the pilot production project, it was clear that farmers who most nearly followed the recommended practices embodied in the POT obtained better yields.

The average grain yield for the three Northern Luzon provinces (Ilocos Norte, Ilocos Sur, and Cagayan) obtained during the four cropping seasons (1983-1987) was 1,249 kg/ha. This yield level was considered economically viable under the conditions for which wheat had been proposed, that is, rainfed, or where only limited water is available.

Cost and Return Analyses

The cost and return analyses showed progressively increasing returns on investment (ROI) from the first cropping season (CS 1982-1983) to CS 1986-1987. From the 10% average obtained in CS 1982-1983, the ROI was increased to 103% in CS 1986-1987. This positive performance was attributed to an improved POT, better supervision of compact pilot areas, and the existence of favorable climatic conditions.

Observed Constraints to High Yields

Much has been gained in terms of assessing the constraints to high wheat yields from the experience obtained in conducting the Wheat Pilot Production Project. A most consistent management problem was that of

late planting, mainly due to late rains delaying the rice harvest or causing difficulties in the preparation of the wheat seedbed. In some cases, late planting was due to the late distribution of seeds and other production inputs. Also related to seeding was the factor of seeding depth. There were significantly more tillers, spikes were larger, and plants were generally more vigorous from a 4-5 cm planting depth than from shallower sowings.

Weed populations within the wheat crop had proved an early problem although the application of butachlor was later shown to be effective against major weeds.

Field observations showed that some wheat diseases were very related to environmental and management-induced stresses. Helminthosporium leaf blotch caused variable losses, up to complete crop failure in the first three years of the project. In the final two years, however, it appeared to be less serious.

Farmers experienced difficulty in harvesting and threshing. The complaint was that wheat was much harder to thresh than rice. The problem was traced to harvesting too early.

Recommendations

The Wheat Pilot Production Project was able to demonstrate that wheat production could be an economically viable option for farmers in northern Luzon. Thus the launching of a Wheat Production Program starting in 1987-1988 in those areas was recommended.

The Northern Luzon Wheat Development Action Project (Phase I)

In June 1987, PCARRD negotiated with the Philippine Association of Flour Millers (PAFMIL) to launch a wheat production program for a period of three years (1987-1990) to be implemented under the "Northern Luzon Wheat Development Project", with the National Tobacco Administration as the lead implementing agency. PAFMIL gave the assurance of providing the market and extending credit assistance for the needed production inputs (fertilizer and chemical pesticides), while the farmers committed to provide the land and labor requirements. PCARRD committed to provide the seed requirement and the needed management/coordination costs.

For the 1987-1988 cropping season, a total area of 70.48 ha was planted to wheat involving 358 farmers. The program involved 334 farmers on 41.6 ha in Ilocos Norte and 24 farmers on 27.88 ha in the Cagayan Valley. Unfortunately, the wheat crop was severely affected by *Helminthosporium sativum* infestation at both locations. The crop was generally a total failure in Cagayan while in Ilocos Norte, only a total of 4.7 tons were produced. A rehabilitation support scheme was then formulated by PCARRD as part of its commitment to continuous support of the participating farmers. Credit and technical assistance packages were extended for the planting of other crops such as mungbean, maize, and rice.

The unfortunate experience during 1987-1988 prompted the Cagayan authorities to temporarily withdraw from the program. Thus, the next two cropping seasons (1988-1989 and 1989-1990) merely concentrated on seed production activities in Ilocos Norte. A total of only 14.5 ha, with 93 farmers, were planted to the crop during those two cropping seasons.

The Northern Luzon Wheat Development Action Project (Phase II)

PCARRD negotiated again with PAFMIL for continued support of the wheat production program covering the next three years (1990-1993). The lead implementation agency was then transferred to the Department of Agriculture and the project was concentrated in the province of Ilocos Norte.

During 1990-1991, a total of 32.86 ha was sown by 123 farmers, while during 1991-1992, the total was 45.0 ha with 63 farmers. Some actual yields obtained by the participating farmers during the past two cropping seasons are still being retrieved and so average yields by locations are yet to be processed. However, available data indicated that the highest yields obtained were 2.2 and 1.9 t/ha for CS 1990-1991 and 1991-1992, respectively.

Conclusions

There were definitely strong indications that a wheat crop can fit very well into the existing cropping systems of small farmers in Northern Luzon. While the stability of production was apparently hampered by some serious constraints, the enthusiasm shown by many farmers in their continued attempts to grow the crop is a manifestation of its potential viability. Moreover, the continued support being extended by the private sector (PAFMIL) is a very healthy development that provides significant impetus towards the establishment of the industry.

The current policy enunciated by the government institutions involved is to maintain the same level of support given to wheat during the past few years. This policy statement includes the same level of funding assistance given to wheat research and development. It should be understood, however, that this statement is anchored on the expectation that improved technologies are in the pipeline and shall be made available very soon. The National Research System hopes that CIMMYT will continue to provide the technological interventions to assist in the renewed efforts to establish a wheat growing industry in the country.

Water Management Constraints in Rice-Wheat Rotations in India

R.S. Narang and M.S. Gill
Department of Agronomy, Punjab Agricultural University, Ludhiana, Punjab, India

Abstract

It is estimated that the ground water table in the rice-wheat areas of Punjab is receding by 20 cm per annum and this phenomenon is reflected in other rice-wheat areas of India to varying extents. The efficiency of water use of this cropping system could be increased through the transplanting of rice in periods of lower evaporative demand and by the adoption of revised irrigation practices in both rice and wheat. There is also a need to make the cost of irrigation water more realistic to induce farmers to adopt the management recommendations which would conserve the water resources.

Introduction

Water has probably been the most extensively discussed subject in the recent years in the context of the rice-wheat rotation in India. Since the introduction of high-yielding varieties of rice in the early 1970s, the rice-wheat rotation has become the most important cropping system in the irrigated belt stretching from Jammu and Kashmir in the extreme northwest to Punjab, Haryana, Uttar Pradesh, Bihar, and West Bengal in the east. This cropping system has also been adopted in the central and the western India irrigated tract comprising parts of Madhya Pradesh, Rajasthan, Gujarat, and Maharashtra. The main points favoring the spread and adoption of the rice-wheat rotation at such a rapid rate has been the stable productivity and the pricing and procurement policies of the Government. While the system has become a permanent feature of the agriculture, it has brought about a number of serious problems. Soil fertility imbalances and water resource depletion are the two most serious ones. This paper discusses the water management constraints of the rice-wheat system in the Indo-Gangetic Plains.

In the early years, it was possible to rapidly expand rice acreage because of the availability of shallow underground water resources. Installation of centrifugal pumps and shallow cavity wells provided cheap assured irrigation. While irrigation stabilized rice production, it also reversed the trend of rising water tables and thus contributed in reclamation of saline lands in canal-irrigated tracts. This indirect benefit stimulated farmers to install additional tubewells and further increase rice area. In the initial stages, the installation of tubewells did not pose any serious problem as only the surplus underground water in the upper layers was being pumped and there was a positive recharge balance from rainfall, seepage from the canals, and inflows from the upper reaches. The rapid increase in tubewells continued due to electrification and lack of any Government restrictions on boring of wells. It was only in 1992 that the Government circulated a Model Bill to the states for regulating the installation of tubewells. The trends of a receding water table had been identified in the early 1980s, but as the intervening years were of above average rainfall and floods helped recharge the aquifer sufficiently, the

problems of the water table and depleted upper aquifer were temporarily deferred.

However, in recent years, with the increase of rice acreage to almost "Critical Maximum Limits" in states such as Punjab, Haryana, and Western U.P., the water constraint has assumed serious proportions. It is estimated that the ground water table in Punjab is receding by 20 cm per annum over two-thirds of the state (Khepar and Sondhi 1992). This is also the situation in other rice-wheat areas to varying degrees. This has reached such alarming proportions that questions are now being asked as to what extent rice cultivation should be permitted in the irrigated Indo-Gangetic Plains, and how to sustain the productivity of the region without loosing the battle on the water front.

The major water management problems can be divided into two levels: macro level/ policy issues at the state and national level, and the micro level/crop management issues and those concerning the development of agronomic practices for efficient water use for sustained productivity without reducing the acreage of rice and wheat from present levels.

Macro-Level Policy Issues

Water needs of the rice-wheat system

Water needs of rice have been reported as between 1300 and 1850 mm (Gupta and Bhattacharya 1963, Dastane et al. 1967, Chaudhary and Pandey 1968, Pande and Mitra 1972, Hukkeri and Pande 1977). It is generally argued that as the water needs of rice are very high, its cultivation should be discouraged in the irrigated Indo-Gangetic Plains as a policy and confined to the high rainfall regions of southern and eastern India. However, this proposal requires further analysis.

The seasonal Evapo-transpiration (ET) constitutes the basic water input needed for raising crops, and supplemental irrigation comprises the managerial component in meeting this basic input. Comparative studies of seasonal ET for subtropical, semi-arid zone (typified by Punjab) show that the basic input for water for paddy does not substantially exceed the other kharif crops. The ET demands of paddy have been estimated at 73 cm as against 60 cm for maize and 65 cm for cotton. (Prihar et al. 1990). Dastane et al. (1967) reported the ET of paddy for Delhi as 50 cm.

Wasteful components of water use in rice

The total water needs of transplanted rice (TPR) may be divided into two components: evaporation losses from soil and the crop canopy, and deep percolation losses.

Earlier work of Dastane et al. (1970) at Delhi on sandy loam soils of high percolation rate (comparable to the alluvial soils of the Indo-Gangetic Plains) showed that out of the total water use of 1750 mm, deep percolation amounted to 1250 mm or about 70% of the total water use. Similar data on percolation losses (Table 1) have been reported from Kharagpur, West Bengal (Yadav 1972)

Thus two problems of rice-culture in the alluvial soil region of the Indo-Gangetic plains are the additional input of energy required in pumping (recycling) of the percolated water, and the control of the wasteful extra component of evaporation causing the lowering of the water table under this rice dominated cropping system.

A trend towards the transplanting of rice in the hot summer months of May and June when evaporation is high is creating a higher demand on ground water resources. The transplanting of rice has now been advanced to early June, and in some areas like the districts of Amritsar and Ferozepur,

to May. The evaporation during this period ranges between 10-11 mm/day compared to 6 mm in July and 4-4.5 mm in August-September. Total seasonal evaporation for a 110-day paddy crop transplanted on June 1, amounts to 670 mm as against 517 mm of a July 1 transplanted crop—a net wasteful loss of 153 mm (30%).

There are also losses from distribution canals. During the rice crop, these are kept wet throughout the season, leading to near potential evaporation rates. The wet surface also leads to profuse growth of phreatophytes on the canal banks and these result in near potential ET. Conservative estimates put the evaporation (E) loss from field canals at 5.1%, distributories 2.1% and main canals at 4.3% (Sally 1962). Lining of the irrigation courses and control of phreatophytes would constitute the basic remedial measures.

Besides the rice crop, there are other contributory factors adding to receding water tables. Cropping intensity is rising at a steady rate of 1.5-2.0%/annum in northwestern India and there are increased acreages under summer-spring season crops such as summer mung (22,000 ha), spring sunflower (100,000 ha), summer maize fodder, sugarcane (100,000), and increased water demand for early-sown (April-May) American Cotton (667,000 ha). In the Punjab there were negligible areas under these crops in 1960-61. The sowing dates of the main season kharif crops are also advancing into the hotter months of May and June. Similar trends are occurring in other states practicing the rice-wheat rotation.

Peak water demands and constraint phases in the rice-wheat rotation

A case study based on the weekly demand for irrigation for the rice-wheat rotation on the Sidhwan Branch of Sirhind Canal has been conducted (Khepar et al. 1990). This shows how the demand for irrigation builds up over the period and the available water supplies come to pose a limiting influence in meeting the desired water needs of these crops.

The water demands for rice peak at transplanting at the end of June and it continues to remain at a very high point for

Table 1. Components of water use (mm) in rice cultivation at Kharagpur, West Bengal.

Componets of water use	Kharif		Summer	
	Shallow submergence	Deep submergence	Shallow submergence	Deep submergence
Evaporation	140 (11)	141 (7)	389 (21)	402 (15)
Transpiration	197 (16)	204 (10)	362 (19)	370 (15)
Percolation	935 (73)	1707 (83)	1114 (60)	1794 (70)
Total water use	1272 (100)	2052 (100)	865 (100)	2566 (100)

Figures in parentheses indicate percentages.
Source: Yadav (1972).

the next 12 weeks, necessitating excessive withdrawals of underground water reserves along with canal waters.

In the rabi (winter) season, the peak water demand coincides with the sowing of wheat, and the need for the first irrigation at four weeks after sowing. The peak demands for the preparatory irrigation and the subsequent urgency of the first irrigation at the four-week stage impose a constraint on the timely sowing of wheat in canal irrigated areas and the need for supplemental tubewell irrigation arises.

The water availability from a canal under the warabandhi or rotational irrigation supply system for a fixed outlet is about 3.05 cusecs/1000 acres (as determined on the Abohar Branch of Sirhind Canal in Ludhiana). This allows sufficient irrigation water for 168 acres/1000 acres of cultivated area or 1/6 of the farm area per week. This means that only 4/6 of the total holding can be sown within the optimum period of the four weeks in November. If farmers have to apply the first irrigation by the scheduled date at four weeks after sowing, no sowing can take place in December and therefore the wheat sowing of the remaining 2/6 of the area is delayed until the first two weeks of January unless tubewells are also available in these canal-irrigated areas.

Thus in the rice-wheat rotation, the availability of water poses a major constraint during June to September in kharif and November to mid-January in the rabi season in Punjab. This situation of critical availability of water is similar in the other rice-wheat growing states of India, causing an excessive pressure on underground water withdrawals.

Micro-Level/Crop Management Amenable Constraints

Optimum depth of submergence for rice

Contrary to earlier views that the rice crop requires deep submergence, recent studies have shown that keeping about 4-6 cm depth of water in rice fields is sufficient for obtaining optimum yields and that it is not necessary to keep rice soils submerged to very great depths for long (Dastane et al. 1970, Raghu et al. 1984) (Table 2). Similarly, continuous submergence (5 cm) was reported to result in the highest yield for rabi (winter) paddy at Killikulam (Tamil Nadu) on gravelly clay soils (Wahab and Daniel 1992) and ponding of 5±2 cm throughout the growth on a sandy loam soil produced highest yields in Bihar (Prasad and Sharma 1984). Thus large quantities of irrigation water (and energy) could be saved by avoiding unnecessary pumping in tubewell irrigated areas.

The need for continuous submergence and optimization of irrigation schedules

Rice can withstand submergence and grows well under flooded conditions. Pot experiments were conducted to assess

Table 2. The effect of submergence depth in IR-8 rice.

Depth of free water	Yield (t/ha)
Surface saturation	5.15
Land submergence at:	
5 cm	5.71
15 cm	6.00
30 cm	6.25
45 cm	6.65
CD at 5%	0.53

Source: Dastane et al. (1970).

whether submergence is essential, on a loamy soil with a percolation rate of about 13 mm/day at Delhi (Dastane et al. 1967). Rice was subjected to two ponding water regimes—no stress regime of 4 cm (submergence to saturation) or a stressed regime (field capacity to 0.50 atm tension). In control pots, the water was maintained to a 4-cm depth throughout. The pot studies showed that the initial period of 40 days (until the end of tillering) was the most critical and that the crop could stand the stress regime with little yield reduction during the last 20 days (post flowering to maturity phase, 80-100 days). In field experiments, ponding was found to be critical for only 0-20 days (tillering phase), followed by that at 40-60 days (primordia growth and flowering stages). This further confirmed that the rice crop could withstand the stress regime during the last 20 days. Similar observations were recorded by Prasad and Sharma (1984) in Bihar.

Efforts were therefore directed to evolve a water management schedule, keeping the ponding for three weeks after transplanting as the basic requirement. The pioneering work at Punjab Agricultural University (PAU) and subsequently at other research stations throughout India under the All India Coordinated Research Project on Water Management showed the most economical water use and optimum yield was obtained from irrigations one day after ponded water had drained. This schedule gave a saving of 10-50 cm of irrigation water, depending on soil types (Rajput and Aggarwal 1983).

Later work at PAU showed that the Water Use Efficiency (WUE) of applied water could be increased still further by following a schedule of irrigation two days after the pond water had drained without any yield reduction and this schedule now forms the basis of water management in rice in Punjab. Further studies conducted at PAU (Narang and Singh 1988) showed that there was no adverse effect on yield even if the ponding of water from transplanting was reduced from three weeks to one week (Table 3). However, for effective weed-kill and better herbicide efficiency, a ponding schedule of two weeks after transplanting can be recommended (Anon. 1991).

Thus, based on extensive field studies, an economical water schedule for paddy has been developed for the rice-wheat rotation areas. This consists of continuous submergence of 5±2 cm for two weeks from transplanting, followed by 5-6 cm irrigations two days after the drainage of ponded water and cessation of irrigation two weeks before the harvesting. Such a water schedule involves 20-30 supplemental irrigations requiring 151 cm of water excluding the effective rainfall of 33 cm (Narang and Gulati 1992).

Irrigation for wheat

Like paddy, excessive watering is also practiced in wheat. Over-irrigation leads to serious weed problems, nutrient leaching loss, and aeration problems, apart from

Table 3. The effect of ponding duration after rice transplanting (means of three years).

Duration of ponding (weeks)	Grain yield (t/ha)	Effective tillers (no./hill)	Irrigation applied (cm)
1	6.4	8.9	195
2	6.5	8.8	215
3	6.5	9.1	235
CD (0.05)	NS	NS	—

Source: Narang and Singh (1988).

wasting water. The problem of water management in wheat assumes more importance on paddy soils in which the soil becomes more compacted during the rice cultivation phase in the preceding season.

Water management of wheat in India changed with the introduction of dwarf high-yielding varieties (HYV) of Mexican origin in the late 1960s and still remains highly dynamic, undergoing subtle shifts in response to changes in cropping patterns (i.e., shifts in the preceding crops, their sowing and harvest dates, the turnaround time between rice and wheat, and the residual moisture at wheat seeding), shifts in the sowing schedules of wheat (sowing is now mostly completed in November as compared to earlier when the bulk of wheat was seeded in December/late November), and changes in wheat genotypes, due to extensive backcrossing with indigenous material. The latter has resulted in plant types that are more moisture stress tolerant and endowed with a deeper, more extensive rooting system than earlier HYV genotypes.

Crop response to water

The introduction of the Mexican wheats necessitated many agronomic management changes—some of those were concerned with water management.

The sowing schedule of Mexican wheats differed from the indigenous wheats. As these were found to perform better under cooler conditions, the sowing schedule of Mexican types was shifted to November-December compared to October for local wheats.

As the Mexican wheats were photo-insensitive, their sowing could be extended as late as mid-January although while the yields were reduced, they continued to be economically viable. This late-sown wheat required a completely different water management strategy, particularly in respect to the first supplemental irrigation and the preparatory irrigation in paddy fields.

Mexican wheats required a shallower sowing depth and this elevated the crown root initiation juncture into the upper dry soil. They therefore required a critical early irrigation, coinciding with the secondary root formation stage at about three weeks after sowing. This period has undergone many shifts over the last 30 years with recommendations from three weeks for November-sown wheat after maize and other upland crops to five-six weeks after July-planted rice and late-sown wheat, and now back to about four weeks (both for upland crops and early (June) sown rice crops). These changes are a consequence of shifts in cropping pattern, sowing schedules of wheat, backcrossing of Mexican wheat, advancing of transplanting schedules of the preceding paddy crops, etc.

The root system of earlier Mexican wheats was relatively shallow and highly compact. This resulted in the development of acute moisture shortages in the topsoil. For this reason, the Mexican wheats came to be known as highly exacting in their watering schedules. This stimulated the development of tubewell irrigation.

Crop response studies of the Mexican and HYV wheats showed that missing an irrigation on loamy sand soils at crown root initiation (CRI) resulted in a 27% yield reduction (Cheema et al. 1973) and that the major cause was low tiller numbers (Singh and Narang 1971) (Table 4). Similar losses were reported even on the clay soils (Jana and Sen 1978, Deshmukh et al. 1992). The Mexican wheats were found to require as many as four-six irrigations (Garg and Saraswat 1972, Cheema et al. 1978). On a deep alluvial sandy loam soil, Prihar et al.

(1974) found that yield was maximized with high water use efficiency when irrigation applications were equal to the cumulative pan evaporation minus rainfall (CPE) and irrigations applied when the CPE was 60 mm. Much work was conducted to define irrigation schedules based on crop growth stages and the schedules of four-six irrigations were recommended (Garg and Saraswat 1972, Cheema et al. 1973, Jana and Sen 1978, Anonymous 1985, Raghu et al. 1984, Singh et al. 1991, Deshmukh et al. 1992).

It was found that wheat could withstand large fluctuations in the timing of irrigation schedules, provided sufficient water is added to recharge the profile at each irrigation and the crop had started with a heavy pre-sowing irrigation. The permissible limits of moisture depletion in the upper 180 cm of soil were determined to be 5-11 cm for light loamy sand soil and 5-17 cm for sandy loam soils (Prihar et al. 1978), showing that wheat has reasonable flexibility in tolerating fluctuations in its irrigation schedule. In fact, the success of "warabandhi" the rotational canal irrigation schedules in Punjab is due to this resilience of wheat.

With continued genetic improvement, evidence is accumulating that present day wheats may not respond to more than three post-sowing irrigations (Singh et al. 1991). Experimental data have shown that irrigations have no further effect after mid-March to timely sown wheat (Table 5) (Cheema et al. 1978) and first week of April for December-sown wheat (Cheema and

Table 4. The influences of the timing of the first irrigation (days after sowing) on local and Mexican wheats.

	Timing of first irrigation (days after sowing)					
	14	21	28	33	43	48
	Main effects					
Tiller no. (per meter of row)	201	258	220	193	189	145
Grain yield (t/ha)	3.11	3.75	3.36	2.71	2.68	2.25
	Varietal response (grain yield, t/ha)					
C-306 (India)	2.28	2.87	3.09	2.38	2.42	2.16
Kalyan Sona (Mexico)	4.16	4.92	3.91	3.20	3.03	2.53
Sonalika (Mexico)	2.90	3.47	3.07	2.55	2.53	2.25
Profile moisture use (mm)	515	445	441	427	472	471
Consumptive use (mm)	547	477	472	458	504	503

Source: Singh and Narang (1971).

Uppal 1987). This results in a lower residual moisture component in the root zone after the harvest and further increases the water use efficiency.

Other agronomic measures aimed at reducing wasteful evaporative components from soil are during the early phase, when the crop surface is not fully covered. Close planting, bidirectional sowing, and yield maximization (through heavy fertilization and higher plant populations) are some agronomic steps aimed at reducing the evaporation component and increase the productivity per unit of water.

There is also a trend for farmers to leave their fields unbunded and let the irrigation water run over large fields uncontrolled, resulting in high percolation losses. This practice has come into vogue among the very irrigation-conscious farmers of Punjab due to the flat charge rate of electricity, unsafe working conditions at night, high labor costs, and the need for bund-free fields for combine-harvesting operations. In the absence of strong incentives and a lack of irrigation advisory service, there seems little scope for the adoption of scientifically designed irrigation layouts or the adoption of sophisticated border-strip type of irrigation systems, though the need for these requires no emphasis.

Conclusions

Water is a finite commodity like fossil fuels and other natural resources. Its use cannot be permitted beyond the given limits (annual replenishable accruals of the region). Under the present rice-wheat rotation, the greatest constraints in water management come in meeting the peak demands of wheat in rabi in November through mid-January and for rice in kharif in June-September. There is also need to sensitize policymakers to effect restrictions on the early sowing of rice, and for making the irrigation water a "cost oriented commodity" to induce the farmers to adopt the measures for using water more efficiently.

Table 5. The effect of the final irrigation on wheat yield.

Date of last irrigation	Charging of soil profile (% field capacity)			
	60	80	100	Mean
March 5	3.74 (5)	3.64 (8)	4.21 (14)	3.86
March 15	3.88 (5)	4.51 (11)	4.62 (17)	4.34
Mean	3.81	4.08	4.42	

CD (0.05): date, 0.36; profile charging, 0.21; two charging levels at same date, 0.31; two dates at same charging level, 0.43.

Figures in parentheses represent the amount of water in cm added at the time of the last irrigation.

Source: Cheema et al. (1978).

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Questions/Discussion

Dr. Narang was asked whether returning rice to its traditional seeding time of July would limit the wheat season or at least necessitate a seeding date later than the optimum. He explained that with the current rice transplanting time of May-June, there is about one and a half months between rice harvest and the optimum wheat seeding time in November. Thus rice could be seeded later during the period of lower evaporative demand and not affect the wheat crop.

On waterlogging and water requirements for wheat, Dr. Narang said that tolerance of waterlogging varied with the stage of the crop. In the Punjab, at crown root initiation, symptoms of lack of oxygen and nitrogen appear after about two-three days of standing water. However, at the heading stage, standing water can be tolerated for a longer period (about seven days) because, although the surface soil layers may be saturated, the wheat roots deeper in the soil can still function.

Under his conditions, the crop water requirements depend on seeding date—for an October planting, the water requirement is about 55 cm, 50 cm for November, and 45 cm for a December-sown crop. After December, the water requirement again increases.

Dr. Narang was questioned on irrigation strategy, particularly his recommendation of reducing the number of irrigations. He explained that the early high yielding varieties introduced in the 1960s had restricted root systems and required frequent and exactly timed irrigations. Breeding programs have crossed introduced lines with indigenous materials and the more recent varieties have increased root systems. Therefore irrigation schedules can be modified.

An important point is that the wheat should be sown on a heavy pre-sowing irrigation to fully charge the soil profile. This lower level moisture can be utilized by the plant later (March).

Following the pre-sowing irrigation, he advocates three irrigations for maximum efficiency, although admits it may be necessary for four irrigations in some years. Each irrigation is 3 acre-inches (7.5 cm). He pointed out that in northwest India, about 10 cm of rainfall are expected in December, January, and February.

Bipolaris Leaf Blight (Spot Blotch) of Wheat in Bangladesh

K.B. Alam and M.A. Shaheed
Wheat Research Centre, Dinajpur, Bangladesh
A.U. Ahmed
Regional Agricultural Research Station, Jamalpur, Bangladesh
P.K. Malakar
Regional Agricultural Research Station, Jessore, Bangladesh

Abstract

Bipolaris leaf blight (Bipolaris sorokiniana) *or spot blotch is currently the number one disease of wheat in Bangladesh. The disease starts at the seedling stage and increases with age. Almost all commercial cultivars are either moderately susceptible or susceptible to this disease. During 1991-92, the yield loss was estimated to 29.0% in the variety Kanchan. While Kanchan is slightly more tolerant to the disease than earlier released varieties, there has been little progress made in the further development of resistance due to a lack of resistance sources. Recently, new sources have been identified and will be used in the breeding program.*

Introduction

Wheat (*Triticum aestivum* L. em Thall.) is the second major cereal crop after rice (*Oryza sativa* L.) in Bangladesh. In 1991-92, area under wheat cultivation was estimated to be 0.6 million hectares with an average yield of 2.3 t/ha (Anonymous 1992).

The climatic and agro-ecological conditions of Bangladesh favor the rapid development and growth of various plant pathogens. Almost all cultivated crops suffer from a number of diseases. Currently, records show 637 diseases occurring in 71 species of plants belonging to 11 groups of crops (Miah 1991). Among these, about 260 diseases are considered major; the rest are minor. In wheat alone, records show 17 diseases of which five are major (Table 1). Prevalence of the wheat diseases increased with the intensification of wheat production coinciding with the introduction of high yielding varieties. Four foliar diseases, ascochyta leaf blight (*Ascochyta tritici* Hori & Enj), curvularia leaf spot (*Curvularia* spp.), ephelis leaf spot (*Ephelis* sp.), and tan spot (*Pyrenophora tritici-repentis* Died. Drechs.), were not reported in Bangladesh, prior to the introduction of HYVs (Alam and Saha 1991).

The wheat growing season (mid-November to mid-April) in Bangladesh is the driest and coolest period of the year. The mean temperature of the coolest month (January) is around 10°C. During the wheat growing season, the relative humidity is quite high (near 68%) and temperature is low (mean 18°C) and dew remains in the field for a long period at night and in the morning.

Status of Bipolaris Leaf Blight

Until recently, leaf rust (*Puccinia recondita* Rob ex. Desm f.sp. *tritici*) was considered to be the most serious disease of wheat in Bangladesh (Ahmed and Hossain 1985). However, following the development of rust-resistant varieties, Bipolaris leaf blight (BpLB) or spot blotch, caused by *Bipolaris sorokiniana* Sacc. in Sorok., has become the

number one problem of wheat in Bangladesh. In recent years, the severity of the disease has increased alarmingly (Ahmed and Hossain 1985, Fakir 1991). The recommended cultivars Akbar and Ananda are moderately susceptible (MS), while Aghrani, Balaka, Barkat, Kanchan, and Sonalika are susceptible (S) to BpLB to various degrees. The incidence of the pathogen in the grain is also common in Bangladesh. Excessive rainfall during grain-filling, particularly if the crop is lodged, causes severe infection in the grain depending upon cultivar and location.

Table 1. Prevailing wheat diseases in the field and their causal agents in Bangladesh.

Disease	Causal agent
Alternaria leaf blight	*Alternaria triticina* Pras. & Prab.
* Ascochyta leaf blight	*Ascochyta tritici* Hori & Enj.
Black chaff	*Xanthomonas translucens* (J.J. & R.) Dows.
** Black point	*Bipolaris sorokiniana* Sacc. in Sorok.; *Fusarium* spp.; *Curvularia* spp.
* Curvularia leaf spot	*Curvularia* spp.
* Ephelis leaf spot	Ephelis sp.
** Foot & root rot	*Sclerotium rolfsii* Sacc.
** Bipolaris leaf blight	*Bipolaris sorokiniana* Sacc. in Sorok.
Leaf streak	Virus
** Leaf rust	*Puccinia recondita* Rob ex Desm f.sp. *tritici*
Loose smut	*Ustilago tritici* (Pers.)
Mosaic	Virus
Scab	*Fusarium graminearum* Schwabe; *Fusarium culmorum* (Smith) Sacc.
** Seedling blignt	*Bipolaris sorokiniana* Sacc. in Sorok.
Stem rust	*Puccinia graminis* Pers f.sp. *tritici* Eriks. & Henn.
* Tan spot	*Pyrenophora tritici-repentis* (Died.) Drechs.
Take all	*Gaeumannomyces graminis* (Sacc.) Arx. & Oliv.

* New disease, ** Major disease.
Source: Alam and Saha (1991).

From the 1985-86 through 1991-92 wheat seasons, surveys were conducted throughout Bangladesh during the wheat season. Disease severity was rated based on the leaf area damaged and the results were expressed in terms of disease incidence. Results indicated that BpLB is the most frequently occurring foliar wheat disease in Bangladesh. At the seedling stage, less than 50% of the fields had BpLB disease. At this stage, infections were observed on the lower foliage with minimal necrosis, with less than 5% of the leaf area damaged. At the booting stage, 100% of the fields had BpLB with more than 50% of the leaf area damaged. At the dough stage, all fields were severely infected by BpLB. Approximately 60% of the foliage was found damaged in all commercial varieties. General observations indicate that the disease appears at the seedling stage and increases with the plant age (Figure 1). At any growth stage, incidence was greatest in the older variety Sonalika.

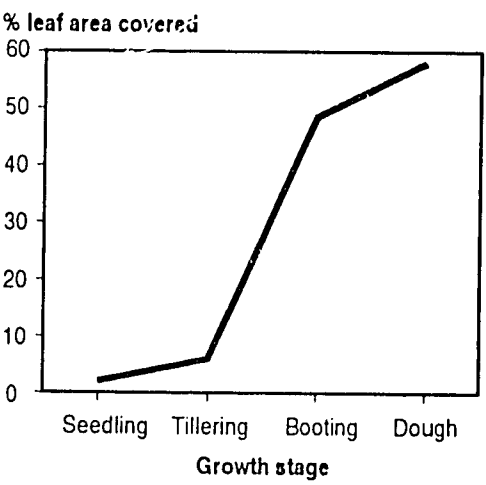

Figure 1. Disease progress curve of Bipolaris leaf blight in Bangladesh.

Yield loss estimates of wheat due to BpLB were carried out during the 1985-86, 1986-87, and 1987-88 seasons at the Plant Pathology Division of the Bangladesh Agricultural Research Institute (BARI), Gazipur. Yield loss due to BpLB was estimated to be 5.7, 8.2, and 10.5%, respectively (Anon. 1986, 1987, 1988). These results may indicate an increasing trend of yield reduction over the years. Data from the Wheat Research Center, Dinajpur, indicated a yield loss of 4 to 21% depending upon variety. Yield losses in varieties Akbar, Kanchan, Aghrani, and Sonalika were found to be 14, 8, 4, and 21%, respectively (Razzaque and Hossain 1991). In 1991-92, yield loss was estimated to be 29% for Kanchan in farmers' fields.

An intensified breeding effort for *B. sorokiniana* resistance has been initiated recently with the best available germplasm, but none have been found absolutely resistant. However, the best of these include COQ'S'/F61.70//CNDR'S'/3/OLN/4/PHO'S' (CM60907-K-1Y-2M-1Y-2M-1Y-4M-2Y-0M), A/6 Glen (CM91220-1ISD-0ISD-1ISD-0ISD), and CRT/ALD'S'//Seri (CM84364-1JE-4JE-7JE-1JE-2JE-0JE). In these lines, the top leaves were free from any infection, but some isolated lesions were found in the lower leaves at late stages.

Conclusions

The observed incidence of *B. sorokiniana* has increased markedly over the past few years, perhaps as a result of favorable weather, but also possibly due to increased recognition following the widespread adoption of newer rust-resistant varieties. In Bangladesh, the traditional tillage systems leave large amounts of standing crop residues on the soil surface. These residues may serve a major role in the long survival, increased virulence and aggressiveness, and source and amount of inoculum of the pathogen. In addition, recommended varieties have been evaluated poorly against the pathogen prior to their release.

The direct selection of genotypes resistant to this disease is complicated by the fact that expression of resistance is very sensitive to environmental conditions. It is possible to overcome this problem by considering the BpLB toxin to be an analogous agent of the pathogen in screening programs of early generation breeding materials to eliminate susceptible genotypes.

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Questions/Discussion

Dr. Alam was questioned on Tan Spot in Bangladesh. He responded that its incidence was very minor, but he had recorded it at the Nashipur station where temperatures in the coolest month (January, less the 10°C mean temperature) are the lowest in the Bangladesh wheat growing areas.

Dr. Alam mentioned in his presentation that possibly there had been a change of virulence of *Bipolaris sorokiniana* on Sonalika. Did he have any evidence? Could the increasing disease level on Sonalika be merely due to steadily increasing inoculum levels? He admitted that this could be so, and that the change in virulence theory was merely supposition. However, *B. sorokiniana* is known to have high genetic variability and a change in virulence is a strong possibility.

He was asked if he considered *Cladosporium* spp. or *Ascochyta* spp., mentioned in the paper, to be pathogenic organisms. He replied that at the moment, they do not seem to be causing any significant damage, but he cautioned that they could increase, and cited the example of Tan Spot in the USA, where in the 1970s, it was of minor importance. However, by the late 1980s it had assumed major importance.

In answer to a question related to screening lines with *B. sorokiniana* toxin, Dr. Alam indicated that the technique is fairly simple and he had plans to use it in the near future.

Production Constraints Due to *Bipolaris sorokiniana* in Wheat: Current Situation and Future Prospects

E. Duveiller and L. Gilchrist
Wheat Program, International Maize and Wheat Improvement, El Batan, Mexico

Abstract

Spot blotch caused by Bipolaris sorokiniana *is the major disease constraint limiting wheat production in the warmer areas. Controlling the disease requires an integrated approach to reduce the fungal inoculum. This can be achieved by using seeds with a low level of infection, spraying appropriate fungicides, eliminating secondary hosts and crop residues, and improving agronomical practices and genetic host resistance. However, breeding progress towards the selection of resistant genotypes, the key factor to increase yields or make wheat a commercial crop in several areas, has been slow due principally to the high variability of the pathogen and insufficient knowledge on environmental factors modulating disease expression and host response. Research needs to improve disease control are reviewed.*

Introduction

In the meeting on "Wheat for the Nontraditional Warm Areas" in Brazil in 1990, *Bipolaris sorokiniana*, the causal agent of spot blotch, was confirmed as the most economically important wheat foliar pathogen in all warm zones, particularly those characterized by mean temperatures of the coolest month above 17.5°C (Dubin and van Ginkel 1991). Factors associated with disease development and the exact damage caused by the nonspecific wheat foliar pathogens, those lacking definitive physiologic specialization and having, such as *B. sorokiniana*, the capacity to attack more than one crop species is, in general, not well understood. In 1992, funding from the Belgian Government has allowed CIMMYT to expand the study on the nonspecific wheat foliar pathogens. Research into the resistance to spot blotch of wheat and the evaluation of cropping systems on the development of this pathosystem will be the project's major objective.

From the numerous studies that have been undertaken, several observations can be made. While the disease is the main limiting factor to growing wheat after rice in several warm areas, progress in genetic resistance to spot blotch has been slow (Rajaram 1988). The pathogen is extremely variable and environmental conditions have a significant effect on epidemics. Host/pathogen interactions and factors controlling the production of toxic determinants or the fungus penetration and growth in plant tissues are not well known or quantified. Yield losses and the economic threshold for fungicide treatment as a complementary measure to crop management and host resistance need to be better documented. Crosses derived from wheat and *Thinopyrum curvifolium* (=*Agropyrum curvifolium*) possess improved resistance to spot blotch and may offer promising perspectives to overcome limitations due to this disease (Villareal et al. 1992).

This paper briefly presents the status on spot blotch of wheat and introduces several research possibilities based on current knowledge. Feedback of collaborators on research needs under the rice-wheat system is welcome.

The Pathogen and Its Cycle

Bipolaris sorokiniana (Sacc. in Sorok) Shoemaker, teleomorph *Cochliobolus sativus* (Ito & Kuribayashi) Drechs. ex Dastur, (syn. *Helminthosporium sativum* Pamm. King and Blakke) is a highly virulent pathogen worldwide and particularly in wheat and barley. It can be found on many Gramineae, including rice (Mistra 1973) and may even parasitize beans or other dicotyledonous plants (Kleine and Nelson 1963). Thus, the fungus may be present only in trace amounts on one crop, which serves as a "green bridge" to a "target" crop.

The main sources of inoculum of *B. sorokiniana* are infected seeds, infected crop residues, volunteer plants, secondary hosts, and free dormant conidia in the soil (Reis 1991). Infected seeds are one of the most important ways for the survival of this pathogen between wheat cropping seasons. Immediately after planting, the fungus starts growing on the moistened seed and just after emergence, as early as the first leaf stage, sporulation is induced in the presence of direct sunlight (Spurr and Kiesling 1961). *B. sorokiniana* causes seedling blights, spot blotch on the leaf, crown rot, node infection, head blight, and black point on the kernels. Spot blotch on the above-ground plant parts is dominant in the warmer wheat growing areas, whereas root rot causes more problems in regions such as Queensland (Tinline et al. 1988), the prairies of Canada (Ledingham et al. 1973) and Rio Grande do Sul, in Brazil (Reis 1991).

Conidia produced on the first leaves can be transmitted by rain splashes and wind, building up polycyclic epidemics. Conidia germination on the leaf surface can be completed within four hours; appressoria form frequently at the juncture of the epidermal cell wall after eight hours. Hyphae from initially infected cells enter adjacent cells in 24 hours and host cytoplasm becomes granular 24 hours after pathogenesis (Bisen and Channy 1983).

Most *Helminthosporium* species are favored by moderate to warm temperatures (18-32°C) and particularly by humid, damp weather. For a disease outbreak, leaves must remain wet for more than 18 hours. The number of spores in the field will be maximum at crop maturity; they can survive freely in the soil for about 37 months (Reis 1991). High spore concentration, longer relative humidity, and higher temperature induce less plant resistance and result in faster epidemics. Since crop rotation and environmental conditions influence inoculum potentials, research is needed on disease interaction with soil conditions and farmer-dependent factors such as fertilizers, organic matter, water, plant residues, and weeds.

The fungus is heterothallic and *C. sativus*, the sexual stage, has only been reported in nature in Zambia, where the presence of two compatibility groups must occur to produce perithecia and ascospores (Raemaekers 1988). A nonspecific opportunistic pathogen, such as *B. sorokiniana*, which takes advantage of stress conditions and invades overly mature leaves and seeds, is in fact a weak parasite, perhaps little more than a saprophyte. Strict saprophytes cannot colonize until tissues die. However, *B. sorokiniana* has the ability to form appressoria and penetrate living plant tissue, a relatively unexploited ecological niche (Scheffer 1989). The modulation of these mechanisms, particularly in relation to the

production of toxic determinants (Pringle 1976), should be further studied to understand the molecular basis of disease development and to improve selection methods for host resistance.

Yield Losses

There is a clear need for more intensive research on the main factors causing the yield depression or stagnation in the rice/wheat system following the increased use of this rotation in South Asia. In the Gangetic Plain of India, Nepal, and Bangladesh, leaf blights caused by nonspecific foliar pathogens are considered major constraints to improved wheat yields. In Bangladesh, yield losses due to spot blotch are about 20% in Sonalika whereas 14 and 8% losses have been reported in more recent genotypes such as Akbar and Kanchan, respectively (Razzaque and Hossain 1991). Yield loss estimates may reach 80% in the warmer areas. However, data come principally from experiment station trials and are derived from chemical control trials (Dubin and van Ginkel 1991). In many areas, it is often difficult to estimate losses in farmers' fields and to identify losses actually caused by a single pathogen since several diseases may occur together in some areas; this may be the case for spot blotch and tan spot (*Pyrenophora tritici-repentis*) for instance in Nepal or Paraguay.

Since host resistance is not satisfactory, crop loss assessments should be undertaken to determine points in terms of time and loss at which chemical control becomes an economically viable supplement (Hobbs et al. 1988). No doubt that price and availability of fungicides have a major influence on farmers' choices. Options are likely limited, but farmers need criteria to decide whether a treatment is appropriate or not, and until when they can economically treat during the growing season.

Also, losses due to spot blotch may be related to nitrogen fertilization and agronomy-oriented trials should be planned by pathologists. In rice, the severity of brown spot (*Cochliobolus miyabianus*), a fungus of the same genus as *C. sativus*, increases when nitrogen deficiency is induced after the middle of the growth period, and in a deficient culture solution, N is more effective than P or K in reducing the number and size of lesions (Ou 1985).

Pathogen Variability

B. sorokiniana is a generalized pathogen with a wide host range, but the species is extremely diverse varying from mild pathogens to intermediate types and virulent specialized ones (Kleine and Nelson 1963). It is possible that new biotypes constantly arise in nature and in artificial culture and the frequency and extent of genetic changes may be of great importance in experimental work. Progenies of monoconidial cultures may differ in pathogenicity (Wood 1962). Pathogenicity of 10-day-old conidia on agar has been reported to be significantly higher than those from 15- and 20-day-old cultures (Hetzler 1992). El-Nashaar and Stack (1989) showed a shift towards more aggressive isolates in a population from a wheat field continuously cropped with wheat since 1882 compared to isolates from commercial fields.

Based on a preliminary set of differential cultivars, Mehta (1981b) reported a total of 32 races in five states of Brazil. They appeared very different in adult plants in relation to lesion size and spore production. However, the isolates proved to be variable and even lost their pathogenicity over time and the term "race" for *B. sorokiniana* has been questioned by the same author (Mehta 1985).

More recently, Hetzler et al. (1991) confirmed this high variability and identified 15 pathotypes according to resistance reactions in a 12-member differential set. There was a tendency for isolates from warm and dry regions to be less virulent and most virulent isolates came from Southern and Central Africa, suggesting a geographical racial differentiation (Hetzler 1992). Typing isolates' virulence spectrum and monitoring pathogen populations according to hot spot wheat growing areas should be continued to understand the biological basis of this variability. It probably explains the difficulty to obtain host resistance to spot blotch. In addition, data may help the breeding programs in increasing their resistance basis to the disease. The question that can be raised is whether variation in aggressiveness could be related to a susceptibility of the pathogen to environmental conditions.

Research of Genetic Resistance to Spot Blotch of Wheat

The level of resistance in commercial spring bread wheat is rather low. Though the inheritance of seedling resistance to spot blotch has been reported to be controlled by one or two dominant factors (Srivastava et al. 1971, Adlakha et al. 1984), resistance appears principally polygenic and incomplete since all varieties are eventually infected and show symptoms (Mehta 1981b,1985). However, few studies have been done to quantify the components of this partial resistance like conidial production, sporulation period, latency period (duration of spore germination and formation of appressoria), the rate of lesion extension, and final lesion size (Mehta 1981a,b).

Chinese varieties and genotypes coming from hot spot areas such as Brazil and Zambia are among the best sources of resistance identified to date (Rajaram 1988, Dubin and van Ginkel 1991). In addition, crosses with *Agropyron curvifolium* (i.e., CS/*A.curv.*//Glen.81/3/Ald'S'/Pvn'S') showed good levels of resistance (Villareal et al. 1992). It is important to identify the genetic basis of these differences since single-gene resistance may soon break down in the face of high inoculum pressure (Hobbs et al. 1988). In a comparison of field-resistant and susceptible genotypes including Ciano79 (susceptible) and CS/*A.curv.*//Glen.81/3/Ald'S'/Pvn'S' and the Chinese genotype Suzhoe#1 (both resistant), Alvarez Zamorano (1992) did not find differences between germination time of conidia on the leaves of susceptible and resistant genotypes. However, preliminary qualitative histological observations indicate that resistance is possibly associated to a higher accumulation of tannins and pectic compounds and to a lower presence of polysaccharides in the host tissue. This study should be followed up by quantitative analysis.

The relationship between earliness or lateness and resistance to spot blotch is not clear but tall and late plants tend to have reduced infection. The greater the distance between leaves below the flag leaf and between the flag leaf and ear results in lower levels of spot blotch on those organs, supporting a theory of stepwise progression of the disease up the plant, beginning initially on the lower leaves (Brandle et al. 1987, Raemaekers 1988). Pleiotropic effects between plant height and resistance to spot blotch may exist. However, in Mexico, correlation coefficients between disease score and agronomic and physiological traits are low or not significant (Gilchrist et al. 1992). Interestingly, treatment of plants with a growth retardant increased resistance in wheat (Popova and Temirbekova 1981). In contrast, earliness is a necessity where crop rotations are very narrow. The relationship between earliness/lateness and plant height should be further analyzed.

In agreement with results by Conner (1990) on 18 wheat genotypes, Gilchrist and Pfeiffer (1991) indicated that leaf and spike infection are weakly correlated with grain infection and suggested the occurrence of several mechanisms of resistance to spot blotch. From studies in Mexico, leaf infection appeared to be associated with node and spike damage; spike infection was not related to node damage, but the level of black point infection was independent of infection on leaves, spikes and nodes (Gilchrist et al. 1992). These observations may also indicate a modulation of the aggressiveness of the pathogen population according to plant parts, resulting from the effect of environmental factors on disease expression. Consequently, it seems justified to consider isolates differently from leaves, grain, or crown when samples are collected in a disease survey. In contrast, Raemaekers (1988) reported significant correlation among the vertical spread of spot blotch, head blight, and black point.

Response to spot blotch in wheat should be further analyzed in terms of resistance to the fungus itself or of toxic compounds that are produced by the pathogen and which production or effect might be related to environmental factors. Are the host reactions different due to true genetic differences between the fungus isolates or are they just showing modifications in plant susceptibility? The picture may be rather complicated since at least two toxins, (pre)helminthosporol and victoxine, are involved (Pringle 1976). Why are several genotypes reported resistant in one area and breaking elsewhere? Discrepancies do not necessarily mean inconsistencies but there is a need for more understanding of these relationships. Therefore, a test nursery (known as the Helminthosporium Monitoring Nursery) has been organized by CIMMYT's network on spot blotch to identify host reactions and pathogen aggressiveness in key locations. The need for such information has perhaps not been emphasized enough. In Bangladesh, in a survey of 11 locations where 533 wheat genotypes had been observed, a high majority of which (69%) was susceptible to highly susceptible, Hossain and Azad (1992) reported variations in disease reaction. This information and particularly the name of genotypes that had different reaction according to location may be extremely important, since it may reflect differences in the pathogen population but also in the environment.

Razzaque and Hossain (1991) reported the difficulty to screen for resistance to spot blotch under field conditions and suggested that the 0-9 two-digit screening method does not adequately represent infection severity. It may be necessary to better characterize expression of symptoms as well as the correlation between evaluation made at the seedling stage and on adult plants. In Canada, where the importance of spot blotch may have been underestimated because symptoms are sometimes indistinguishable from tan spot, adult plants (headed), in general, were found more resistant than seedlings (two-leaf) (Gilbert and Tekauz 1992).

Finally, although Dhaliwal et al. (1986) have found little resistance in wild wheats and *Aegilops* spp., wild emmer accessions collected in Israel showed promising levels of seedling protection (Eyal et al. 1990). However, when planted at Poza Rica in Mexico, these genotypes did not show spot blotch resistance (Skovmand and Gilchrist, unpublished data). Nevertheless, the low disease severity observed in crosses derived from *A. curvifolium* sown in the hot spot area of Poza Rica indicates that the alien sources of resistance, including infusions of *T. tauschii* and *Elymus* spp., should be exploited.

Host/Pathogen Relations and Toxic Determinants

Pathogenicity potential and toxin production are two different aspects of the disease and it is therefore important to differentiate resistance to the fungus from resistance to its toxins. Spot blotch symptom type seems variable; chlorosis is not always observed around the lesion. The relationship between toxin production and fungus development is not known. Evidence has been obtained that wheat cultivars expressing a moderate resistance in one location may not maintain their resistance in another place (Eyal et al. 1990). The deeper study of the mechanisms of toxin production and the host/pathogen relationship might help to provide guidelines for the accumulation of genes of resistance. Are the differences in disease response only due to a variation among fungal strains or are they resulting from an alteration or differences in the mechanism of production of toxin, the latter being inhibited under certain environmental circumstances? Toxin production may depend on light and the question is to know the factors modulating toxin production and the relationship with either the biotrophic or necrotrophic phases of the disease.

Although no host-specific toxin nor a great quantity of any toxic substance has been found in culture filtrates of 26 different isolates of *B. sorokiniana*, the amount of the toxic metabolite, victoxine, produced by these strains may be correlated, generally, to their aggressiveness towards wheat (Pringle 1976). Studies on chloroplasts isolated from leaves of healthy, diseased, and toxin-treated plants showed that *B. sorokiniana* and its toxins inhibited photosynthetic electron transport and the photophosphorylation. Fungal infection and toxin treatment have different effects on the alternative pathways of electron transfer in the chloroplasts. Fadeev et al. (1988) showed that the energy supply in chloroplasts was limited as a result of inhibition of synthesis of ATP and reductant molecules in the initial phases of photosynthesis. In a study on 33 strains all differing in virulence, resistance in wheat appeared to be related to genotype reactions to fungal toxins, but some virulent strains of the fungus may produce moderate amounts of toxin while a weak strain may produce the maximum amount (Fadeev et al. 1982). Future work will aim to characterize the spectrum of toxins produced at the strain level and to obtain purified nondenatured components of the toxin spectrum to study their toxicity.

In vitro screening techniques of callus cultures derived from immature embryos and surviving exposure to purified culture filtrate (Dutrecq et al. 1978) produced by *B. sorokiniana* may offer another possibility to select for genetic resistance, providing that the improved resistance induced by mutagenesis is heritable and that other undesirable changes do not occur during the selection process. Using this technique, Chawla and Wenzel (1987) obtained 17% surviving calli out of 2,000 from two wheat genotypes after treatment with the toxins. In contrast, other results indicate the difficulty to standardize culture filtrate assays for selecting wheat resistance to *B. sorokiniana* using phytotoxins. Culture filtrates do not necessarily reflect the conditions *in vivo* and the time needed to produce the toxin *in vitro* may be significantly longer than in leaves (Eyal and Barash 1989).

Control

Control of *B. sorokiniana* depends on an integrated concept namely: the use of resistant varieties, disease-free seed, seed treatment with fungicides, proper crop rotation and fertilization, plowing of infected plant debris, and the use of chemicals.

Fungicides such as triadimefon, fentinacetate-maneb, and propiconazole have been reported to be effective, but product cost and availability will be the major criteria for the small farmers (Hobbs et al. 1988). Under a favorable environment, 1- to 2-week intervals for as long as necessary may be needed to maintain the disease under control.

In Brazil, it is recommended not to plant seedlots with more than 30% black point (Reis 1991). Seed disinfection may prove to be appropriate although the inoculum remaining on secondary hosts or in the soil may reduce the treatment efficiency. Seed treatments with phytoalexin inducer appeared to provide good protection to wheat seedlings against *B. sorokiniana* infection (Hait and Sinha 1986).

Removing or plowing in the stubble, grass weeds, and volunteer cereals reduces inoculum as does crop rotation (Diehl et al. 1982). The effect of tillage practices and crop rotation systems on the epidemiology of spot blotch require further investigation. Finally, the mixture of varieties should not be ignored.

Conclusions

We have attempted to give an overview on the current status of spot blotch of wheat. Insufficient research is being done on wheat pathology in the warmer areas (Dubin and van Ginkel 1991) and spot blotch is no exception. Therefore, it is intended to develop in-depth knowledge on *B. sorokiniana* with the aim to overcome the current yield losses or stagnation due to this disease. To make progress will require more than routine screening for disease resistance. Although screening may perhaps be refined to take into account possible type of disease response, it is essential to better understand the effect of environmental factors driving epidemics and host/pathogens relationships. Likewise, survey efforts and loss quantification should be increased to develop spot blotch management strategies. Research of a durable and widely effective resistance remains the key objective for all wheat scientists working in the warmer areas, but the reality requires more than ever an interdisciplinary collaboration between pathologists, breeders, and agronomists to understand the interactions occurring within the rice-wheat rotation for the control of spot blotch in this cropping system.

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Questions/Discussion

Dr. Duveiller was asked to describe an effective method for creating artificial epidemics of *Bipolaris sorokiniana*. He admitted that as artificial epidemics were not necessary in Mexico, he had little first-hand knowledge of effective techniques. However, he tentatively recommended the following: Grow the culture on agar medium to obtain a solution conidia concentration of no less than 60,000 spores/ml, add Tween as a sticking agent, spray starting at an early crop stage, preferably in the late afternoon. In discussion, it was noted that attempts of inoculation normally result in initial infection, but this does not often develop further. Brazilian experience suggests that if the artificial epidemic is to develop, the inoculated plots need to be misted for about four hours in the late afternoon and early morning following the inoculation. Dr. Duveiller noted that, for a natural outbreak to occur, about 18 hours of continuous dew were required.

On scoring in order to separate resistant and susceptible lines, Dr. Duveiller said he did not believe it was possible to fix a definite score (e.g., on the 0-9 scale) for these delineations as they would differ depending on growth stage. At present, the CIMMYT program scores at Feekes stages 10.5.1, 10.5.4, and 11.1 (between flowering and early dough). However, he recommended earlier readings in addition, as differences in the progress of the disease may be identified which would be important for resistance/tolerance.

In response to a question on the genetics of resistance, he said he was not sure. He referred to work in India and elsewhere that suggested resistance to *B. sorokiniana* was controlled by a few genes, perhaps one or two. However, he said the CIMMYT program feels it may not be this simple and their results point to a polygenic resistance.

Soilborne Diseases of Wheat in Warmer Areas of South Asia: An Update

H.J. Dubin
International Maize and Wheat Improvement Center (CIMMYT), Kathmandu, Nepal
H.P. Bimb
National Wheat Research Program, Bhairahawa, Nepal

Abstract

A brief review and update of the information related to soilborne diseases of wheat in the warmer areas of South Asia are given. Results of experiments on yield losses due to soilborne diseases in lowland Nepal are also presented. Little well documented information is available on the importance of soilborne diseases in the commercial warmer areas. Where information is available, the principal pathogens appear to be Sclerotium rolfsii *and* Bipolaris sorokiniana. Fusarium *spp. are also observed in some areas, as are nematodes. The nematodes observed are* Meloidogyne *spp. and* Tylenchorenchus vulgaris. *Soil solarizaton experiments at the National Wheat Research Program (NWRP), Nepal, indicate significant yield losses by soilborne pathogens (12-23%). Farmers' field trials in one year indicated a conservative yield loss estimate of 4%. Solarization reduced root and sub-crown internode necrosis significantly as well as increased height, total yield, and several yield components.* B. sorokiniana *was considered to be the most important pathogen detected. Various fusaria were isolated, but appeared of secondary importance. Where soilborne diseases are important in the warmer areas integrated control measures are called for, including resistance/tolerance, crop management, biological, and chemical.*

Introduction

The introduction of wheat into nontraditional, warmer climates requires a special emphasis to be placed on understanding and controlling the stresses the crop incurs in these unique environments.

In relation to pathology, it is common that above-ground diseases receive great attention because symptoms may be easy to discern. The soilborne biotic stresses are often underestimated or overlooked for various reasons. The causal organisms generally do not produce dramatic symptoms, yet significant effects may occur to root health and give concomitant yield loss. Furthermore, they are often more difficult to work with than other types of diseases.

In South Asia, there has been mainly descriptive research on soilborne wheat diseases (root rots, foot rots, and nematodes). In contrast, in the warmer areas of South America, particularly Brazil, a significant amount of applied and strategic research has been done and is in progress (Mehta and Gaudencio 1991).

This paper attempts to focus on the actual research situation of soilborne diseases in South Asia and presents initial research results with respect to them in the terai (lowlands) of Nepal.

Although a recent review gives a fairly comprehensive report on the status of wheat diseases and disease research in the warmer areas (Dubin and van Ginkel 1991), it is worthwhile to mention some of the

salient points pertaining to soilborne diseases in South Asia and later we will give a brief update since that review.

Since few well designed and implemented surveys of soilborne diseases have been done in the commercial, warmer areas, it is difficult to estimate the importance of these diseases in the region. Limited surveys and observations, however, show them to be of importance in some of these areas. For example, seed treatment trials in 87 farmers' fields in Bangladesh allowed an estimate of soilborne disease effects at the seedling stage. Ten percent losses were attributable to diseases affecting germination and plant stand in that year (Dubin and van Ginkel 1991). Based on the fungicide used and other observations, it appeared that *Sclerotium rolfsii* Sacc. was the principal organism involved.

The following fungi appear to be the most important in relation to root and foot rots in warmer areas of South Asia: *Bipolaris sorokiniana* [Sacc. in Sorok.] Shoem., *S. rolfsii*, *Fusarium* spp., *Rhizoctonia* spp. (Dubin and van Ginkel 1991). *Pythium* spp. were reported to be important in loss studies in lowland Nepal (Dubin and Bimb 1992).

Little is known about nematode damage, but observations indicate their importance in some areas. In Gujarat, India, *Tylenchorenchus vulgaris* and *Meloidogyne* spp. are damaging to wheat following tobacco (Sethi 1988).

South Asia Updates

Bangladesh

Recent reports from Bangladesh indicate that *Pythium* sp. may be a root pathogen of wheat at the Nashipur experiment station. This was based on seed treatments with metalaxyl (Saunders 1990). Observations and experiments with nematicides indicate that *Meloidogyne* sp. is also a root pathogen at the experiment station (K. Alam, pers. comm). A disease survey was carried out in 1991-92 and although incidence was low, *B. sorokiniana*, *S. rolfsii*, and *Fusarium* spp. were the most common fungi encountered. *Gaeumannomyces graminis* Walker was found in two fields

India

In India, previous reports noted *S. rolfsii* as an important pathogen of wheat in Karnataka and Madhya Pradesh (Dubin and van Ginkel 1991). Recent pot studies from Karnataka demonstrate that some wheat lines may possess resistance or tolerance to the fungus. Cultivars such as UP262, HD2402, and HI1077 and others showed reduced levels of disease compared to checks (Goel 1992). Further studies are needed to confirm these observations. Similarly, Kaushal and Dhawan (1990) reported that some bread wheat lines tested in Gujarat possess resistance/tolerance to *Meloidogyne* spp.

Two rice-wheat diagnostic surveys were recently done in eastern Uttar Pradesh, India. The 1991 survey in Faizabad District did not find any wheat soilborne diseases and the one done in Nainital, Rampur, and Pilibhit Districts (1990) indicated presence of possible *Helminthosporium* spp. and *Fusarium* spp. (Hobbs et al. 1991, 1992)

Nepal

Loss estimates due to foot or root rot in Nepal are very limited, however, data are available from various soilborne disease control experiments in farmers' fields and at the National Wheat Research Program (NWRP) in Bhairahawa, Rupandehi District.

Preliminary surveys in the District had shown that initial plant stand was low and that this could possibly be caused by soilborne diseases. Nevertheless, three seed treatment experiments with compounds

specific for diverse groups of fungi, insects, and nematodes, did not support the hypothesis that poor initial plant stand was caused by biotic factors.

Other studies used soil solarization as the control method of choice for estimating losses since it is environmentally friendly (Katan and DeVay 1991, Dubin and Bimb 1992). Loss estimates due to soilborne diseases were made in three farmers' fields (Table 1). On average, the yield lost was estimated to be about 4% (P=0.10). Solarization reduced necrotic lesions on the roots and subcrown internode (P=0.10) (Dubin and Bimb 1991). *B. sorokiniana* and various fusaria were the most common fungi found associated with the lesions. Studies on timing of solarization showed that these figures are probably conservative (Dubin and Bimb 1992).

Dubin and Bimb (1992) showed the effects of root necrosis on yield at NWRP. Their data, generated from a series of solarization experiments in 1989, 1990, and 1991, clearly showed the strong negative effect of root necrosis on yield (r= -0.77**). This may be taken as a measure of potential losses that could occur if this level of root necrosis occurred in farmers' fields. It clearly showed that we have significant root rot and yield reduction on the experiment station of the NWRP. Declining experimental yields at NWRP may be partially attributed to soilborne diseases. Data from other experiment stations in lowland Nepal indicate similar problems.

Between 1989 and 1992, isolations were made from necrotic lesions in the roots, subcrown internodes, and crowns of wheat plants in the solarization experiments to determine the probable pathogens. Table 2 indicates the different fungi. *B. sorokiniana*, *Pythium* spp., and *Fusarium* spp. are the most common pathogens associated with the necrotic roots and subcrown internodes. Crowns had very little necrosis under our conditions. Several other pathogens were noted but in very low numbers. *S. rolfsii*, *Rhizoctonia* sp., and *P. macrospinosa* are all known to attack wheat roots.

Table 1. Effects of soil solarization on wheat yields and root rots in farmer' fields, Bhairahawa, Nepal.

	Yield kg/ha	Subcrown internode with lesions	Root rot
Solarization	3225	2.1	1.5
No solarization	3102	2.9	2.7
LSD (0.10)	126	0.49	0.36

Three fields; two replications per field.
Analyzed as RCB with six replications.
Rating taken at GS75 = Early dough stage.
Subcrown internode lesions and root rot ratings = 0 to 5 scale: 0 = 0 to trace; 1 = 1-10%; 2 = 10-20%; 3 = 20-30%, 4 = 30-40%; 5 = 40-50%.
Source: Dubin and Bimb (1991).

Table 2. Fungi isolated from necrotic lesions of wheat root sat NWRP, Bhairahawa, Nepal, 1989-92.

+	*Bipolaris sorokiniana*
+	*Pythium graminicola*
?	*F. spinosum*
?	*Pythium* spp.
?	*Fusarium nygamai*
?	*F. solani*
-	*F. oxysporum*
+	*Sclerotium rolfsii*
+	*Curvularia* sp.
+	*Rhizoctonia* sp.
+	*Periconia macrospinosa*
?	*Pyrenochaeta acicola*
?	*Alternaria* sp.
-	*Myrothecium verrucaria*

+ = Known pathogen of wheat.
- = Not known to be pathogen of wheat.
? = Not sure.

Tables 3 and 4 show that fusaria were the fungi most commonly isolated from the necrotic roots and *B. sorokiniana* second, whereas from the subcrown internode *B. sorokiniana* was more common. Although fusaria were most common on the roots, *B. sorokiniana* was more pathogenic based on pathogenicity studies. Table 5 indicates the results of artificial pot inoculations of wheat seedlings with *B. sorokiniana* in soils with different treatments. Regardless of soil treatment, the *B. sorokiniana* produced significantly more root lesions than the controls ($P=0.05$) and significantly reduced the number of plants ($P<0.01$). In preliminary tests, only *F. nygamai* of the fusaria tested produced obvious necrosis, but no reduction in seedling number (data not presented). The fusaria appeared to be secondary organisms in the root rot syndrome. Based on symptoms, we believe that *Pythium* spp. are important in the root rot syndrome since watery type lesions that contain oospores are common. Various pythia have been isolated and are in the process of being identified.

It was previously noted that time of solarization affected its efficacy. Tables 6 and 7 are typical of the situation seen at NWRP regarding timing of solarization. November solarization, just before wheat planting, although it can be effective, does not increase wheat yields as much as May solarization. The May solarization, just before rice planting and subsequent planting of wheat in the same plots, gives more effective control of soilborne pathogens. This appears to be due to the higher temperatures obtained compared to November solarization. Residual effects on yield continue for at least one year. Losses based on these experiments ranged from 12-23%. Other salient points from Tables 6 and 7, besides yield and soilborne disease effects, are that root volume is increased and foliar blight is reduced. These effects are commonly observed and should be important in yield increase. There are several points worthy of note regarding the effects of solarization. As with other control measures, solarization will affect various soil factors, not just microorganisms. Soil structure and nutrient balance will also be influenced. Notwithstanding this, reduced root necrosis is highly correlated with solarization (Dubin and Bimb 1992). Further studies are necessary, under our conditions, to understand the effects of solarization on

Table 4. Percent incidence of the genera of the fungi isolated from necrotic subcrown internodes in untreated plots of solarization experiments, NWRP, Bhairahawa, 1990-91.

Bipolaris sorokiniana	*Fusarium* spp.	*Bipolaris* spp.	*Curvularia* spp.
59	31	3	6

Total number subcrown internodes observed: about 70. Total number of isolations: 167.

Table 3. Percent incidence of the genera of the fungi isolated from necrotic roots in untreated plots of solarization experiments, NWRP, Bhairahawa, Nepal.

Fusarium spp.	*Bipolaris sorokiniana*	*Pythium* spp.	*Curvularia* spp.	*Bipolaris* spp.	*Alternaria* spp.
50	21	10	12	3	4

Total number roots observed, n = 50. Total number of isolations, n = 248.

Table 5. Pathogenicity of *B. sorokiniana* (BS) on wheat roots: artificial inoculations with various soil treatments.

Soil treatment	Root necrosis[a]	Plants/pot[b]
Solarized + BS	1.05 *	8 **
Solarized - BS	0.83	15
Autoclaved + BS	1.75 *	8 **
Autoclaved - BS	0.50	14
Natural soil + BS	1.40 *	13 **
Natural soil - BS	0.83	17

[a] * = root necrosis significantly different from check (-BS) at 0.05. Analysis done on log transformed root necrosis scale to correct for nonadditivity. Original data shown. Roots rated at boot stage as follows: 0 = clean; 1 = 10%; 2 = 20%; 3 = 30%.

[b] ** = plants survived significantly different form check (-BS) at <0.005. Determined by chi square analysis.

antagonistic microorganisms and possible suppressive effects as well as the soil structural and nutrient factors involved.

Data clearly show that the NWRP experiment station has a significant soilborne disease problem and that yields would be increased by their control. However, only very preliminary data exist to indicate the importance of soilborne diseases in the terai of Nepal. Surveys and subsequent loss studies would pinpoint the priority needed for control of these diseases.

Conclusions

It appears that information is relatively sparse and little quantitative research has been done on soilborne diseases in the warmer areas of South Asia.

Table 6. Effects of November solarization on wheat yields and disease symptoms, NWRP, Bhairahawa, Nepal, 1990

	Solarization	No solarization
Yield (t/ha)	2.9a	2.6b
Stems/m²	280a	235b
1000 grain wt. (g)	39.7a	39.0a
Grains/head	27a	30b
Height (cm)	80.3a	76.1b
Root necrosis (1 to 5 scale, P = 0.10)	1.9a	2.4b
Subcrown internode necrosis (1 to 4 scale)	2.6a	3.0a
Root volume (1 to 3 scale)	2.5a	2.1b
Foliar blight (GS 83) (% flagleaf necrosis)	36a	49b

Values across columns followed by a different letter are significantly different (LSD P < 0.05) except where noted.

Source: Dubin and Bimb (1992).

Table 7. Residual effects of May solarization on the following wheat crop, NWRP, Bhairahawa, Nepal, 1990.

	Solarization	No solarization
Yield (t/ha)	3.1a	2.4b
Stems/m²	344a	280b
1000 grain wt. (g)	35a	33a
Grains/head (P = 0.10)	28a	25b
Height (cm)	87a	80b
Root necrosis (1 to 5 scale)	1.3a	2.1b
Sub-crown internode necrosis (1 to 4 scale)	1.8a	2.6b
Root volume (1 to 3 scale)	2.2a	1.4b
Foliar blight (GS 77) (% Flag leaf necrosis)	28a	44b

Solarization done in May 1990, before planting of rice. Wheat planted in December. Values across columns followed by a different letter are significantly different (F test, P = <0.05) except where noted.

Source: Dubin and Bimb (1992).

Further in-depth surveys are needed to ascertain the importance of soilborne diseases and losses should be quantified in areas where they appear significant.

In the areas where present data indicate significant losses, like Bangladesh, studies on epidemiology and control should be intensified.

Integrated control is the one of choice. It should be multicomponent and stress strategies such as genetic resistance/ tolerance, crop management, biological, and chemical controls.

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Questions/Discussion

Dr. Dubin was questioned on the effect of solarization on beneficial soil organisms. He felt there would be little effect as generally, beneficial soil organisms have a higher tolerance to elevated temperatures, probably in the +50°C range. He has found, for instance, that *Trichoderma* spp., which are known to be suppressive against the footrots, have survived well through the solarization treatments. His results showing the effects of a May solarization treatment carrying through to November-December suggest that solarization has produced a more suppressive system.

He clarified that the solarization treatment was used as a method for assessing disease loss due to soilborne pathogens and that the goal was not to produce a technique for farmer use. However, there have been requests for them to look at its use by very small farmers and this is currently under investigation.

Dr. Dubin was asked to outline his pathogenicity test. He explained inoculum is produced on sterilized wheat grain, the grains are then dried and three inoculated grains are sown with each viable grain, with 20 viable grains per pot and four-five pot replicates.

Finally, he clarified the plant nutrition-disease interaction. He said that in the case of facultative parasites, a plant with well balanced nutrition will better resist the organism. The inverse is true in general for obligate parasites—if you have a rust susceptible plant that is overly nourished, it will show more disease. A malnourished plant will have less rust.

Seed Treatment as a Means to Increase Wheat Yields in Warm Areas

C.A. Meisner
CIMMYT Wheat Program, Dhaka, Bangladesh
M. Badaruddin
Wheat Research Centre, Dinajpur, Bangladesh
D.A. Saunders
Interag, Pty. Ltd., Victor Harbor, South Australia
K.B. Alam
Wheat Research Centre, Dinajpur, Bangladesh

Abstract

Wheat production and area in Bangladesh, while having expanded since 1975, have reached a plateau in recent years. The research results of the last few years indicate that production can be increased substantially by the introduction of a few technologies without increasing the area. The Wheat Research Centre of the Bangladesh Agricultural Research Institute has conducted multi-location experiments as well as on-farm testing of various seed treatments, each having differing efficacies for differing pathogens. Results from both the researchers' plots and farmers' fields indicate a fairly consistent minimum 10% yield improvement due to seed treatment with Vitavax 200. A review of the use of carboxin and thiram (components of Vitavax 200) is presented, especially emphasizing the research and experiences from Pakistan, India, and Nepal.

Introduction

Wheat grown in warm areas is subjected to early seed and seedling diseases, affecting plant populations. Saunders (1990) determined poor plant populations to be one of the constraints for increased yields in Bangladesh, an area of considerable wheat in Southeast Asia. A joint Bangladesh-FAO soil survey project in 1975 determined that 2.3 million hectares of land were physically suitable for wheat production under rainfed conditions in Bangladesh (Brammer et al. 1988). An additional 0.8 million hectares were suitable for wheat production under irrigation. However, wheat cultivation in 1991 was approximately 600,000 hectares, representing only 20% of the total land suitable for wheat cultivation in Bangladesh. Areas sown to wheat have ranged from 120,000 to 700,000 hectares over the years (Figure 1).

Bangladesh, with a population currently over 115 million, has a -0.7% annual growth rate per capita of cereal production. This negative growth rate is due to the population expanding more rapidly than cereal production (CIMMYT 1991). However, wheat experienced a 9.3% annual increase in area from 1967 through 1989. Traditionally, Bangladeshis are rice-eaters; however, the annual growth rate of per capita wheat consumption from 1967 to 1989 was 3.6%. How does Bangladesh meet its growing demand for wheat and wheat products? Each year Bangladesh imports close to 2 million tons of wheat, some of which is food aid, but a significant portion is imported upon cash payment (Figure 2). All the above demonstrates the importance of increasing wheat production in Bangladesh. However, even with only 20% of the potential area being currently

cultivated, wheat continues to be the second most important cereal crop in Bangladesh's rice-based cropping system.

Also evident from Figure 1 is yield stagnation that has occurred in the past 6-10 years. There are many theories for this stagnation. The most plausible is the competition with winter rice, which has expanded to many of the former wheat producing areas while wheat production areas are pushed to more marginal or previously winter-fallow lands. Thus, any expansion of wheat area, while shown to be possible, has not occurred in Bangladesh. Still, there is room for improvement of yield potential through better crop management and inputs. Seed treatment is a technology that has been well researched in Bangladesh that has resulted in consistent yield increases in wheat in both researchers' plots and farmers' fields.

Seedborne Wheat Diseases in Bangladesh

The major seedborne diseases have been established in wheat in Bangladesh. Fakir (1982) cites six of the nine diseases as directly transmitted through seed: seedling blight and leaf spot (*Bipolaris sorokiniana*), tan spot (*Pyrenophora tritici-repentis*), black mold (*Cladosporium herbarum*), black point (*Alternaria tenuis* and *Bipolaris sorokiniana*), loose smut (*Ustilago tritici*), and germination failure due to *Aspergillus* spp. and *Fusarium* spp. Other diseases not confirmed as seedborne, but suspected to be, include foot and root rot (*Sclerotium rolfsii*), take-all (*Gaeumannomyces graminis*), and black chaff (*Xathomonas translucens* f.sp. *undulosa*). Three were listed as major diseases causing economic losses: seedling blight, foot and root rot, and loose smut.

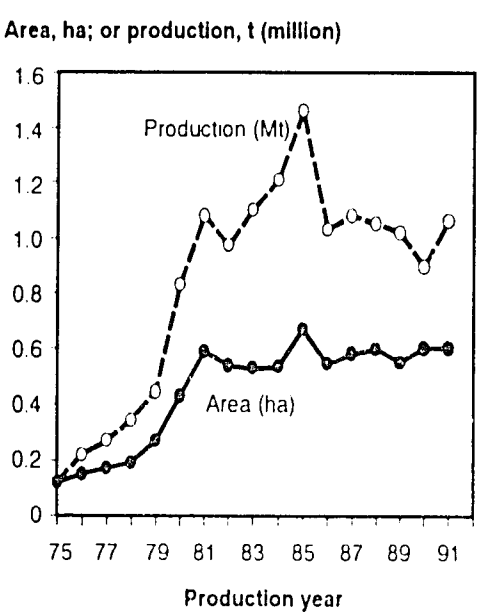


Figure 1. National production and area in Bangladesh (from FAO except 1991 data, which are estimates).

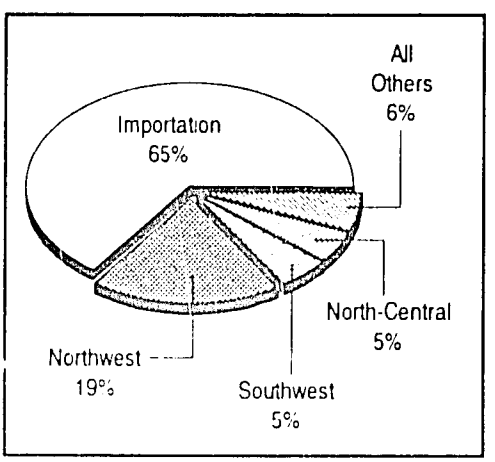


Figure 2. Sources of wheat supplies in Bangladesh for production years 1991 and 1992 (data from IFPRI).

History of Seed Treatments

Historically, seed treatment in the 1940s involved using only heavy metal fungicides, which currently are used less due to both ecological and safety reasons. These organo-mercury groups were not effective for control of soil and seedborne pathogens of wheat. Shortly thereafter came a class of seed dressings that were considered safer for animals and the environment. This class of fungicides included thiram (Figure 3). Thiram is still a widely used seed treatment for control of damping-off diseases.

The class of carboxamides discovered soon after thiram embraces a large number of commercial fungicides with systemic activity particularly against diseases caused by Basidiomycetes. Carboxin (Figure 4) is one of the seed treatments in this class of fungicides. Vitavax 200 is a popular fungicide used throughout the world as a seed dressing, combining both thiram and carboxin into a product that represents a wide-spectrum, systemic fungicide used in controlling externally and internally seedborne diseases of wheat. Carboxin has been shown to reduce the incidence of many seed rotting and seedling blight pathogens including *Helminthosporium* spp., *Fusarium*, spp., *Rhizoctonia* spp., and *Pythium* spp.

Methodology for Determining Soil or Seedborne Diseases

Experiments were conducted throughout Bangladesh from 1989 to 1991 using various fungicides with differing efficacies for differing pathogens. Carboxin (active against Sclerotia/Rhizoctonia), Metalaxyl (active against the Phycomycetes), and Captan (active against the Imperfect fungi were used at three rates (1, 3, and 5 g/kg of seed) for two years over a number of locations in Bangladesh. The first-year results (Figure 5) indicated that both *Sclerotium rolfsii* and Phycomycetes might

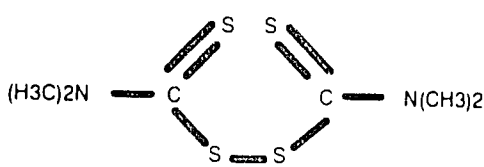
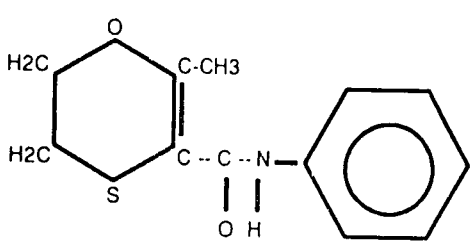


Figure 3. Chemical structure of thiram (tetramethyl-thioperoxydicarbonic diamide).



5,6 -dihydro-2methyl-N-phenyl-1, 4-oxathilin-3carboxamide

Figure 4. Chemical name and structure of carboxin.

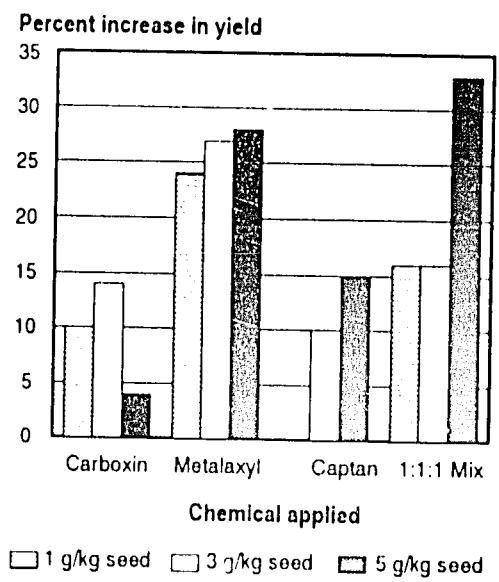


Figure 5. Results of a fungicide seed treatment trial at the WRC, Nashipur, 1989-90.

be involved. While there were indications of chemical toxicity in the following year, the data still suggested that these both may be the active soil pathogens (Figure 6). From further research, one seed treatment, Vitavax 200 was found superior to the others tested. This fungicide is composed of 37.5% carboxin and 37.5% thiram.

Research Results on Use of Vitavax 200

In Bangladesh, the Wheat Research Centre has been conducting experiments with seed treatments for the past five years. Preliminary studies in 1987-88 at Jessore using Vitavax showed a plant stand increase of 23% and a yield increase of 18%. In the farmers' fields where plant establishment is even lower, of 87 demonstrations, the average yield increase due to the use of Vitavax was 10-12% in 1988-89. The following year (1989), on-station research indicated again a 23% plant stand increase and a 5% yield increase with a range from 0 to 10% over the six environments tested. During the same year, 89 on-farm demonstrations indicated, regardless of variety or whether the field was irrigated or dryland, there was a 10 to 13% yield increase due to the use of Vitavax 200 seed treatment. In 1990, on-farm demonstrations indicated a 17% increase in yield while research plots indicated inconsistent yield increases from 0 to 18%. In 1990-91, the average yield among 185 demonstrations increased with the use of Vitavax 200 by 17% and ranged from 13-36%. The inconsistency of results on research stations is due to the continuous use of the same land being treated, indicating some carry-over effect. Results from farmers' fields are very consistent.

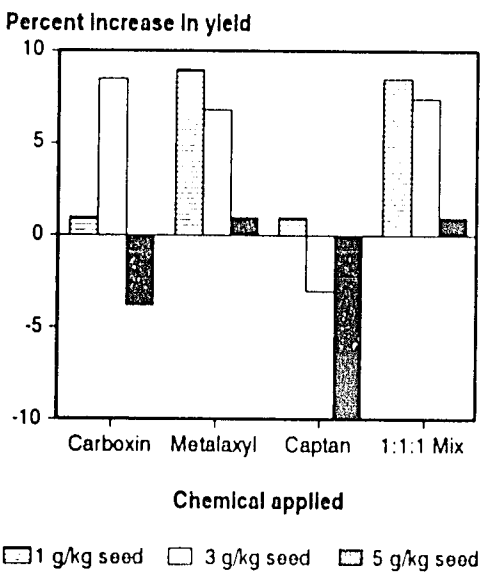


Figure 6. Mean results from a fungicide seed treatment experiment conducted by the WRC at 3 sites in 1990-91.

Literature Review on the Efficacy of Vitavax 200 and its Components

There are many references in scientific literature on the efficacy of seed treatments for control of seedling diseases. Vitavax has been shown to be effective not only for controlling seedling diseases, but for loose smut in wheat (Ciurdarescu and Paraschivu 1987, Akhtar and Khokhar 1987), a disease that affects less than 3% of the wheat in Bangladesh. However, carboxin was found to have variable results with smut due to environmental effects (Gaudet et al. 1989). *Sclerotium rolfsii* foot rot disease was controlled by carboxin and thiram (Harlapur et al. 1988). In a comparative study with 19 seed fungicides, carboxin was found to perform best against *S. rolfsii* (Srikant-Kulkarni et al. 1986). Experience with the use of carboxin on wheat in Pakistan showed that carboxin at a rate of 2 g/kg seed had a beneficial effect on grain yield and other plant characteristics, the effect being more pronounced on yield than on vegetative growth (Ahmed et al. 1987).

One study in the literature showed that carboxin actually increased the coleoptile length of wheat seedlings and that seed dressing plus proper seed coverage with soil and planting at a proper depth increased establishment by 98% (Radford and Wildermuth 1987).

While most of the scientific literature on the use of carboxin is from the Western World where smut is the major disease, research on seed dressing effects in the more tropical regions where soilborne pathogens are a problem is sparse.

A thrust program (funded by the Canadian Government) was initiated by the Government of Nepal to introduce Vitavax as a seed treatment in 1978-80 (Shah 1983). Results showed that the incidence of loose smut was reduced from 30 to 5% due to seed treatment.

Carboxin breaks down in the soil rapidly (about seven days) and has no carry-over effect in the plant. Any adverse effects of carboxin to soil microbes, such as rhizobia, have been found to be negligible (Chaube 1985). Carboxin in different formulations and mixtures with other chemicals, particularly thiram or captan, is used widely in more than 75 countries in the world and is an approved fungicide in Bangladesh.

Toxicity

Of the two compounds that compose Vitavax 200, carboxin is the less toxic while thiram is more so. Vitavax has an acute oral LD_{50} in rats greater than 1600 mg/kg (for comparison, Aspirin has an LD_{50} of 1750 mg/kg), an acute dermal LD_{50} in rabbits greater than 10,000 mg/kg, an acute inhalation LC_{50} greater than 14 mg/L, and a severe eye irritation but no skin irritation in rabbits. If wheat seed were treated at 3 g/kg of seed (equivalent to 2.2 g active ingredients), a population of 1-kg rats would have to consume 0.7 kg each of treated wheat to kill potentially 50% of the population. When extrapolating to humans, 35 kg of treated wheat seed would have to be consumed by one person at one time to have a 50:50 chance of dying from the fungicide. Additionally, all seed treatments contain a reddish blue dye that signals to all that the seed has been treated and should not be consumed.

Expense of Seed Treatment

Since another major constraint of wheat production in Bangladesh is the cost of inputs, all new technologies researched by the Bangladesh Agricultural Research Institute (BARI) have their economic impacts evaluated. The current cost of Vitavax 200 is US$12.30/kg, which at the present conversion rate means 1 kg costs 475 Taka (Tk). Recent survey results indicate that farmers' average seeding rate is close to 145 kg/ha (Saunders 1990, 1991; Meisner 1992) and therefore the cost per hectare at the recommended rate of 3 g Vitavax/kg of seed is 207 Tk. If the average yield of 1992 is used, 2.2 t/ha, and a farmer obtains a 10% yield increase, the yield increase on 1 ha sown with treated wheat seed would be 0.22 t/ha. If one assumes the market price of selling 1 kg of wheat is 6 Tk/kg, then the gross profit from using the seed treatment would be 1,320 Tk. Thus the profit after subtracting the 207 Tk input price would be 1,113 Tk, a return on investment of about 540%.

Nepal Experience: A Model for Bangladesh

A useful model for Bangladesh to follow in transferring a seed treatment technology is the one reported by Shah (1983). The Government of Nepal imported and distributed 49 t of Vitavax to farmers in 1975-76. In that year, there were mixed

results and reports of poor efficacy due to faulty treatment procedures. Subsequently, in 1978-80, 23 t of Vitavax were imported courtesy of the Canadian Government through the Canadian International Development Agency (CIDA) as a gift to farmers in those areas of Nepal that have a high smut incidence. By 1981-82, farmers were purchasing 12 t of Vitavax 200, but again with mixed results. Surveys indicated that farmers were not following the written instructions for application given with the fungicide. In time, the Department of Agriculture Extension (DAE) was able to better demonstrate the application of the fungicide to the seed for optimum disease control. The DAE intensified the information program for seed treatment and this resulted in a greater proportion of the growers' wheat seeds being treated over time. A target was set over a five-year plan that would expand this even further.

Shah (1983) defined various problems Nepal had in expanding the use of seed treatment and made recommendations for future seed treatment programs that:

- The subsidized program should be well planned and placed into areas where seedborne diseases are more prevalent.
- The subsidy program should not be withdrawn haphazardly.
- Mere distribution of chemicals directly to the farmers should be discouraged, while more use of the DAE as a training agency should be encouraged
- Procurement and distribution of the chemicals in the needed area should be well ahead of sowing time.
- More emphasis should be given to practical approaches to train farmers rather than the use of radio and newspapers as many do not have exposure to such materials.

Conclusions

Many pathogens were found associated with the seedling diseases and poor plant stands limiting wheat yields in Bangladesh. While a systematic methodology for determining major pathogens within the soil did not give clear evidence, one seed treatment gave consistent results in farmers' fields. Vitavax 200 seed treatment was found to be a technology that resulted in a consistent 10% yield increase or higher, across the country.

A plan to transfer this technology was investigated and proposed to the Government of Bangladesh. The proposal emphasizes use of seed treatment by:

- Committing the chemical company to begin the sale of the treatment in the private marketing system;
- Publishing a poster on the research results of the use of the seed treatment in both station and farmers' fields;
- Requesting a donor agency to consider subsidizing the treatment of the government stocks of wheat seed; and
- Evaluating the program of previously treated certified seed among the producers to validate their satisfaction with the treatment.

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Questions/Discussion

Dr. Meisner was questioned about the properties of Vitavax-200. He said the manufacturer hints at the fact that the product may have some hormonal or plant regulating properties. However, they were not able to supply evidence or published data on this aspect. He was not aware of any insecticidal properties, but carboxin does have some anti-bacterial activity.

He explained that both of the component chemicals, carboxin and thiram, were effective against *Sclerotium rolfsii* while thiram has been shown effective against *Bipolaris sorokiniana*.

The Virulence Spectrum of Leaf Rust and the Status of Leaf Rust Resistance in Nepalese Wheats

C.B. Karki
Central Plant Pathology Division, Khumaltar, Lalitpur, Nepal

Abstract

Leaf rust caused by Puccinia recondita *f.sp.* tritici *is a major disease of wheat in the terai region of Nepal. It has reduced grain yield by 14% with a moderate infection. The leaf rust pathogen is known to survive in self-sown wheat plants in the higher hill regions of the country. Fourteen different pathotypes of* P. recondita *f.sp.* tritici *have been recorded in Nepal, attacking many of the resistant genes present in the Nepalese cultivars. Twelve leaf rust-resistant genes* Lr 1,3,10,13,14a,16,17,23,26,27,31, *and* 34 *were postulated from 25 promising and recommended varieties in Nepal.* Lr13 *and* Lr 23 *were the genes most frequently found. Among the list of future strategies, emphasis will be on the development of a complete map of virulence and avirulence of pathotypes present in the leaf rust pathogen population and development of wheat varieties with durable and adult plant resistance and having a wide genetic base with slow rusting characteristics.*

Introduction

Wheat is the third cereal crop after rice and maize in Nepal. It is grown both in the terai plains (60-300 masl) and hills (up to 3,000 masl). Wheat is considered a new crop in Nepal and it is grown on 593,000 ha and has recently produced 836,000 tons (1.4 t/ha) (Anonymous 1992). Although the area planted to wheat has increased substantially since the semidwarf wheats were introduced in the country in the early 1960s, productivity has not increased in the same proportion. Diseases are one of several causes of low productivity. As in other countries, wheat in Nepal is attacked by more than a dozen diseases. Among them, leaf rust (*Puccinia recondita* Rob ex Desm. f.sp. *tritici*) and *Bipolaris sorokiniana* leaf blight in the terai and yellow rust (*Puccinia striiformis* West. f.sp. *tritici*) and loose smut (*Ustilago tritici* Rostr.) in hills are the major diseases that have caused significant grain yield losses (Karki and Sharma 1990).

It has been substantiated by Nagarajan and Joshi (1985) that leaf rust oversummers in self-sown wheat plants. It is known that there is no role of the alternate host *Thalictrum* spp.

Leaf rust was the number one disease in the late 1960s and early 1970s when Kalyansona and some local wheats were grown extensively in the country (Karki 1973). A loss of 14% grain yield was assessed on the variety Kalyansona when there was only a moderate level of rust infection (Dongol 1979), but the potential loss was estimated to be 20% when there was high rust severity. Rust severity declined in some years after the release of RR 21 (Sonalika) in 1969, but soon the pathogen spectrum changed and began to attack RR 21 as well. A complete virulence analysis of the leaf rust pathogen was not done, but based on the analysis of some leaf rust samples, seven races (12, 20, 22, 26, 57, 77, and 106) were identified with the help of Indian scientists (Unpublished data). Races 57 and 12 were the most frequent races in the late 1960s.

No gene postulation work was done in the past in Nepal. A number of wheat lines from the National Wheat Research Program, CIMMYT, and the national programs of India, Pakistan, Bangladesh, and other countries were multi-location tested in Nepal for sources of resistance to rust. Some lines/cultivars were reselected for variety improvement while others were used in the national breeding program. As a result, a series of semidwarf wheats were identified and recommended and have been grown since the 1980s. There has been no serious outbreak of leaf rust since then in the newer wheat cultivars. The cultivars released in Nepal were not tested regularly at the seedling stage but many exhibited adult plant resistance. Resistance of some recommended cultivars has not been broken and they seem to have durable resistance (Johnson 1984) even though the pathotypes have changed. Although RR 21 has been grown in Nepal for the last 20 years, it still retains some resistance to rust. This paper highlights some of the work on the virulence spectrum of leaf rust and leaf rust resistance gene postulation in Nepal.

Virulence Spectrum of Leaf Rust

Unless a complete picture of the virulence spectrum of any pathogen is known, breeding for disease resistance as a means of control may not be successful. Since there was no facility for work on virulence studies in Nepal, leaf rust samples were sent to the rust laboratories at Shimla, India, and the United States Department of Agriculture (St. Paul, Minnesota) for identification of virulent genes of leaf rust pathogens of Nepal. Standard and supplemental wheat leaf rust differentials (Nagarajan et al. 1983, Long and Kolmer 1989) were used. According to the Shimla Laboratory, 11 different pathotypes were recorded from 30 samples collected from different parts of the country (Nayer et al. 1992). The avirulence and virulence formulas are given in Table 1a. The three most common groups of pathotypes were 12, 77, and 104. Among them the most complex pathotypes were of the 77 group (virulent to leaf rust resistance gene *Lr1*, *Lr2a*, *Lr2c*, *Lr3*, *Lr10*, *Lr13*, *Lr14a*, *Lr15*, *Lr18*, and *Lr20*) while the pathotype group 12 was less virulent. Many of the pathotypes were avirulent to *Lr17*, *19*, and *24*. Interestingly, pathotype 77-1, which could attack *Lr26*, and pathotype 77-2, which could attack *Lr17*, were recorded. Earlier, Lr26 was considered to be highly resistant to many of the prevailing pathotypes in Nepal (Nagarajan et al. 1983). Pathotypes 20, 22, 26, and 57, which were recorded earlier, could not be found in the present studies. The change in pathogens may be caused by the change in the wheat cultivars grown in the country.

Pathotypes identified at the St. Paul rust lab from the 1987-88 samples were TBTB and those of the 1989-90 samples were TBSB and TBSL (R.P. Singh, pers. comm.). The avirulence/virulence formula for these pathotypes is in Table 1b. Three pathotypes identified at St. Paul seemed to attack a smaller number of *Lr* genes. Additional *Lr* genes *9*, *16*, and *30* included in the St. Paul's differential sets were not attacked by the pathotypes recorded in Nepal, while *Lr14a*, which was universally susceptible to all pathotypes was not included in the differential sets. Many of the pathotypes recorded at Shimla were either avirulent or showed differential reactions on *Lr17* while the pathotypes TBSL and TBTB were virulent to *Lr17*. This could be due to environmental differences.

Status of Leaf Rust Resistance

Some very effective fungicides such as triadimefon (Bayleton), Indar (RH-124), and several others are available in some countries to control leaf rust, but due to the

high cost and health hazards, very few farmers use them. Resistant varieties have been and will continue to be a cheaper means to counteract rust and other foliar diseases. Efforts have been made to develop resistant varieties by introduction, multilocation testing, hybridization, and selection. Some success has been obtained in getting agronomically superior, durable, and adult plant resistant wheat cultivars. They have been recommended for general cultivation in the country. But because of diverse climatic conditions and insufficient support for the breeding program, very few varieties have been identified that are adapted for all regions and localities. To cope with the frequently changing race pattern of the rust pathogen, gene deployment and varietal diversification are needed. It is, therefore, necessary to know the leaf rust resistance genes in the recommended and promising varieties. With this aim, gene postulation with the help of CIMMYT was carried out on some of the recommended and promising varieties of Nepal.

Based on the report of CIMMYT, leaf rust resistant genes *Lr1*,*Lr3*,*Lr10*,*Lr13*,*Lr14a*,*Lr16*, *Lr17*,*Lr23*,*Lr26*,*Lr27*,*Lr31*, and *Lr34* were postulated from 25 wheat varieties of Nepal (Table 2). Among them, *Lr13* and *Lr23* were the most frequent genes present in Nepalese wheat cultivars. No variety had either *Lr9* or *Lr19*, which are considered resistant to many virulent leaf rust genes (Nagarajan et al. 1983, Roelfs 1988). *Lr13* is considered to provide durable adult plant resistance to leaf rust (Roelfs 1988). RR 21, which is known to possess *Lr13*, is widely adapted both in the terai and hills and it still has some resistance in the field, probably due to the presence of *Lr 13*. *Lr13*, in combination with *Lr34*, provides durable resistance in some wheat cultivars (Nayer 1992, Roelfs 1988, Singh 1992), but not a single Nepalese

Table 1. The avirulence/virulence formulas of pathotypes identified at Shimla (India) and St. Paul (USA).

Pathotype	Avirulence/Virulence Formula
a) Identified at Shimla	
12	Lr 1,2a,10,13,15,17,19,20,24,26/Lr 2c,3,14a,18
12-2	Lr 1,2a,10,13,15,17,18,19,20,24,26/Lr 2c,3,14a
77	Lr 10,17,19,24,26/Lr 1,2a,2c,3,13,14a,15,18,20
77-1	Lr 17,19,24/Lr 1,2a,2c,3,10,13,14a,15,18,20,26
77-2	Lr 19,24,26/Lr 1,2a,2c,3,10,13,14a,15,17,18,20
77A	Lr 17,19,24,26/Lr 1,2a,2c,3,10,13,14a,15,18,20
77A-1	Lr 17,19,20,24,26/Lr 1,2a,2c,3,10,13,14a,15,18
104	Lr 10,13,15,18,19,20,24,26/Lr 1,2c,3,14a
104A	Lr 10,13,15,19,24,26/Lr 1,2c,3,14a,18,20
104B	Lr 10,15,19,20,24,26/Lr 1,2c,3,13,14a,18
107	Lr 1,3,10,17,19,20,24,26/Lr 2a,2c,13,14a,15,18
b) Identified at St. Paul	
TBSB	Lr 9,16,18,19,21,24,26,30,/Lr 1,2a,2c,3,3ka,11,17
TBSL	Lr 9,16,18,19,21,24,26,30,/Lr 1,2a,2c,3,3ka,11,17
TBTB	Lr 10,16,18,19,21,24,26/Lr 1,2a,2c,3,3ka,11,17,30

wheat cultivar was shown to possess the two genes in combination. *Lr34* was detected in the Nepalese cultivars Vasker, NL 588, and NL 623, but in combinations other than with *Lr13*. *Lr26*, which is attacked by pathotype 77-1, is still effective in the field. Nagarajan et al. (1983) reported that *Lr10* has not been attacked by any Nepalese isolate of the leaf rust pathogen at the seedling stage, but Vasker which contains *Lr10* had moderate rust infection.

Future Strategies

Our main objective is to develop wheat varieties that sustain yield by breeding for resistance. Several strategies could be developed to combat the rust problem. First, a complete virulence/avirulence map needs to be developed either by establishing a laboratory in the country or by strengthening cooperation with rust laboratories in other countries. The main breeding strategy involves identification of sources of

Table 2. Postulated leaf rust resistant genes in some promising cultivars of Nepal and their leaf rust scores under field conditions.

Cultivar	Parentage	Leaf rust score	Lr gene postulated
Annapurna-1	Kvz/Buho'S'//Kal/Bb(Vee#5)	10MR	23,26
Annapurna-2	Npo/Tob'S'//8156/3/Kal/Bb	30MS	1,13
Annapurna-3	Kvz/Buho'S'//Kal/Bb(Vee#5)	10MR	23,26
RR 21	II54-388/An/3/Yt54//N10B/LR64	60MSS	13+
UP 262	S 308/Bajio 66	20MS	13,23
Siddhartha	HD 2092/HD1982//E4870/K65	20MR	10,13+
Triveni	HD 1963/HD 1931	30MS	13,17
Vinayak	LC55	20MR	13,23
Vasker	Tzpp/PL//7c	40S	10,34
Nepal 297	HD 2137/HD 2186//HD 2160	5MR	13,23
Nepal 251	WH 147/HD 2160//*WH147	30MS	13,23
Lumbini	E4871/Pj62	40S	1,3
NL 539	Kbz/5/Cc/Inia/Cno/Elgau//Son64	5MR	16,26
NL 582	Kbz/Buho'S'//Kal/Bb=(Vee# S)	5MR	13,26
NL 588	Gaa'S'	20MR	23,26,34
NL 590	Pea'S'	10MR	23,26
NL 591	Pea'S'	10MR	23,26
NL 623	Cont/Coc 75/3/Plo//Fury/Ana75	20MS	10,14a,34
NL 625	Him/Coc//Nac/3/Nac	20MR	10,27,31
NL 626	HD 2169/Imu/3/Cbs-38	0	10,23,27
BL 1020	Bb/Kal/Ald'S'/3/Y50E Kal(3) //Emu'S'/4/Pvn76	10MR	13,23
BL 1022	Pvn'S'/Buc'S'	5MR	13,26
BL 1135	Qtz/Tan'S'	10MR	3,23
BL 1252		40MS	3,23
Morocco	Susceptible check	90S	—

Source: R.P. Singh (pers. comm.).

resistance through multilocation testing at "hot-spot" locations with known virulence genes of the rust. The second strategy would be to postulate Lr genes in additional advanced and promising wheat cultivars to determine if key genes are present.

Breeding for rust resistance in Nepal is much more advanced than it was 15-20 years ago. But wheat cultivars presently under cultivation do not possess wide genetic bases for resistance. As stated earlier, wheat cultivars in Nepal have mostly the *Lr13* and/or *Lr23* genes. *Lr13* is considered to be a useful gene and it may provide durability in leaf rust resistance, particularly if it could be combined with *Lr34* (Nayer et al. 1992, Roelfs 1988, Singh 1992). Development of slow rusting and adult plant resistant varieties would be another strategy.

Varietal diversification (Wolfe 1985) and deployment of different resistant genes (Browning 1988) for different environments are needed for better management of the rust and to sustain yield for longer periods of time as Nepal has varied climatic conditions. Improvement of old varieties such as RR 21 is another approach. RR 21, which was released in Nepal some 20 years ago, is still grown over large areas in Nepal and it not only contains the useful *Lr13* gene, but it also has other useful qualitative characters. For this reason, farmers of Nepal still prefer the variety RR 21. This variety could be improved by incorporating some useful genes.

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Questions/Discussion

Dr. Karki elaborated on his reference to "slow rusting" genotypes. He explained that the slow rusting character is governed by polygenes and lines with this character not only show less disease, but also smaller pustule size and a longer latent period. He is selecting for this resistance and testing on a multi-location basis to assess the resistance against all the virulent races existing across Nepal. Although the production of a slow rusting line will be time-consuming, he feels it is worth the effort and should result in durable resistance.

Wheat Research Efforts in Northeastern Thailand

S. Rajatasereekul, P. Kantatat, S. Ruangsook, P. Konghakote, and S. Srivisuthi
Ubon Ratchathani Rice Research Center, Ubon Ratchathani, Thailand

Abstract

Wheat farmers in northern Thailand produce about 460 t of grain annually. In order to meet the demands of national consumption and partially substitute for the amount imported, more wheat has to be produced. Wheat cultivation after irrigated rice seems to have great potential. Wheat research in the northeast under the Ubon Ratchathani Rice Research Center was initiated in 1986. Rice-wheat rotation research is another challenge for agricultural research scientists to develop appropriate cropping practices. Research has shown that wheat production has good potential in some areas of the upper northeastern region.

Introduction

Thailand is a tropical country lying between 5 and 21°N latitudes with a total area of about 513,000 km². It is currently the largest rice exporter in the world, amounting to 4 million tons, which is about one-third of world trade.

The per capita consumption of wheat in various forms has doubled over the last 30 years and is now 6.07 kg, while that for rice is 145 kg. Wheat grain and flour imports in 1990 were 388,000 t and cost near US$80 million. Wheat farmers in northern Thailand produce about 460 t of grain annually to supply local industries producing liquid glucose, soy sauce, etc. There is no wheat production in the northeastern part of the country.

Potential Wheat Area in the Northeast

The farmers in the northeast usually grow photoperiod-sensitive aromatic rice varieties that can be harvested at the end of November. Medium- to late-maturity varieties are not suitable for a rice-wheat cropping pattern. The use of earlier maturity rice varieties will allow wheat to be sown at more optimum timings from November to December (Saunders 1988). In the upper northeast, a thorough survey of potential area has not been made, but there are lowlands at about 160 masl suitable for wheat cultivation. Mean minimum and maximum temperatures from November to February are 16.8 and 30.0°C, respectively (Table 1). The soils are loamy, moderately light in texture and are within well developed irrigation schemes.

Research and Development

The first wheat varieties released in Thailand were Samoeng 1 and Samoeng 2 (Chandhanamutta 1985). In 1988, four additional varieties were released: Fang 60, Phrae 60, Insee 1, and Insee 2. These adapted varieties are selections from introduced material. Samoeng 2 and Fang 60 are well adapted to northeastern Thailand. However, the crop has not yet been commercialized because of production and research constraints.

Wheat research in the northeast was initiated at the Ubon Ratchathani Rice Research Center in 1986 and is conducted

under various conditions with irrigated wheat as a secondary crop after rice.

The breeding program has concentrated on the selection of germplasm for high yield and wide adaptation, tolerance to heat, and resistance to helminthosporium spot blotch and sclerotium wilt. Segregating populations are received from CIMMYT. Selection of the superior progeny from crosses are made under both favorable and unfavorable conditions. F2s are space-planted and individual plant selection is made on the basis of visual characters. The pedigree method of selection is used. Individual plant selections are made until the lines reach homozygosity. The selected lines are included in the Wheat Observation Nursery (WON), followed by replicated yield trials with irrigation at six locations. A number of the selected lines appear extremely promising (Table 2).

Research has also been conducted on agronomy to develop suitable management practices for these environments, such as seeding date, seeding rate, fertilization, weed control, and water requirements.

Table 1. Average temperature (means of six provinces) in upper northeastern Thailand during the wheat growing season.

	Average temperature (°C)			
	Nov.	Dec.	Jan.	Feb.
Minimum	18.6	15.6	15.1	17.7
Maximum	30.1	29.0	29.4	31.3
Average	24.3	22.3	22.2	24.5

Table 2. Some promising lines from the Wheat Observation Nursery at Chumphae, northeastern Thailand, 1991.

Name/pedigree	Mean yield (kg/ha)
V655=Gva/Az// Mus/3/BHWF79; PB18615-1B-1B-4LMP	3719
Bau	3213
Punjab 81	3131
Fang 60 (check)	3125

Conclusions

Research has been carried out in the northeast by the Ubon Ratchathani Rice Research Center. This research has identified wheat varieties having acceptable yield potential and desirable grain quality. Selections made from the various wheat nurseries distributed by CIMMYT have performed well. Additional research has been conducted to determine appropriate management practices. Over the last five years, a significant potential for wheat production has been demonstrated in the upper northeast. Many farmers are now exploring the possibility of growing wheat and it will be a new option to increase food output during the cool, dry season.

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Possibilities of Selecting Wheats with Fast Grain-Filling Rate for Warmer Areas

M.R. Bhatta
National Wheat Research Program, Bhairahawa, Nepal
J.E. Hernandez and J.S. Lales
Department of Agronomy, University of the Philippines at Los Baños, Philippines

Abstract

Twelve spring wheat genotypes of similar maturity were evaluated in two replicated field experiments in Los Baños, Philippines, to study the variation in grain yields, morpho-physiological characters, and the relationship between grain yield and plant traits over two planting periods. Most characters were altered when planting was delayed by one month from the normal seeding date. Declines in grain yield, kernels per spikelet, and 100 grain weight were relatively of small magnitude. Average grain-filling duration was shortened by four and maturity by six days in the later-planted experiment. Despite these reductions, some genotypes showed stability of grain yield between the two planting periods, indicating possible genetic variability in grain-filling rate. Correlation studies indicated that flag leaf sheath length, extrusion length, plant height, spike length, kernels per spike, and biological yield are important determinants of grain yield in wheat under Los Baños conditions.

Introduction

Under high temperatures, the wheat crop completes its cycle much faster than under temperate conditions (Fischer 1985). All crop stages have a short duration. Consequently, there are fewer days to accumulate assimilates during the life cycle and production of biomass is reduced (Fischer and Maurer 1976). High temperatures accelerate organ production without any increase in net photosynthesis (Begga and Rawson 1977) resulting in smaller organs.

High temperature in the post-anthesis period shortens the duration of grain-filling (Wiegand and Cuillar 1981) such that each degree increase during grain-filling results in about three days' decrease in the duration of filling regardless of cultivar (Asana and Williams 1965, Bagga and Rawson 1977). Evans and Wardlaw (1976) and Sofield et al. (1977) concluded that neither illumination conditions nor grain-filling rates affect the duration of grain-filling.

In the study reported here, it was assumed that the grain-filling rate is controlled by genetic factors (genotype) and duration of filling is controlled by environmental factors such as temperature. Thus, the rate of dry matter filling among genotypes might vary within a similar grain-filling period.

The objective of this study was to observe the genotypic variations in morpho-physiological characters including grain yield and plant traits related to grain yield over two planting periods under hot humid conditions.

Materials and Methods

Twelve spring wheat genotypes with similar maturity were evaluated from December 1990 to April 1991 in two replicated field experiments at the Central Experiment Station, University of the Philippines at Los Baños (21.1 masl and 14° 10' N and 121° 15' E). The first experiment was planted on 26 December and the second one on 27 January. The experimental plots were irrigated every week to avoid moisture stress and the plots were kept weed-free throughout the growing period. Twenty-six different morphophysiological characters in addition to climatic factors were observed in each experiment.

Results and Discussion

The mean daily air temperature varied from 25 to 27°C during the first experiment and 25 to 28.3°C during the second one. The relative humidity was slightly higher (80-85%) during the first experiment compared to the second (77-83%). Daily evaporation ranged from 3.8 to 6.1 mm during early planting and 4.1 to 7.0 mm during the late planting. Daytime soil temperature at the 10-cm depth within the crop canopy varied from 33 to 52°C (Figure 1).

Days to heading, maturity, grain-filling duration, grain yield, and biological yield are presented in Table 1. Correlation coefficients between grain yield and plant traits related to it are shown in Table 2.

Most plant traits were altered when planting was delayed from 26 December to 27 January. Traits not influenced by planting dates were length of awns, spikelets per spike and number of kernels per spike. The number of days from sowing to ear emergence and from sowing to anthesis was reduced by three days, maturity by six days, and grain-filling duration by four days with delayed planting (Table 1).

The average plant height was reduced from 86 cm in the 26 December planting to 71 cm in the 27 January planting. The reduction in other plant parameters was in the following order: average flag leaf length was reduced from 18.6 to 14 cm, flag leaf area from 25.4 to 17.7 cm^2, extrusion length from 14.3 to 12.4 cm, flag leaf sheath length from 18.6 to 15.9 cm, and spike length from 9.2 to 7.8 cm when planting was delayed.

Reductions in other characters were: spikes/m^2, 22%; 100-kernel weight, 3%; biological yield, 17%; and grain yield, 6% in the late-planting experiment compared to the early planting.

Despite four to five days' reduction in grain-filling duration in the 27 January planting, genotypes Trigo-2, C 278-9, C 676-4, C 1690-1, and ACC 43686 produced similar high grain yields in both

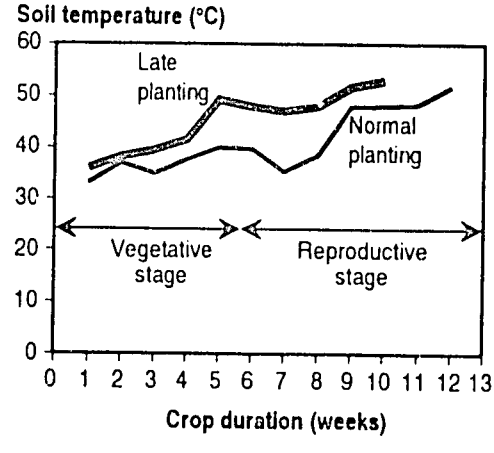

Figure 1. Soil temperature during the vegetative and reproductive stages in the two experiments.

experiments (Table 1), indicating the presence of possible genetic variability for rapid grain-filling rate.

Correlation studies between selected morpho-physiological characters and grain yield indicated that flag leaf sheath length, extrusion length, plant height, spike length, kernels per spike, and biological yield were well related to grain yield in both conditions (Table 2). Flag leaf length, area, length of awns, and productive tillers showed significant positive correlation with grain yield only in later-planted conditions.

Table 1. The effect of seeding date on growth durations and yield.

	26 Dec. planting					27 Jan. planting				
Genotypes	Days to heading	Days to maturity	Grain-filling duration (days)	Grain yield (kg/ha)	Biological yield (kg/ha)	Days to heading	Days to maturity	Grain-filling duration (days)	Grain yield (kg/ha)	Biological yield (kg/ha)
Trigo-2	52	78	26	1,648	3,509	49	71	21	1,651	2,766
C 278-9	54	81	26	1,731	3,296	51	75	23	1,601	2,592
C 676-4	51	79	26	1,897	3,944	48	72	22	1,812	3,859
C 213-36	53	80	25	1,579	3,259	50	74	23	1,387	2,528
C 1690-1	49	78	28	1,941	3,276	47	71	22	1,792	2,690
C 925-1	53	81	26	1,696	3,602	50	72	21	1,262	2,462
ACC 46116	45	74	28	1,618	2,630	44	69	23	1,226	2,006
ACC 49528	50	77	25	828	2,056	48	72	22	1,328	2,400
ACC 43686	52	80	27	1,861	3,824	49	72	22	1,746	3,157
ACC 49360	48	75	25	1,355	2,194	45	69	22	1,160	1,959
CM 70596-2	48	77	23	1,493	2,778	45	69	22	1,471	2,337
PI-18	49	77	25	1,309	2,685	48	71	21	1,361	2,620
Overall Mean	50**	78**	26**	1,579**	3,087**	47**	72**	22 nsl	483**	2,538
CV %	1.4	1.4	3.8	13.0	11.6	1.3	1.2	4.7	11.7	9.0

** = P <0.01.

Table 2. Plant characters correlated with grain yield at the two seeding dates.

Plant characters	26 Dec. planting	27 Jan. planting
Flag leaf length	0.31**	0.82**
Flag leaf area	0.26	0.69*
Flag leaf sheath length	0.77**	0.91**
Extrusion length	0.77**	0.71*
Awn length	0.54	0.72*
Plant height	0.78**	0.9**
Spike length	0.62*	0.78**
Kernels/spike	0.61*	0.59*
Spikes/m²	0.53	0.73*
100 kernel weight	0.66*	0.41
Biological yield	0.85**	0.83**

* P<0.05 and ** P<0.01.

Conclusions

High temperature along with other environmental factors affected the photosynthetic areas, productive tillers, plant height, and total biomass. Traits least influenced were awn length, spikelets per spike, kernels per spike, and 100-kernel weight under Los Baños conditions. Genetic variability for rapid grain-filling rate possibly exist in different wheat genotypes.

High correlation coefficients between grain yield and the components of photosynthetic areas such as flag leaf length, flag leaf area, flag leaf sheath length, extrusion length, and awn length support the concept that photosynthetic area is an important determinant of dry matter production in the wheat grain.

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Selecting Traits for Breeding Heat-Tolerant Wheat Varieties

M.A. Samad, M.M. Rahman, M.R. Amin, Z.I. Sarkar, and M. Islam
Wheat Research Centre, Nashipur, Dinajpur, Bangladesh

Abstract

*Sixteen genotypes chosen from tropical and subtropical environments were evaluated for some agronomic traits in an experiment planted at Nashipur, Dinajpur, Bangladesh. High grain yield genotypes produced high biomass at anthesis (r= 0.72**). The correlation coefficient between yield and length of the life cycle was poor. Rapid early growth (ground cover at tillering) was correlated with yield in these genotypes.*

Introduction

In Bangladesh, up to 70% of the wheat crop is sown late due to delayed harvest of transplanted aman paddy rice. Due to this late sowing, wheat plants are subjected to heat stress during the anthesis and grain-filling stages. High temperatures can speed up the growth and development phases, usually negatively affecting the crop establishment, leaf area growth and development, ground cover by foliage, radiation interception, and photosynthesis per unit ground area (O'Toole and Stockle 1991). These affect the yield related components such as spike number, spikelets/spike, spike weight at anthesis, potential grain number, and individual grain weight.

Attempts are being made to determine traits for heat tolerance in local and introduced germplasm. Genotypes possessing these traits will be utilized in a hybridization program to develop material more suitable for the heat stress conditions in Bangladesh. To initiate this program, an experiment with 16 genotypes was conducted during 1990-91 at the Wheat Research Centre, Nashipur.

Materials and Methods

The genotypes used in the experiment were varieties extensively grown or widely adapted to warm or hot locations around the world. The experiment was sown on 10 December 1990 with fertilizer applications of 100 N, 60 P_2O_5, 40 K_2O, and 20 S kg/ha. Irrigations were given three times according to the need of the crop. Foliar diseases were controlled by applying 'Tilt' regularly to physiological maturity. Data were taken on days to physiological maturity, days to 50% anthesis, 1000-grain weight, plant height, spikes/m^2, and percent ground cover at tillering and at 50% anthesis. Biomass was taken at 50% anthesis and maturity stages from six rows/50 cm long. Grain yield was taken from six rows/3 m long. An analysis was run with nine characters (except biomass at 50% anthesis). Correlations were computed for yield with some of the plant characteristics.

Results and Discussion

Significant differences were observed for all characters except ground cover at tillering and days to 50% anthesis (Table 1). The local variety Kanchan was the highest yielding genotype for both grain and final biomass.

Strong correlations were found between grain yield and biomass, particularly final biomass (r=0.72***), plant height (r=0.33**) and ground cover at tillering (r=0.38**) and at anthesis (r=0.29**). Correlations between grain yield and biomass have also been found in trials with the same genotypes conducted at seven locations around the world (Reynolds et al. 1992). In those trials, the majority of locations showed grain yield well correlated with final biomass, straw biomass, spikes/m², and ground cover at anthesis. As in those locations reported by Reynolds et al. (1992), in this experiment there were very low correlations between yield and days to anthesis or maturity. This suggests that genetic variability for a longer life cycle is not a key trait conferring yield potential in warmer climates.

Rapid early growth to maximize light interception has been implicated as an important strategy in warm climates (Rawson 1988). The strong positive relationship between grain yield and ground cover at tillering in this study confirms this. The fact that biomass at maturity correlated better with yield than biomass at anthesis suggests that assimilation after anthesis is an important yield determinant.

In addition to the known potential morphogenetic traits, which may be used by breeders for selecting heat-tolerant genotypes, some physiological approaches are needed. For example, leaf chlorophyll content, canopy temperature, membrane stability, etc. have been indicated as useful tools in the selection for heat tolerance (Kohli et al. 1991, Blum et al. 1982, Shanahan et al. 1990).

Table 1. Yield and yield contributing characters of 16 wheat genotypes grown at Nashipur, Dinajpur, Bangladesh.

Genotype	Grain yield (kg/ha)	Biomass (kg/ha) at maturity	Biomass (kg/ha) at 50% anthesis	Days to maturity	Days to 50% anthesis	Ground cover (%) at tiller initiation	Ground cover (%) at 50% anthesis	Spikes /m²	1000-grain wt. (g)	Plant height (cm)
Anza	3,102	9,537	7,440	108	70	62	70	551	45.8	79
Bacanora 88	4,583	11,481	8,219	109	72	68	77	335	46.0	91
Ciano 79	4,329	9,259	7,291	105	72	63	78	404	40.5	84
Debeira	3,704	10,185	7,619	106	71	[illegible]	80	384	48.3	89
Fang 60	4,329	10,648	8,886	102	71		87	392	42.2	99
Genaro 81	4,537	11,481	9,220	111	71	70	80	354	38.3	93
Glennson	3,912	10,740	7,200	109	70	68	80	325	44.8	96
IP-4	3,328	7,500	6,410	99	72	62	75	405	44.3	99
Kanchan	5,069	11,667	8,160	103	72	72	77	328	52.7	101
Nacozari	4,399	9,629	7,762	101	72	64	77	524	44.2	86
Nesser	3,949	9,722	6,980	106	72	57	85	428	46.2	78
Pavon 76	4,236	9,630	8,047	104	72	75	83	347	41.0	95
Sen 82	4,699	10,833	8,606	110	72	73	75	325	45.2	92
Siete Cerros	3,495	8,241	7,510	104	72	65	78	330	44.2	88
Sonora 64	3,935	8,518	6,727	95	70	67	77	417	39.1	85
Trigo 3	4,329	10,463	8,328	100	72	70	83	368	44.0	122
Mean	4,121	9,971	7,775	105	72	68	79	387	44.2	92
LSD (0.05)	545.0	1,363.5	-	1.5	NS	NS	6.1	117.6	2.6	4.0
CV (%)	10.6	11.6	-	1.2	4.5	13.2	6.6	25.7	5.1	3.0

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A Review of the History and the Current Situation of Wheat Production in Dehong Prefecture, Western Yunnan Province, China

Zhao Shangqi
Dehong Agriculture Bureau, Dehong Prefecture, Yunnan, China

Abstract

Wheat was introduced to Dehong in 1952 and the area now exceeds 20,000 ha with an average yield of 2.92 t/ha. The development of wheat production has proceeded through four distinct phases. Intensive research, demonstration, and extension have taken place, along with the development of a wheat processing industry.

Introduction

China's Dehong Dai and Jingpaw Autonomous Prefecture is in western Yunnan, lying between 93°31'-98°43'E and 23°50'-25°20'N. It borders with Myanmar for some 504 km to the southwest and northwest. Totaling 11,526 km², it is high in the north and low in the south, sloping from 2000 to 800 masl. Cultivated area totals 116,200 ha; about 70,000 of which are in five river valleys (with average altitudes under 1000 masl), which are the main wheat production areas in the prefecture.

Dehong's climate is tropical, damp, and hot with an annual rainfall between 1400-1800 mm, annual sunshine between 2280-2450 hours, and average annual temperature of 18.4-20.1°C. Because of the influence of the equatorial monsoon, the difference between its dry and wet seasons is very pronounced. The dry season lasts from November into April (the wheat growing season) with an average temperature of 15.4°C. Rainfall during the dry season makes up only 10-15% of the annual rainfall but sunshine during this period constitutes 60% of the annual total. The abundant radiation and the dramatic temperature difference between day and night are very beneficial for wheat production.

Before the foundation of the new China, there was no wheat production in Dehong, with only one rice crop grown per year. The first attempt to grow wheat was in 1952. By 1992, after 40 years of development, the wheat area had reached 20,200 ha, the production was 58,900 t, while the average yield had increased 4.2 times to 2.92 t/ha.

Four Periods of Wheat Production

The history of wheat production in Dehong can be divided into four stages (Table 1): initial experimentation (1952-64), early development (1964-68), stagnation (1968-77), and in recent years accelerating development (1977-92).

The first stage (1952-1964)

During this period, much experimental work was conducted along with demonstrations to farmers and extension activities. A feature of this early work was that demonstration and extension of wheat growing and wheat processing for food

were carried out simultaneously so that the rapid development of a wheat processing industry stimulated wheat production.

Investigations of the life cycle of stem rust during this time laid the foundation for the comprehensive disease control program in place today. Accumulated experience, the development in improved management techniques and disease resistant varieties resulted in a yield record of 7.5 t/ha on a small area in 1960.

The second stage (1964-1968)
The steady growth in production continued and while the area increased 1.4 times, the yields increased by 54%, resulting in a production increase of 2.7 times. During this period, wheat became established within the rice system and the rice-wheat cropping system evolved. In 1965, much interest was aroused by a yield of 2.5 t/ha on 34 ha at the Mangshi demonstration field (910 masl). By this time, the potential of wheat in the rice system had been established.

The third stage (1968-1977)
During this period of stagnation, wheat production area decreased 24%, although yields increased slightly allowing production to remain virtually static. During this period, neither area nor production approached the 1967 record year when 11,800 t were produced on 14,600 ha. The "Cultural Revolution" caused many problems for the agricultural system. Varietal deterioration and rust also complicated the situation.

The fourth stage (1977-1992)
Sustained growth has now occurred for the last 15 years. Wheat area has nearly doubled and yield has increased 1.83 times resulting in a 450% increase in total production. During this time, there has been a number of significant technological developments:

- Three superior varieties were released, which effectively solved the rust disease problem.
- Increased quantities of NPK fertilizers were recommended, and, very importantly, recommendations were formulated for the application of B, Zn, and KH_2PO_4 fertilizers and plant hormones to combat an ear sterility problem.

Table 1. The stages of wheat production development in Dehong, China.

	Area		Yield		Production	
Period	ha	% increase	t/ha	% increase	tons	% increase
1952-	60		0.56		34	
1964	5,700	9,500	0.48	-14	2,725	7900
1964-	5,700		0.48		2,725	
1968	13,500	137	0.74	54	10,000	267
1968-	13,500		0.74		10,000	
1977	10,300	-24	1.03	39	10,630	6
1977-	10,300		1.03		10,530	
1992	20,200	96	2.92	183	58,898	454

- Following intensive research, the following parameters required for maximum yield were established: seedling population, 300-370 plants / m^2; 670-750 effective ears / m^2; 1000-grain weight of 35-45 g; average weight per ear of about 2.2 g.

- After comprehensive research and analysis of Dehong's weather characteristics, it was established that the optimum sowing period was mid-October to mid-November.

- Since wheat production is due to "30% initial preparation and 70% good management", we have developed a methodology to monitor and control the development of the wheat crop, which can be summarized as "during the early stage, growth-forcing; at the middle stage, stabilizing; at the late stage, protecting".

- Comprehensive measures for the control of pests, diseases, and weeds have been developed

The Replacement and Breeding of Wheat Varieties in Dehong Prefecture, Yunnan Province, China

Yu Yia-xiong
Dehong Prefecture Agricultural Sciences Institute, Dehong, Yunnan Province, China

Abstract
The history of the constant replacement of wheat varieties grown in the subtropical river valleys in Dehong is reviewed. Breeding program objectives and trends in various plant characters are presented.

Introduction

Wheat is now one of the major crops in Dehong Prefecture, second only to rice. Wheat production, located in the subtropical river valleys, began in 1952 and after 20 years, has now reached 20,200 ha. During this period, there have been four stages in varietal replacement and these new releases, plus improvements in other techniques, have greatly affected wheat yield and production.

The Replacement of Wheat Varieties

When wheat production was initiated, much work was conducted to evaluate potential varieties using multi-location testing, resulting in the release of Nanda 2419, Xiaobaimai, and 36-428 as the first generation of wheat varieties for Dehong Prefecture.

From the late 1950s into the early 1960s, there were three major stem rust epidemics in Dehong, substantially decreasing yield. After 1963, new varieties Kanxiu 1, NP 798, and Afu, with improved disease resistance and stable, high yield were introduced. This, we refer to as the first replacement of wheat varieties in the Prefecture.

After the spread of these varieties, rust was essentially under control and wheat area increased. However, by the end of the 1960s, their disease resistance had deteriorated, necessitating the second replacement with new wheat varieties, namely Nanyan 1, Junnai 3, and Yunmai 3.

As experience and better cultural methods evolved, varieties with increased yield potential and earlier maturation (and disease resistance) were identified and by the end of the 1970s, there was a third replacement of wheat varieties. New varieties in this third wave included Sonora 64, Muoyi, 2114, and Fan 13.

In the late 1980s, the fourth generation of wheat varieties with much improved disease resistance was released. Demai 3, 980-15, Mianyang 11, and 84-346 are now the main varieties in wheat production in Dehong.

Changes Resulting from Varietal Replacements

Following each varietal replacement phase, yields increased. In the original years (1952-1963), yields averaged only 0.61 t/ha; during the first replacement (1964-1973), they increased to 0.71 t/ha, during the second varietal replacement (1964-1973), to 0.94 t/ha, and since the fourth replacement (1987-1992), average yield has reached 2.67 t/ha.

Over the years, improved rust resistance has been attained. The Dehong Prefecture has

considerable diversity and variability in the stem rust race spectrum. By frequent varietal replacement, stem rust epidemics have been avoided.

The varieties have changed in morpho-physiological characters. Height has progressively decreased; grain size and grain number per ear have increased; there has been a pronounced shift to spring genotypes; and maturity has become earlier (Table 1).

Strategy for Varietal Replacements

For an effective breeding program, clear objectives must be established. In Dehong, the pre-anthesis period is warm, with no frost or low temperature damage, and has low relative humidity with very little rainfall. During grain-filling, temperatures rise rapidly and wheat can be affected by hot, dry winds. We have determined that for high yield in the Dehong environment, varieties should be early maturing spring types of short stature with strong stem and leaf rust and powdery mildew resistance.

The breeding effort in Dehong needs to be increased to achieve greater gains. Breeding work in the Prefecture was initiated only 15 years ago. However, by intensive observation, screening and appraisal, superior local varieties have been developed. Among these, Demai 3 is now sown on 23% of the whole wheat production area.

To most effectively utilize resources, the introduction of material should be rationally based. There have been several fruitful sources of germplasm: CIMMYT (Sonora 64, Muoyi), Italy (Nanda 2419, Afu), Sichuan Province of China (Mianyang 11, 15, and 20), and local varieties (Kanxiu 1, Nanyan 1, Yunmaixitong). Genotypes introduced from areas south of 30°N latitude have proved quite successful in the program. However, genotypes introduced from more northerly locations have not been successful due to vernalization and photoperiod requirements.

Finally, for effective varietal replacement, we recommend that the Experiment-Demonstration-Extension Method be used. New varieties are bred or introduced, evaluated, yield-tested in small plots, and followed by multi-location tests. This can be followed by larger scale demonstration evaluations, which allow extension decisions to be made.

Table 1. Yield structure and maturation period of newly introduced wheat varieties in the Dehong Prefecture.

Replacement stage	Plant height (cm)	Grains/ ear	1000-gr. wt. (g)	Weight/ ear (g)	S-W characteristics (%)			Maturation characteristics (%)		
					S	W-S	W-W	Early	Middle	Late
Testing	108	22	31.1	0.68	40	20	40	-	20.0	80.0
First	118	35	44.0	1.53	57.9	31.6	10.5	42.1	21.1	38.8
Second	99	43	47.9	2.07	76.5	17.7	5.8	23.5	58.8	17.7
Third	92	44	48.9	2.15	73.7	26.3	0.0	36.8	47.4	15.8
Fourth	91	46	49.2	2.18	94.5	5.5	0.0	58.9	32.7	8.4

S= spring; W= winter.

Cultivation Techniques for High Yield in Dehong Prefecture, Yunnan Province, China

Du Daiwen
Dehong Prefecture Science and Technology Commission, Yunnan Province, China

Abstract
In Dehong, over a period of 40 years, an annual system of rice followed by wheat has become established. A set of management principles involving variety selection; optimum sowing time; plant, tiller, and ear populations; and irrigation and fertilizer applications for maximum utilization of the climatic conditions are discussed.

Introduction

Following 40 years of development, wheat production in 1992 in Dehong Prefecture reached nearly 59,000 t from an area of 20,200 ha at an average yield of 2.92 t/ha. Some 14,000 ha of this, grown below 1100 masl, averaged 3.44 t/ha. Currently, the record yield is 8.67 t/ha. Wheat production constituted only 0.003% of total cereal production in 1952, which has risen to 18.7% in 1992.

The climatic characteristics of the wheat growing season November to April are as follows: about 1560 hours of sunshine with a total of approximately 72,500 calories/ cm^2 radiation, a lowest mean temperature of 12°C in January with an increase of about 1°C per month either side of January, a dramatic temperature difference of 17°C between day and night, and rainfall of 130-150 mm.

These climatic features have both beneficial and restrictive elements to wheat production. Scientists and extension workers have devised a set of principles and techniques to best utilize the beneficial and avoid the harmful climatic features.

Selection of Superior Varieties

We have selected a number of varieties that are well adapted to the local ecological conditions such as 980, Yunzhi 437, and Mianyang 11. These are short-strawed, early maturing, large eared, and leaf and stem rust resistant.

Sowing Period

Due to the U-shaped temperature pattern during the wheat growing period, we have found the optimum sowing period to be the last 10 days of October for medium-maturity varieties to mid-November for the early maturing types. The low January temperatures allow normal heading and flowering to proceed and conditions are ideal for good pollination.

Optimum Populations

Very high plant populations can reduce yields. We have found highest yields can be obtained when seedling populations are about 300/m^2, maximum tiller number is about 600/m^2, and when there are approximately 450 ears/m^2 (Table 1). This ratio of 1:2:1.5 allows effective utilization of the available radiation and minimizes the incidence of stem diseases.

Scientific Management

Water and fertilizer applications are critical to obtain high yield, particularly in view of the crop's fast development rate under the Dehong environment. We have developed a management strategy that can be summarized as "forcing growth in the early stages, stabilizing at the mid-development stage, and protecting during the last stage"

We have found from experiments that to produce a 7.6 t/ha crop, we need to apply about 240 kg N, 200 kg P_2O_5, and 60 kg K_2O/ha. Applications are split between basal at seeding and top-dressing applications which are used to "force" the crop (Table 2). We consider fertilizer (and irrigation) management at the two-leaf seedling stage critical to the crop development. After heading and into the grain-filling period, we emphasize the application of KH_2PO_4, the micronutrients boron and zinc, and herbal hormone.

Rainfall during the wheat crop is not sufficient and irrigation is a key element in final yield. We emphasize proper timing and quantity of irrigation at the various growth stages.

By the application of all these methodologies, we feel that wheat production will continue to accelerate in Dehong Prefecture.

Table 1. Optimum population of plants and plant components for high yield.

Variety	Plants	Tillers/m²	Ears	Plant:tiller:ear ratio	Yield (t/ha)
980-15	279	533	423	1:1.9:1.5	8.67
Yunzhi 437	326	594	419	1:1.8:1.3	7.60
Mianyang 11	303	620	455	1:2:1.5	6.82

Table 2. Relative applications of basal fertilizer topdressing and foliar applications for high yield.

	Basal fertilizer (%)			Topdressing (%)			Foliar fertilizer (%)		
Variety	N	P	K	N	P	K	N	P	K
980-15	62.5	92.5	80.9	37.5	6.6	17.6	0.0	0.9	1.5
Yunzhi 437	46.0	100	100	54.0	0.0	0.0	0.0	0.0	0.0
Mianyang 11	52.5	88.8	74.8	47.5	10.5	24.4	0.0	0.7	0.8

Wheat Cultivation in Northern Vietnam

Tran Dinh Long, T.D. Minh, and N.T. Thu
Vietnam Agricultural Science Institute, Hanoi, Vietnam

Abstract
For wheat to become a significant crop in Vietnam, a number of problems restricting wheat production must be solved. We have identified irrigation, varieties, farming systems, and processing difficulties as factors that must be addressed.

Introduction

In Vietnam, almost all wheat flour is imported and consumption is increasing. Wheat can be grown in northern Vietnam and research has been conducted at the Vietnam Agricultural Science Institute since 1968.

Currently, the National Wheat Program is focusing attention on the development of wheat in the mountainous areas in the north. Varietal improvement is a high priority as is the identification of the factors that are limiting yields in farmers' fields.

Table 1 shows the climatic conditions during the wheat season in Cao Bang Province in the northeast of the country.

Table 1. Mean monthly climatic parameters in Cao Bang Province, Vietnam (1980-1990).

Month	Average Temp (°C) Min.	Max.	Relative Humidity (%)	Rainfall (mm)
November	15.2	24.2	81	49.3
December	11.3	20.5	80	22.2
January	10.3	18.2	78	23.1
February	12.1	19.3	70	24.4
March	15.9	23.2	80	39.5
April	19.6	27.6	80	90.0

Level of Production

According to Government figures, about 350,000 ha of suitable land could be sown to wheat during the winter-spring season. Previous attempts at commercialization of wheat were based on old local varieties with yields of less than 1 t/ha. The highest recorded production was 1500 t in 1971.

Problems

The problems currently restricting wheat production have been identified as:

- Unavailability of irrigated land,
- The use of local seed or the use of mixed seed bought in the market,
- Poor management (seed not correctly sown, no fertilizers used),
- Lack of processing facilities, and
- Inadequate support for research.

Prospects

The national strategy is to improve the status of wheat research and the wheat production program. During the last five years with the support of CIMMYT, we have made good progress in the varietal improvement program and several new varieties have been identified (Table 2). We believe that the increased yield of the new varieties will stimulate the development of wheat production.

Table 2. Yield and yield components of promising varieties in Cao Bang Province, Vietnam 1992.

Variety	maturity (days)	Plant height (cm)	1000-grain weight (g)	Resistance to: *Helm. sativum*	Resistance to: *Erysiphe graminis*	Yield (t/ha)
FAO-H(SR) Ci-92	125	129	41	0	0	3.81
SMG-42	119	92	46	0	0	3.26
Long Mai-12	122	113	36	0	3.0	3.81
Coq/F 61	122	110	40	0	0	2.88
Tui'S'	129	90	43	0	0	2.88
Punjab-81	122	71	38	0	0	2.84

Research on Tillage for Wheat in the Rice-Based System in Bangladesh

M. Badaruddin, M.A. Razzaque, C.A. Meisner, N. Islam, B. Zaman, P.K. Malakar, M.K. Mozumder, and M.A. Reza
Wheat Research Centre, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur, Bangladesh

Abstract
With the expansion of high yielding rice cultivars, major areas of rice are being cultivated in puddled soil. High yielding, longer duration rice varieties are normally harvested in December resulting in late wheat seeding. Zero or reduced tillages were found effective to minimize turn-around time as well as increase wheat yield in these situations. Nitrogen efficiency was lower under reduced tillage under dryland conditions. The tillage and nitrogen rate experiments are continuing.

Introduction

Bangladesh is basically a rice growing country. The rice crop covers over 80% of the total cultivated area. Depending on the land type and irrigation facilities, one, two, or three crops are grown each year on the same land. Recent on-farm survey results showed that over 80% of the total wheat crop followed rice, and rice-rice-wheat, and other-rice-wheat are the major wheat-based patterns followed by the wheat growers in Bangladesh.

With the expansion of high yielding rice varieties, aman rice is grown mainly on puddled soils during the monsoon season. Wheat follows the aman rice in the cooler dry season. This pattern is under irrigated, partially irrigated or dryland conditions. After aman harvest, the puddled land dries out and becomes very difficult to prepare for wheat. In many cases, an extra irrigation is necessary for land preparation. About 49% of the farmers consider this situation to be a major problem for growing wheat after rice (Ahmed and Clements 1983).

Number of plowings and ladderings for wheat varies but several surveys (Saunders 1990, 1991; Meisner 1992) have indicated that on average, five-six plowings were necessary to prepare land for wheat in aman fields.

Tillage and Turn-Around Time

Preparation of a suitable seedbed takes much time, with the risk that wheat plants suffer low temperatures in early winter and high temperatures during flowering and grain-filling periods. Tillage methodology should aim to reduce the time interval between rice harvest and wheat seeding to allow wheat seedlings to avoid these low and high temperatures.

A conventional plow drawn by a pair of weak bullocks normally takes 12-20 days to prepare 0.4 ha of land. Within this time, five to six plowings and ladderings are done. A One- to two-day interval is necessary between each plowing to dry out excess moisture.

Different tillage levels were tested at the Agricultural Research Station, Pabna, during 1984-85. After harvest of BR-11 aman rice, wheat was planted immediately by making a furrow and then sowing (minimum tillage). Wheat planting was delayed up to 18 days when the number of plowings increased up to 5 times (Table 1). Minimum tillage increased grain yield compared to cultivated plots. The lower yields in conventionally tilled plots were due to loss of moisture by tillage and/or to the delay in sowing under the residual soil moisture situation. Further experiments comparing the conventional tillage and minimum tillage were conducted at Gaibandha, Lalmonirhat, Kushtia, and Dinajpur. Results from these experiments indicated that minimum tillage reduced turn-around time by 7 to 12 days.

Tillage and Grain Yield

To obtain a good tilth, soil should be tilled within the appropriate moisture range and tillage may need to be delayed if the soil is excessively wet, which not only wastes residual moisture, but increases turn-around time. A zero tillage system can lessen turn-around time and save soil moisture and increase yield (Table 1).

A total of 47 unreplicated demonstration trials were conducted in different locations of Bangladesh comparing conventional and minimum tillages. Results indicated that, on average, grain yield was decreased by 7.42% with minimum tillage compared to conventional tillage (Table 2), although most farmers did not sow the minimum tillage plot until tillage on the other plot was complete and thus the treatment did not benefit from a more optimum seeding date. The lower yield with minimum tillage may have been due to higher weed infestation. Wheat cultivation under minimum tillage needs better weed control than conventional tillage. Weed control in wheat is not common in farmers' fields. Weed control and fertilizer management in minimum tillage often limit grain yield of wheat.

Deep Tillage

Long-term cultivation of rice crops under puddled conditions induces a subsoil compact layer that restricts root penetration and water intake. Deep tillage could break high bulk density soil layers to increase

Table 1. Effect of different tillage levels on sowing time and yield of wheat under nonirrigated conditions.

Treatment	Turnaround time (days)	Days to maturity	Spikes /m²	Grain yield (t/ha)
Minimum tillage (sowing in furrow)	0	105	208	1.69
One plow + one ladder (line sowing)	9	104	162	1.00
Three plows + one ladder (line sowing)	14	99	177	1.20
Five plows + five ladders (line sowing)	18	96	189	1.27

Table 2. Grain yield of Kanchan under conventional and minimum tillage.

Location	No. of trials	Grain yield (t/ha)	
		Min. tillage	Conv. tillage
Rangpur	24	3.52	3.60
Rajshahi	9	3.49	3.88
Jessore	1	3.16	3.26
Dhaka	5	2.93	3.63
Mymensingh	6	4.01	4.72
Mean		3.51	3.80

water intake, aeration, root growth, and utilization of subsoil water. Deep tillage and conventional tillage were compared at the Wheat Research Centre, Dinajpur, during the 1990-91 and 1991-92 crop seasons. Irrigation was applied in both tillage treatments at 25 and 50% moisture depletion in the 1990-91 season and three or four irrigations for both treatments in 1991-92. Deep tillage increased wheat yield by 18% in 1990-91 over conventional tillage with irrigations at 25% moisture depletion. In 1991-92 deep tillage resulted in significantly higher yields (400 kg/ha with three irrigations and 270 kg/ha with four irrigations) over conventional tillage. In both these experiments, the crops were planted very late (December 20-30) and the results suggest that deep tillage might help reduce late season moisture stress and increase yield.

Tillage operations in aman rice affects the tillage system in wheat and vice-versa. It has been observed in an ongoing trial at Dinajpur that if deep tillage is carried out before aman rice, minimum tillage for wheat increases yield. Similarly, deep tillage in wheat may help to reduce tillage operations for aman rice.

Tillage and Nitrogen Fertilizer

No tillage or minimum tillage wheat production systems have sometimes been observed to be less efficient in using nitrogen fertilizers. Experiments conducted in different locations of the country have shown that nitrogen response is limited in minimum tillage up to about 40 kg N/ha compared to 80 to 100 kg N/ha in a conventional five-plowing system under nonirrigated conditions (Table 3). Nitrogen response was, however, similar under well irrigated conditions in other experiments. These experiments are still ongoing. Results of these experiments suggest that if the wheat crop is not stressed either by weeds or moisture, minimum tillage on puddled rice soils could be effective for wheat production.

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Table 3. The interaction between tillage and yield response (kg/ha) to applied nitrogen fertilizer under dryland conditions.

Tillage treatment	Nitrogen applied (kg N/ha)			
	0	40	80	120
One plowing	1432de*	1753 cd	1860 cd	1693 cd
Three plowings	1015 e	1953bcd	2109abc	2622a
Five plowings	972 e	1901bcd	2396ab	2413ab

*DMRT (5%).

Wheat Production and Research in Myanmar

Daw San Winkyi
Central Agricultural Research Institute, Yezin, Myanmar
Khim Yhin Kyaw
Myanmar Agriculture Service, Sagaing Division, Myanmar

Abstract

Wheat is a major crop in Myanmar where it is produced mainly under rainfed conditions. Breeding is aimed at producing varieties with drought and heat tolerance, leaf rust resistance, high yield, and acceptable grain type. Production is constrained by the present varieties; poor crop establishment; insufficient use of fertilizers; and diseases, insects, and rodents.

Introduction

Wheat is the third largest crop in Myanmar after rice and maize. The major production area is in Sagaing Division (Figure 1), which represents 79% of the national wheat area of which only 10% is irrigated or partially irrigated. A further 10% of the total wheat area is situated in each of Mandalay Division and Shan State (Figure 1), virtually all under rainfed conditions. Areas and production statistics are shown in Table 1.

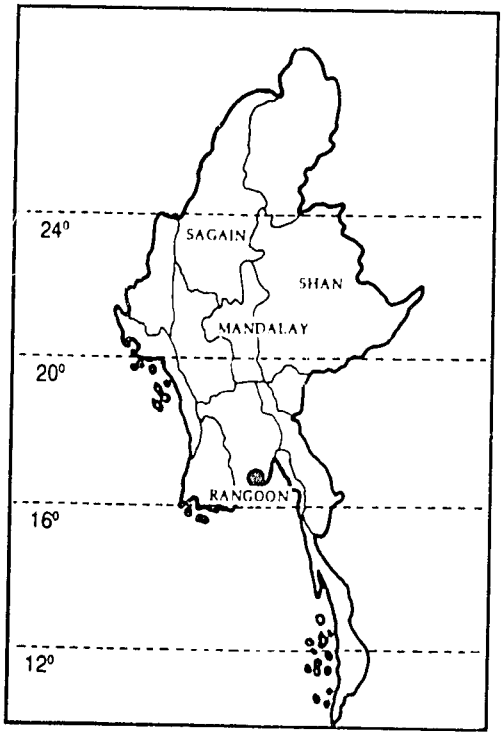

Figure 1. Major wheat production areas in Myanmar: Sagaing Division (79%), Mandalay Division (10%), and Shan State (10%).

Wheat Breeding Objectives

The wheat area in Myanmar can be divided into two distinctly different areas—lowlands, representing 90% of the total area, of which 10% is irrigated, and highlands,

Table 1. Area and production of wheat in states and divisions of Myanmar in 1990-91.

States/ divisions	Area (ha)	Grain production (tons)	Grain yield (kg/ha)
Sagaing	118,145	78,200	752
Mandalay	14,442	20,647	1,495
Magway	806	609	782
Ayarwady	1,422	885	668
Shan	14,829	20,914	1,493
Kachin	23	18	808
Chin	87	41	477
Kayah	24	20	891

over 900 masl, all of which is rainfed and represents the remaining 10% of the area.

For this reason, two separate breeding programs have been initiated, at Zaloke and Pankon in the north for lowland wheat and at Heho in Shan State for the highland rainfed situations.

In general, the breeding objectives are as follows:

- High yield with good grain quality;
- Early maturity;
- Tolerance to heat, especially during the grain-filling period;
- Tolerance to terminal drought;
- Leaf rust resistance;
- Acid soil tolerance (for the highlands).

National Breeding and Testing Systems

Crosses are made at the three key stations and involve both crosses between local and introduced genotypes and combinations of introduced materials. The F1 is grown under optimum conditions and the segregating F2 to F5 generations are grown with and without irrigation at Zaloke and Pankon farms and under dryland conditions at Heho. Selection (pedigree method) in the segregating generations is based on earliness, drought and disease resistance, grain quality and yield.

Selected plants from promising F5 materials are bulked and entered into the "A" (Preliminary Yield) trials, normally containing 15-30 lines. These trials also include introduced lines, and are grown under irrigated or rainfed conditions depending on the location.

Selected lines are advanced to the "B" (General Yield) trial, composed of 15-20 lines. The most promising are then advanced to the "D" (Advanced Yield) trial (10-15 entries), grown in a wider range of locations.

The elite materials from the "D" trials, which show stable high yield across locations and years, are entered into Verification/Demonstration Trials of three to five lines, which are conducted in farmers' fields in the major wheat areas. The lines having the highest, most stable yield and farmer acceptance are submitted to the National Seed Committee for varietal registration.

While locally bred lines are now promising in the advanced trials, the current varieties are all derived from introductions (Table 2).

Table 2. The major varieties cultivated in Myanmar.

Variety	Pedigree	Year of release	Area (ha)	Grain yield (kg/ha)
Yezin-1	LYP-73	1980	448	1,499
Yezin-2	SA-75	1980	313	1,208
Yezin-3	V.1287	1980	13,205	1,353
Yezin-4	LU-26	1980	1,872	1,369
Yezin-5	Blue Silver	1980	1,204	1,394
Yezin-6	Veery #5	1986	1,998	1,564
Yezin-7	UP-262	1986	61	2,118
Kalyansona	-	1968	383	945
Mexipak	-	1968	11,426	1,298
Monywa White	IP-4	1946	102,428	694

Factors Limiting Production

Intensive breeding efforts are required to improve the yield potential over that of the existing varieties, especially with regard to tolerance to terminal drought and late heat. Monywa White performs relatively better than other varieties under moisture and heat stress conditions, but it is highly susceptible to leaf rust. Its grain is better accepted by the local millers than that of the high yielding varieties.

The improved varieties are rust resistant to varying degrees, but they have unstable yield under moisture deficit conditions. Under irrigated conditions, they give excellent yields.

Crop establishment is generally poor due to low soil moisture conditions at seeding (a result of a protracted period of tillage), soil pathogens and insects.

There is inadequate use of fertilizers, especially urea, and the efficiency of utilization could be improved.

Diseases and pests are a major constraint. Leaf rust is a major disease and causes tremendous losses, particularly in the older varieties such as Monywa White. In some years, rodents are major pests both in the fields and in storage.

Wheat Yield Losses in Farmers' Fields Due to Foliar Blight Infection

M. Ruckstuhl
International Maize and Wheat Improvement Center (CIMMYT), Kathmandu, Nepal

Abstract

A study of 14 farmers' fields in the Rupandehi District, Nepal, was conducted to assess the yield losses due to foliar blights. The pathogens were controlled by repeated applications of Tilt-250. The yields of untreated plots were 9.1% lower than plots with disease control. To fully clarify the relationship between foliar blight infection and yield loss, studies should be undertaken on fully and partially protected crops.

Introduction

In the Terai Belt of Nepal, losses in wheat grain yield due to foliar blight infection were repeatedly reported as results of experiments at research stations. This study aimed to estimate the grain yield loss under farmers' conditions. Data recorded at 14 locations were used to establish a relationship between foliar blight infection and the reduction of the thousand-grain weight (TGW) or the grain yield, respectively.

During 1990-91, *Bipolaris sorokiniana* Sacc. was found to be the dominant foliar blight organism, whereas *Pyrenophora tritici-repentis* (Died.) Drechs. was less often, but commonly observed.

Materials and Methods

This experiment was conducted in 14 farmers' fields in the terai of Rupandehi District. The fields were selected after plant establishment in early January. Two conditions necessary for field selection were 1) use of the foliar blight-susceptible variety UP262 and 2) three or more years of a rice-wheat crop rotation. The crop was entirely managed by the farmers so that agronomic factors differed widely between sites.

Propiconazole (Tilt-250EC) was applied with a backpack sprayer at the rate of 125 g a.i./ha in 750 L of water at different growth stages to suppress the development of foliar blight symptoms.

Disease severity was read as the percentage of the infected leaf area on the flag leaf, f-1, and f-2 of five plants per plot at GS69 (anthesis complete), GS75 (medium milk), and GS83 (early dough). Yield data were established by harvesting 1-m^2 crop samples and standardizing for 12% moisture content. Each field was treated as an experimental set with RCBD layout with four replications and two treatment.

Results

Propiconazole spray gave excellent protection against foliar blight infection. Combined ANOVA of the data showed significant losses due to foliar blight. The grain yield reduction was 9.1% on average, whereas the reduction in TGW, a parameter with generally less variability, was 4.4%. Grain yield ranged from 1.2 to 3 t/ha and the TGW from 31.4 to 48.6 g.

Table 1 shows the results from the individual sites as well as from the combined analysis. The last two sites were not included due to rodent damage.

Conclusions

Losses due to foliar blight infection in 1990-91 in farmers' fields were considerably lower than reported for the Bhairahawa Research Station in the previous three years where yield was increased by 20 to 30% by keeping the crop disease-free (H.J. Dubin, pers. comm.). Reasons for higher losses on the experiment station may be due to the amount of wheat stubble and debris remaining in the experimental plots during the rice season as well as more intensive management inducing soilborne problems.

Even though cross-site analysis results in significant yield loss, a clear relationship between foliar blight infection and decreasing yield was not achieved. This may be due to several factors:

- Incidence and severity of blight infection was sporadic and therefore led to high variation.
- The effect of low levels of disease late in the season does not affect yield significantly.
- Due to full protection of the sprayed plots and low disease level, the results were not distributed over a wide range of infection, but rather grouped, either low or high (unsprayed).

This study indicates that yield loss experiments with full and partially protected plants must be carried out to clarify the relation between foliar blight infection and yield loss, preferably in both research stations and farmers' fields.

Table 1. Results of the foliar blight loss study in 14 farmers' fields during 1990-91 at Rupandehi District, Nepal.

Site	Yield % loss[a]	TGW % loss[b]	Blight severity on the flagleaf		Correlation (r) of % infection with	
			% infect.	GS	Yield	TGW
1	3.0	1.8	18.7	85	0.022	-0.373
2	16.7	5.4**	19.4	85	-0.451	-0.873**
3	8.5	5.2*	26.2	87	-0.268	-0.719*
4	12.1	5.6*	20.1	83	-0.584	-0.773*
5	14.6	0.2	9.8	79	-0.488	0.016
6	-	6.8*	19.4	85	0.084	-0.851**
7	21.3	12.6*	87.8	83	-0.430	-0.748*
8	1.2	2.9	14.1	85	-0.131	-0.727*
9	8.1	4.8*	8.0	77	-0.324	-0.623
10	12.3	5.0*	23.8	83	-0.632	-0.827**
11	2.2	1.2	17.5	77	-0.057	-0.397
12	11.8	1.4	17.8	75	-0.581	-0.398
13	-	1.4	6.8	85	0.224	-0.228
14	-	8.9	No data recorded			
Mean	9.1***	4.4***			0.358***	-0.294**

* P<0.05, ** P<0.01, *** P<0.001.

[a] % loss = 100 x (sprayed-unsprayed)/sprayed.
[b] Calculated without datasets from sites 13 and 14.

Closing Remarks

R.A. Fischer
Director, CIMMYT Wheat Program, El Batan, Mexico

From CIMMYT's point of view, we are very proud to have been associated with this conference—meeting in a relatively isolated part of the world and with many wheat scientists who do not often travel outside their own countries. It's wonderful to see you all coming together like this, especially to see all the Bangladeshi wheat scientists with us. I want to remind those of you from Bangladesh that the Wheat Research Centre here in Dinajpur and the level of support from the Government give you the possibility of having a major impact through research on wheat in this country. I challenge you to take full advantage of this opportunity.

Before I close the Conference, it is important to thank a host of people. Dr. Razzaque and his colleagues from the Wheat Research Centre have all been working very hard behind the scenes and during the weeks leading up to the Conference and I think I can speak for all here that the activities have gone very smoothly—it has been a very pleasant stay. I know it has been a lot of work and we are very grateful. I would also like to thank Craig Meisner, CIMMYT's representative in Bangladesh, who has also put a great deal of effort into the logistics and organizational aspects for the Conference. Finally, the person responsible for the program—Dr. Chris Mann—put it altogether in a fairly short time and ended up with an excellent program and we thank him for those efforts.

In addition, I think we should thank those who went to the trouble of preparing posters—there were about 10 and we plan to include them in the proceedings.

Finally, I would like to thank the speakers, particularly those who had to speak a language that is not their native tongue and some of whom are speaking at a meeting far from their own country for the first time.

Now, I would like to say a little about the UNDP project that has been referred to from time to time at this meeting and has been one of the sources of support, not only for this meeting, but for a lot of the research that has been reported at the meeting. This project has been going on in Southeast Asia for almost 10 years. A number of CIMMYT scientists have been associated with it including David Saunders (technical editor for the proceedings of this meeting) and Chris Mann.

Chris, who has probably had the longest association with the warmer areas wheat program, is unfortunately leaving the region in mid-1993. I would like to pay special tribute to him for the effort, the time, and the dedication that he has put in, working with the national programs in the region. I know I speak for everyone in this room in expressing appreciation for those long years that Chris has spent in Thailand working in warmer area wheat. He has become a unique expert on the problems of wheat in South and Southeast Asia as a result of these efforts.

What will be CIMMYT's involvement in the warmer areas in the future? Although I can say that CIMMYT will not be abandoning wheat problems and wheat scientists in this part of the world, I too am worried about what is going to happen, in terms of the fact there will be substantial reduction in the

support we can offer you. This is worrying and was well put by Mr. Devkota during this meeting when he said "Things were impossible, but with the help of CIMMYT, they became possible."

We cannot obtain financial resources to keep the level of support at anything more than maybe 20% of the support you have had over the last 10 years in the South and Southeast Asian countries. There is particular apprehension regarding Thailand, Vietnam, Myanmar, the Philippines, and South China—there is a lot of wheat in these places and/or a lot of potential and CIMMYT will do its best.

Nurseries—directed at warmer area problems, helminthosporium and fusarium resistance—will still be coming. Also, the high temperature wheat yield trial will be sent out from Mexico, but I, like many of you, feel that the possibility of selecting for these warmer environments in the Mexican program is not so great as they are for selecting for the temperate environments in which CIMMYT material has been much more successful. We will definitely continue our work on *Helminthosporium* spp. for at least five more years and that should give us a chance to really make an impact on host plant resistance in these two diseases.

On agronomy, we didn't really get going in Asia before we ran out of money and time. There are some very interesting things happening in Thailand and we have heard about some of these at this meeting. I believe there will be results coming out of the rice-wheat work in South Asia described earlier by Dr. Hobbs that will spillover into Southeast Asian countries, particularly Myanmar, which is not very different from parts of India and parts of Bangladesh. Agronomy is very important in these warmer areas and where a big impact could be made, but unfortunately we have not been able to muster resources to make that impact.

I mentioned how proud CIMMYT felt to be associated with this conference and to see the growth in the wheat program in Bangladesh. I would think that Dr. Sufi Ahmed as someone who, beginning almost 25 years ago, has been associated with wheat in Bangladesh ever since, would feel equally proud to see the number of scientists now working on wheat and the number of young scientists, reasonably well trained and equipped. I think you would agree, Dr. Sufi, that the manpower resources are largely in place to do the job that Bangladesh needs to increase its wheat production.

So now to close this meeting is quite an enjoyable duty because it has been a very successful event. I particularly appreciated the quality of the papers and the posters that demonstrated the multi-disciplinary activities that are going on among breeders, agronomists, and pathologists in the effort to develop wheats and management practices for the heat-stressed environments of Asia.

Participants, Wheat in Warm Area, Rice Farming Systems, Dinajpur, Bangladesh, 13-15 Feb. 1993

Australia
R.D. Graham
Dept. of Plant Science
Waite Institute
Glen Osmond

D.A. Saunders
Interag Pty. Ltd.
Victor Harbor

Bangladesh
Aftabuddin Ahmed
Regional Agricultural
Research Station
Jamalpur

Mahbub Uddin Ahmed
Wheat Research Centre
Nashipur, Dinajpur

Sufi M. Ahmed
Gulshan, Dhaka

Kazi Benozir Alam
Wheat Research Centre
Nashipur, Dinajpur

Md. Ruhul Amin
Wheat Research Centre
Nashipur, Dinajpur

M. Badaruddin
Wheat Research Centre
Nashipur, Dinajpur

Md. Bodruzzaman
Wheat Research Centre
Nashipur, Dinajpur

Naresh Chandra Deb
Wheat Research Centre
Nashipur, Dinajpur

Ashmin Kumar Dey
Regional Agricultural
Research Station
Jamalpur

Md. Moynul Haque
Wheat Research Centre
Resional Agricultural
Research Station
Jamalpur

A.B.S. Hossain
Regional Agricultural
Research Station
BARI
Jessore

Md. Abdul Hossain
Wheat Research Centre
Joydebpur, Gazipur

Mostafa Anwar Hossain
Regional Agricultural
Research Station
Ishurdi, Pabna

Md. Nazrul Islam
Wheat Testing Station
BARI
Joydebpur, Gazipur

Paritosh Kumar Malaker
Regional Agricultural
Research Station
Jessore

Craig A. Meisner
CIMMYT Wheat Program
Gulshan, Dhaka

Dipal Kumar Parh
Wheat Testing Station
BARI
Joydebpur, Gazipur

Salina Parvin
Wheat Testing Station
BARI
Joydebpur, Gazipur

M. Moznur Rahman
Regional Agricultural
Research Station
Jessore

Rahimullah
Wheat Testing Station
BARI
Joydebpur

Md. Abdur Razzaque
Crop Diversification
Programme
Dhaka

M.A. Razzaque
Wheat Research Centre
Nashipur, Dinajpur

Mostafa Ali Reza
Wheat Research Centre
Nashipur, Dinajpur

N.K. Saha
Regional Agricultural
Research Station
Jessore

M. Saifuzzaman
Wheat Testing Station
BARI
Joydebpur, Gazipur

M.A. Samad
Wheat Research Centre
Nashipur, Dinajpur

Z.I. Sarker
Whear Research Centre
Nashipur, Dinajpur

Anawar Shahid
Whear Research Centre
Nashipur, Dinajpur

Mir Md. Abu Bakr Siddeque
Regional Agricultural
Research Station
Jessore

M.A. Sufian
Wheat Research Centre
Nashipur, Dinajpur

Canada
Jeanne Corriveau
Asia Branch, CIDA
Hull, Quebec

J. Trevor Sykes
RNA/CIDA
Hull, Quebec

Simon Thiboutot
Agriculture Canada
Ottawa

China
Shi Changjian
Guangdong Academy of Agricultural Sciences
Guangzhou

Du Daiwen
Agricultural Sciences Institute
Dehong, Yunnan

Zhao Shangqi
Dehong Agriculture Bureau
Dehong, Yunnan

Yang Yanhua
Food Crop Research Institute
Yunnan Academy of Agricultural Sciences
Kumming, Yunnan

Yu Yia-Xiong
Agricultural Sciences Institute
Dehong, Yunnan

India
R.S. Narang
Dept. of Agronomy
Punjab Agricultural University
Ludhana

Mexico
Etienne Duveiller
CIMMYT
El Batan

R.A. Fischer
CIMMYT
El Batan

Gene P. Hettel
CIMMYT
El Batan

Myanmar
Khim Yhin Kyaw
Myanmar Agriculture Service
Sagaing Division

Daw San Winkyi
Maize and Other Cereal Crop Division
CARI
Yezin, Pyinmana

Nepal
M.R. Bhatta
National Wheat Research Program
Bhairahawa

Ravindra N. Devkota
National Wheat Research Program
Bhairahawa

H.J. Dubin
CIMMYT
Kathmandu

Peter R. Hobbs
CIMMYT
Kathmandu

C.B. Karki
Central Plant Pathology Div.
Khumaltar

Thailand
Yinbo Gan
Faculty of Agriculture
Chiang Mai University
Chiang Mai

Boonrat Jongdee
Phrae Rice Research Center
Phrae

Chrisoph E. Mann
CIMMYT
Bangkok

Sutira Moolsri
Samoeng Upland Rice and Temperate Cereals Experiment Station
Chiang Mai

Satit Rajatasereekul
Chumphae Rice Experiment Station
Chumphae, Khon Kaen

B. Rerkasem
Dept. of Agronomy
Chiang Mai University
Chiang Mai

Khanchai Vongburi
Phrae Rice Research Center
Phrae

Vietnam
Tran Dinh Long
Vietnam Agricultural Science Institute
Van Dien, Hanoi

Ta Duy Minh
Vietnam Agricultural Science Institute
Van Dien, Hanoi

Dao Quang Vinh
National Maize Research Institute
Dan Phoong, Hatay

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